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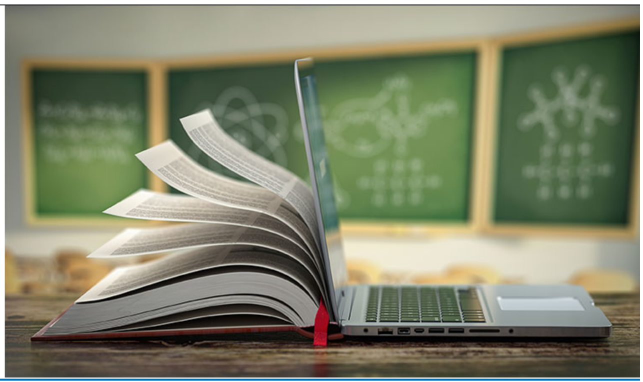

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Strength, chloride resistance and corrosion reinforced of High-strength concrete

Hung Ngo Xuan, Lam Tang Van, B I Bulgakov and O V Alexandrova
Moscow State University of Civil Engineering, Yaroslavskoe shosse, 26, Moscow, 129337, Russia

xuanhung1610@gmail.com

Abstract. Typical low-calcium fly ash (LC-FA) and silica fume SF 90 (SF-90) was used as a binder in the mixture of high-strength concrete (HSC), replacing (20-40)% and (5-15)% of the weight of Portland cement, respectively. The slump of fresh HSC mixtures, compressive strength, density and water absorption of HSC samples were investigated. Applying the standard NT Build 356 combined with standard ASTM C1202-97 for assessment of the chloride resistance and the corrosion resistance reinforced of tested concrete produced using high-calcium fly ash and Silica fume was studied in this work. The results show that the compressive strength of examined concrete decreased with increasing LC-FA content and was lower than the concrete used mix control, while the compressive strength of concrete mixtures with SF-90 at 5%, 10% and 15% by mass cement was higher than the sample tested with mix control and significantly higher than the LC-FA concrete mixtures. LC-FA and SF-90 in HSC decreased the charge passed and tends to decrease, while the times of initial crack of the test specimens gain increased with increasing LC-FA and SF-90 contents. The chloride ion penetrability of HSC is very low.

1. Introduction

Nowadays, high-strength concrete (HSC) containing many industrial, agricultural and quarry wastes used as a substitution for raw materials has been studied extensively [1-3]. HSC is a new category of high-performance concrete characterized by its compressive strength in the hardened state. From the review of published research [4] reported that concrete having a 28 days compressive strength more than 60 MPa was designed as a high strength concrete. According to Russian standard GOST 25192-2012 [5] shown that types of concrete having a 28-day compressive strength of 70 MPa or more was designed as a high strength concrete.

The use of fly ash (FA) and silica fume (SF) in HSC mixtures improves rheological properties and reduces cracking of concrete due to lower heat of hydration [6, 7]. However, the strengths of HSC concrete containing FA are lower than that of pure Portland cement concrete (concrete control), while SF concrete has strengths higher than that concrete control [8-12].

As it is known, two general classes of fly ash can be defined: low-calcium fly ash (LC-FA) and high-calcium fly ash. The CaO content in the LC-FA is less than 10% [13]. Also as other pozzolanic material, LC-FA is used in combination with Portland cement to require $Ca(OH)_2$ to form calcium silicate hydrate (C-S-H) gel, which reduces the porosity of the binder and increases the strength of cement stone.

Recently, there are a few studies [14, 15] focused the effect of high-calcium fly ash and SF on the strength and chloride penetration of self-compacting concrete, especially the use of high-calcium fly ash incorporating with SF at high cement replacement level.

It is known that reinforced corrosion is an important problem in the reinforced concrete structure. One of the most important issues in the corrosion of reinforced steel is the ingress of chloride ion into the concrete. Although reinforced steel embedded in hydrating Portland cement paste forms a thin passive film around the embedded steel that tightly adheres to the steel and gives it complete protection from reaction with oxygen and water, unfortunately, the chloride ion can destroy the passive film and initiate the corrosion of reinforced steel bar [16]. This is especially dangerous in the marine environment.

The main objective of the present investigation is to study the compressive strength, the chloride resistance and the corrosion resistance reinforced of concrete, containing (20-40)% of low-calcium fly ash and (5-15)% of silica fume in the construction of marine environment in Vietnam. The simulation of the relationships between compressive strength at 28-day and contents of LC-FA and SF was presented. In addition, the density and volume of porosity and water absorption of the concrete sample were also measured.

2. Research programs

2.1. Materials properties

1. Limestone fine aggregate (LFA) sourced original from quarry "Kien Khe" (Vietnam) be crushed finely and was used as fine aggregate in concrete mixtures of this study.

2. Crushed granite stone (CG) produced from the quarry "Kien Khe" in the North of Vietnam was used as coarse aggregate. In Table 1 are given the physical properties of both LFA and CL.

Table 1. The physical properties of LFA and CL used

Aggregate type	Aggregate size (mm)	Loose density (kg/m^3)	Dry density (g/cm^3)	Saturated density (kg/m^3)	Water absorption (%)	Fineness modulus
LFA	0.15 ÷ 5	1420	2.66	1650	0.50	2.9
CG	5 ÷ 10	1500	2.67	1600	0.30	-

3. The sulfate-resisting Portland cement (SRPC) is used SEM I 42.5 N, which manufactured at "Tam Diep" factory (Vietnam) with the specific weight of 3.15 g/cm^3. Table 2 are presented the mineralogical compositions and mechanical properties of this Portland cement.

Table 2. Mineralogical compositions and characteristics of sulfate-resisting Portland cement "Tam Diep"

Mineral composition (wt. %)					Surface area (cm^2/g)	Soundness - Lechatelier (mm)	Time of setting (min)		Compressive strength (MPa)	
C_3S	C_2S	C_3A	C_4AF	Other			Initial	Final	3 days	28 days
60.5	22.5	3.9	10.8	2.3	3540	2.5	120	250	30.5	50.7

4. Low – calcium Fly Ash (LC-FA) used in this investigation was obtained from TPP "Vung Ang" (Vietnam), while Silica fume SF 90 Silica Fume SF-90 (SF-90) (Vina Pacific) was used as an additive in the concrete mixes. In this case of the work, LC-FA and SF-90 were used as a binder. In details, the binder (BID) contained sulfate-resisting Portland cement, low – calcium fly ash and silica fume. The basic characteristics of LC-FA and SF-90 are given in Tables 3.

Table 3. The physical properties of LC-FA "Vung Ang" and SF-90

Material type	Specific weight (g/cm^3)	Unit weight of natural porous state (kg/cm^3)	Surface area (cm^2/g)	Water demand	Passing sieve 10 μm (%)
LC-FA	2.34	850	3980	28.5	15
SF-90	2.15	760	10150	31.8	-

The analysis results of chemical compositions of both SRPC, LC-FA, SF-90 and LFA are presented in Table 4.

Table 4. The chemical properties of SRPC, LC-FA and SF-90

Material type	Compositions (wt. %)										
	SiO_2	Al_2O_3	Fe_2O_3	SO_3	K_2O	Na_2O	MgO	CaO	CO_2	P_2O_5	Loss on ignition
SRPC	22.3	3.9	2.8	1.8	0.6	0.2	0.9	65.3	-	0.4	1.8
LC-FA	53.8	18.8	11.6	1.5	1.2	1.3	4.6	3.7	-	-	3.5
SF-90	91.3	2.3	2.5	-	-	0.6	-	0.5	-	0.1	2.7
LFA	6.01	0.46	0.21	-	-	0.13	0.52	54.9	37.6	0.17	-

5. SR-5000F superplasticizer (S5000) "SilkRoad" (Hanoi-Korea co., Ltd., Vietnam) with a specific gravity of 1.1 g/cm^3 at 25°C was used to reduce the water-to-cement ratio and achieve the desired workability of concrete mixtures.

6. Local clean water (W) is used throughout this work for both making concrete mixes and curing of tested specimens.

2.2. Calculation of the compositions of the concrete

- In this experimental program, the high-strength concrete Class B55 with the minimum required average compressive strength at 28 days was 70 MPa by according to GOST 25192-2012 and the slump value of the fresh HSC mixture was also controlled within the range of 9÷15 cm.
- Besides, low-calcium fly ash (20-40)% by weight was used to replace part of Portland cement.
- Based on studies of High-strength concrete using silica fume [1, 17], the water- binder ratio ($\frac{W}{BID}$) is chosen as $\frac{W}{BID} = 0.29$ and plus 5 to 15% silica fume by mass of Portland cement for all mixture proportions of concrete tested.
- The volume of crushed granite stone (V_{CG}) at compacted state in 1 m^3 of concrete mix with D_{max} = 10 mm and the modulus of sand M_K = 2.9 is V_{CG} = 0.65, according to ACI 211.4R-2008 [17].
- The calculation of limestone fine aggregate content in 1 m^3 of concrete of the control sample is done by absolute volume method.
- The SR-5000F superplasticizer is equally to 2.0% by mass of the binder [18].
- The relative volume of the entrapped air was assumed at 1.0% in 1 m^3 of the tested concretes.

On the basis of the above data and combined with the absolute volume method, the sixteen of the HSC-mixes with varying contents of LC-FA and SF-90 were made for the current study (see Table 5).

Table 5. Ingredient proportions for the preparation of HSC and properties of fresh concrete mixtures

Mixes	Ratios of raw materials		Concrete mixture (kg/m^3)							Fresh unit weight (kg/m^3)	Slump (cm)
	LC-FA (%)	SF-90 (%)	RSPC	LC-FA	SF-90	LFA	CG	S5000	W		
Mix-1 (control)	0	0	572	0	0	683	975	11.4	166	2430	14.5
Mix-2	20	0	477	95	0	660	975	11.4	166	2400	14.5
Mix-3	30	0	440	132	0	651	975	11.4	166	2391	14
Mix-4	40	0	409	163	0	643	975	11.4	166	2378	13
Mix-5	0	5	545	0	27	673	975	11.4	166	2415	14.5
Mix-6	0	10	520	0	52	663	975	11.4	166	2406	14
Mix-7	0	15	497	0	75	654	975	11.4	166	2397	13
Mix-8	20	5	458	92	23	652	975	11.4	166	2390	13.5
Mix-9	30	5	424	127	21	644	975	11.4	166	2378	13
Mix-10	40	5	394	158	20	637	975	11.4	166	2370	13
Mix-11	20	10	440	88	44	644	975	11.4	166	2381	13
Mix-12	30	10	409	123	41	637	975	11.4	166	2371	12
Mix-13	40	10	381	153	38	631	975	11.4	166	2366	11
Mix-14	20	15	424	85	64	637	975	11.4	166	2377	11.5

Mix-15	30	15	394	118	59	631	975	11.4	166	2369	10.5
Mix-16	40	15	369	148	55	625	975	11.4	166	2358	9.5

2.3. Test Method

On the one hand, the mixture compositions of HSC were designed in accordance with ACI 211.4R-2008 standards and combined with the absolute volume method and were mixed in the mixer "Controls 0.5" at the laboratory with a rate of 50 rpm from 3 to 5 minutes at a temperature of 25^{o}C. On the other hand, the workability of fresh concrete mixture workability was determined according to the GOST 10181-2014 (Russian standard), using the slump cone with dimensions of 100×200×300 mm. Additionally, the compressive strength test of the HSC samples was measured at different ages following the guidelines of GOST 10180-2012 (Russian Federation standard). Besides, the density of concretes is determined by a 150x150x150 mm cube specimen.

a). The water absorption of HSC-samples was determined according to ASTM C642-13. The concrete samples were dried in an oven "XMTA, China" at a temperature of (100-110)^{o}C for 24 hours at the laboratory, the allowed samples to cool in an oven for 12 hours and determined its mass. After cooling, the samples were immersed in water for 48 h and then boiled the sample for 5 h. The water absorption of HSC-samples was calculated by the formula (1):

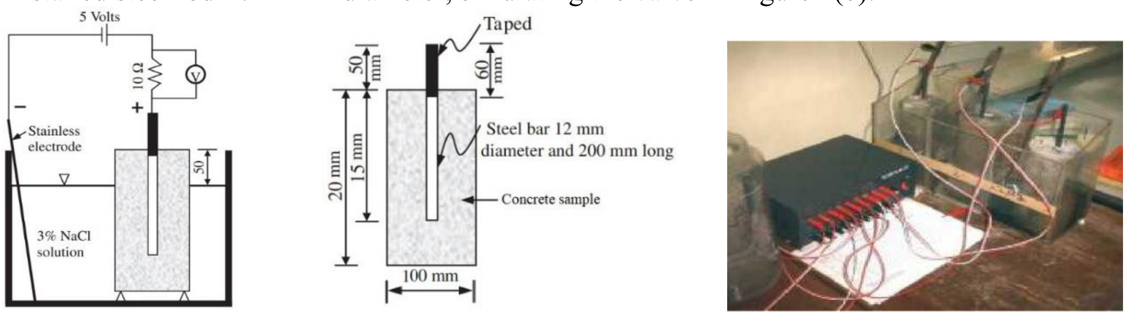
$$H = \frac{m_1 - m_2}{m_2} \times 100\% \qquad (1)$$

In the form: H - water absorption after immersion and boiling of the sample tested (%); m1 - the mass of surface-dry sample in air after immersion and boiling (g) and m2 - the mass of the oven-dried sample (g).

All the tested specimens were demoded after 1-day right after casting and subjected to standard maintenance (20 ±5^{o}C and humidity > 90%) until the testing. The test was performed using a computer-controlled compression tester "Controls Advantest 9" with a constant loading rate of 2000 N/s in order to keep the loading rate to a minimum rate in comparison with the test results of test specimens.

b). Corrosion of reinforced steel in test HSC specimens. The tests were conducted according to standard NT Build 356 [19]. The considered method is aimed at an accelerated assessment of the degree of protection against corrosion's reinforced in concrete structures, operated under the ground, in water and in other aggressive environments.

The experimental setup and HSC samples, with which the experiment was conducted, are shown in Figure 1. The samples had the shape of a cylinder the size of 100x200 mm, in the middle of the sample was installed steel rod 10 mm in diameter, simulating the valve in Figure 1(b).



(a) (b) (c)

Figure 1. (a) - Scheme test setup, (b) - Prepared the concrete sample for accelerated corrosion test by standard NT Build 356 and (c) - Measuring of amperage through the concrete sample tested

During the experiment, conducted continuous measurement of the current passing through the HSC samples. In the initial tests when the concrete layer is still able to protect the steel rod, the recorder records the occurrence of feeble current strength. As the penetration of the chlorine ions from the 3% NaCl solution through the concrete cover to the steel rods is an increase in current strength. A potential of 5 V direct current was applied across the HSC samples, the steel rod being the positive electrode and a stainless steel sheet being the negative electrode as shown in Figure 1(a).

c). In this study was evaluated the permeability of chloride-ion in the structure of HSC samples according to ASTM C1202-19 [20].

This method is based on the principle of measuring the value of electrical energy transmitted through a cylindrical concrete sample with a diameter of 102 mm and a height of 51 mm in a period of 6 hours. Test concrete samples were placed between the anode and the cathode. The 60V DC voltage is applied to two sides of the cylindrical concrete sample. In which, one side is contacted NaOH solution 0.3 N (cathode), the other is communicated in NaCl solution 3% (anode). The experimental concrete samples were conducted at the age of 28 days. Under the influence of electric fields, chlorine-ion diffused through the capillary pores of the concrete, move from the cathode to the cathode and create electricity. The intensity of the electric current was measured every 30 minutes for 6 hours. Further, the total of electrical energy transmitted through the tested HSC sample, in Coulomb (C), was calculated by the formula (2):

$$Q = 900 (I_0 + 2I_{30} + 2I_{60} + ... + 2I_{300} + 2I_{330} + I_{360}) \quad (2)$$

where: Q - power transmission through the sample (C) and I_τ - the amperage at a time τ minute (A).

3. Results and Discussion

3.1. Properties of Fresh Concrete Mixtures

The properties of concrete mixes are presented in Table 5. All sixteen mixtures showed the excellent workability with its slump of (9.5 - 14.5) cm after immediately mixing completion. Also, a more, it can be seen from Table 5 that the addition of (20-40)% LC-FA and (5-15)% SF-90 affected the workability of the fresh HSC mixtures although in these mixes have used 2.0% content of superplasticizer "SR-5000F" and the water- binder ratio of 0.29. This result is caused by the increase in the fineness of the Low – calcium Fly Ash, as also its specific surface area, particularly with silica fume SF 90, due to the increase in fines amount and hence a higher content of water is required to wet the surface of particles of the binder, as well as cementitious material. This result in agreement with a result of published from previous research [13, 14, 21].

3.2. Properties of HSC specimens

Results of the properties of High-strength concrete with 100% of limestone fine aggregate using to replace quartz sand and (20-40)% of low-calcium fly ash; (5-15)% of silica fume SF-90 replacement a part of sulfate-resisting Portland cement are listed in Tables 6 and 7. It is evident that the concrete samples containing LC-FA and SF-90 at different contents have modified the concrete properties in not only the fresh but also hardened state.

Table 6. The average values density, water absorption, charge passed and time of initial crack of concrete samples tested

Mixtures	LC-FA (%)	SF-90 (%)	Average density (kg/m^3)	Water absorption (%)	Charge passed (Coulomb)	Time of initial crack of the concrete tested (days)
Mix-1	0	0	2359	7.27	2823	43
Mix-2	95	0	2334	6.05	1685	61
Mix-3	132	0	2324	5.88	1478	66
Mix-4	163	0	2314	5.64	1430	63
Mix-5	0	27	2351	4.61	1256	67
Mix-6	0	52	2342	4.08	905	83
Mix-7	0	75	2333	3.95	415	89
Mix-8	92	23	2326	3.51	1158	71
Mix-9	127	21	2317	3.31	1104	73
Mix-10	158	20	2308	3.25	1019	68
Mix-11	88	44	2319	2.36	527	91
Mix-12	123	41	2310	2.85	406	80

Mix-13	153	38	2303	2.38	312	75
Mix-14	85	64	2312	2.06	358	76
Mix-15	118	59	2304	2.05	327	72
Mix-16	148	55	2297	2.11	288	65

Table 7. Compressive strength of concrete tested at different curing period

Mixes - No.	LC-FA (%)	SF-90 (%)	Compressive strength (MPa)					
			1-day	3-day	7-day	14-day	28-day	90-day
Mix-1	0	0	16.6	53.8	62.6	69.4	73.1	82.8
Mix-2	95	0	15.4	48.7	55.7	63.8	69.3	80.5
Mix-3	132	0	14.4	40.4	49.1	57.3	65.9	78.4
Mix-4	163	0	12.7	35.9	42.6	52.3	58.2	68.3
Mix-5	0	27	16.5	55.6	65.7	70.4	75.3	83.4
Mix-6	0	52	17.3	59.8	69.7	75.8	79.0	86.1
Mix-7	0	75	18.1	65.5	75.2	80.4	83.8	88.4
Mix-8	92	23	15.2	49.7	58.4	64.1	70.5	81.1
Mix-9	127	21	14.7	39.8	50.4	60.7	67.2	79.5
Mix-10	158	20	13.3	26.8	44.7	54.9	60.6	71.7
Mix-11	88	44	16	40.7	56.9	65.6	74.7	81.9
Mix-12	123	41	15.7	42.1	57.4	62.1	73.5	81.8
Mix-13	153	38	13.4	30.8	45.2	56.0	60.9	73.6
Mix-14	85	64	18.4	67.4	76.1	79.3	83.1	89.3
Mix-15	118	59	13.6	33.1	47.8	57.2	61.8	77.6
Mix-16	148	55	13.2	40.5	45.9	52.8	59.5	69.8

a). Density and water absorption of concrete samples

Both values of density and water absorption of all HSC-samples at the age of 28 days are presented in Table 6 and Figure 2. The average density values were in the range of 2297-2351 kg/m^3, while water absorption values were between 2.05 and 7.27%.

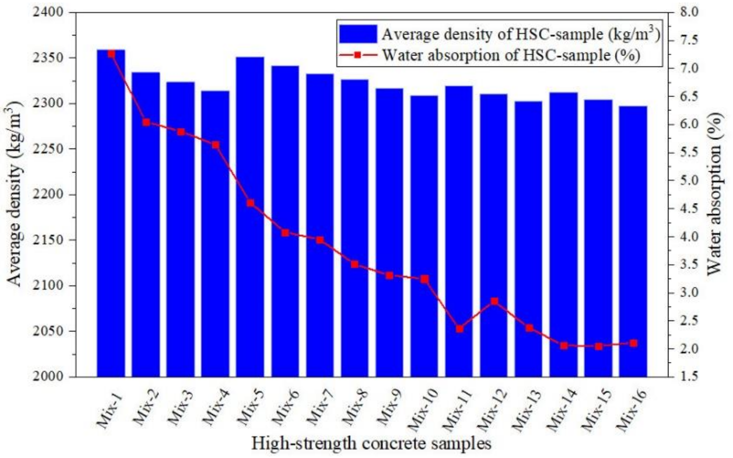


Figure 2. Density and water absorption of all concrete samples tested at the age of 28 days

Data presented in Figure 2 indicates that at the same water-binder ratio $\frac{W}{BID} = 0.29$, there appeared to be no clear difference in the average values of density of all concrete tested when containing various amounts of LC-FA and SF-90, which were used to replace part of cement. This could be explained by the specific weight of LC-FA and SF-90 slightly lower than Portland cement when the amount of binder was kept constant of 572 kg for all mixtures. The density of hardened concrete varies, depending on the content and density of the fine and coarse aggregates, the amounts of air voids that is entrained or entrapped and the water and cement, as well as additives [22]. However, with the content and density of the aggregate and water content are kept constant, the density of concrete in a hardened state only depends on the content of air voids and binder content.

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Data from Figure 2 was also given values water absorption of all concrete samples tested at 28 days. As it is known, water absorption of concrete has a direct relationship with the density and its porosity [14]. During the hydration reaction of the binder, including Portland cement, Low-calcium fly ash and silica fume, all hydration products of these compounds filled the voids in the cement stone, thus the water absorption of HSC-sample was decreased [15]. With at the same water- binder ratio, the water absorption of all HSC-specimens containing FC-FA and SF-90 was lower than mix control and tends to decrease with increasing SF-90 content.

b). Compressive strength of HSC specimens

As it is known, the most important mechanical property of concrete is the compressive strength. The compressive strengths of the concrete specimens at the age of 3, 7, 28 and 90 days are given in Table 7. Moreover, the relationship between compressive strength and curing age for examined High-strength concrete shown in Figure 3. The compressive strength of all concrete mixtures increased with increasing curing time.

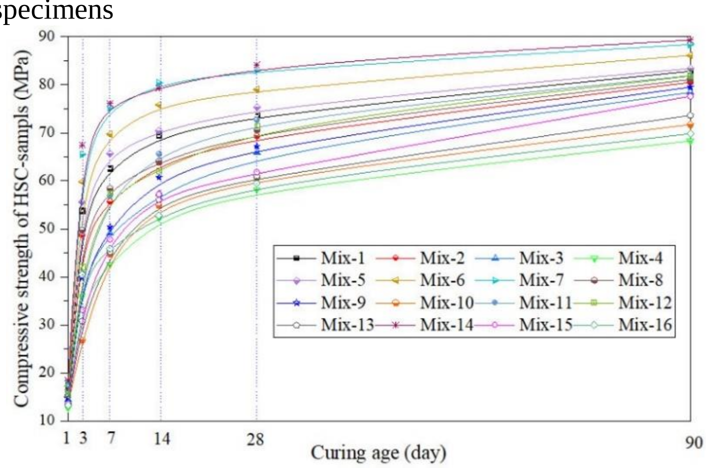
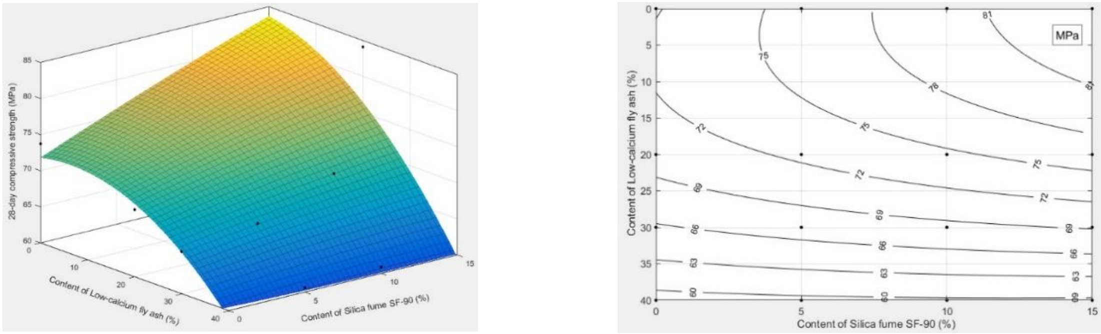


Figure 3. Compressive strength development of HSC at different curing period

The compressive strength of Mix-2, Mix-3 and Mix-4 containing 20%, 30% and 40% of LC-FA, respectively, were lower than the mix-1 (mix control). In addition, the results of this study show that the compressive strength of all concrete mixtures at (20-30)% by weight of cement replacement decreased with increasing LC-FA content, at all test ages. The reduction of compressive strength of all examined concrete containing LC-FA is due to its slow pozzolanic reaction and the dilution effect with a surface area of the Low-calcium fly ash small. While the compressive strength of concrete mixtures with SF-90 at 5%, 10% and 15% by mass cement was higher than the mix control (Mix-1) and significantly higher than the concrete mixtures containing the amount of (20-30)% LC-FA. This is due to the greater pozzolanic reaction and micro filler effect of SF-90 [21] thanks to the high content of amorphous silica and its surface area large.

In addition, it can be observed that the types of examined concrete were obtained when using low calcium fly ash incorporating with silica fume at different Portland cement replacement level. Metha et al. and Wongkeo et al. [4, 12, 14] reported that concrete having a 28 days compressive strength more than 60 MPa was designed as a high strength concrete. In the case of this study, types of concrete having a 28-day compressive strength more than 70 MPa was designed as a high strength concrete by according to GOST 25192-2012. From results in Table 7 shown that the mixtures of 20%LC-FA+5%SF, 20%LC-FA+10%SF, 30%LC-FA+10%SF and 20%LC-FA+15%SF at W/BID = 0.29 have compressive strength at 28 days over 70 MPa. Therefore, these mixtures containing low calcium fly ash and SF-90 that contributed 28-day compressive strength more than 70 MPa can be designed as a high strength concrete.

c). Response surface for compressive strength at 28 days



(a) (b)

Figure 4. (a)-Response surface and (b)-Contour plot for compressive strength at 28 days of specimen

Figure 4 (a) and (b) shows the response surfaces and contour plots for 28-day compressive strength of HSC samples. Compressive strength varies linearly with silica fume SF-90 content and nonlinearly with Low-calcium fly ash. For a given water- binder ratio, an increase in the content of Low-calcium fly ash so the decrease in Portland cement content reduces the compressive strength, while the effect of silica on compressive strength is predominant at the higher pozzolanic reaction and micro filler effect for the microstructure of concrete.

Whereas, in Figure 4 was identified the fitting relationship between the 28-day compressive strength and contents of LC-FA and SF-90 of HSC specimens, which were shown by second-order model with regression equation (3):

$$Y = 71.04 + 0.2017x_1 + 1.119x_2 - 0.01273x_1^2 - 0.02037x_1 x_2 - 0.01175x_2^2 \quad (3)$$

In Equation (3), Y is the 28-day compressive strength (MPa) and x_1 and x_2 are contents of LC-FA (%) and SF-90 (%), respectively. The values $R^2 = 0.8689$ and Adjusted $R^2 = 0.8034$ are represented a relatively strong negative correlation between the two initial parameters of LC-FA and SF-90 contents for compressive strength of HSC-samples at the age of 28 days.

d). Chloride resistance

To evaluate the resistance of concrete to chloride ion ingress, the charges passed through concrete specimens in coulombs is measured in accordance with the ASTM C1202-19. The results of the charges passed of all HSC-samples performed at 28 days are listed in Table 6 and shown in Figure 5.

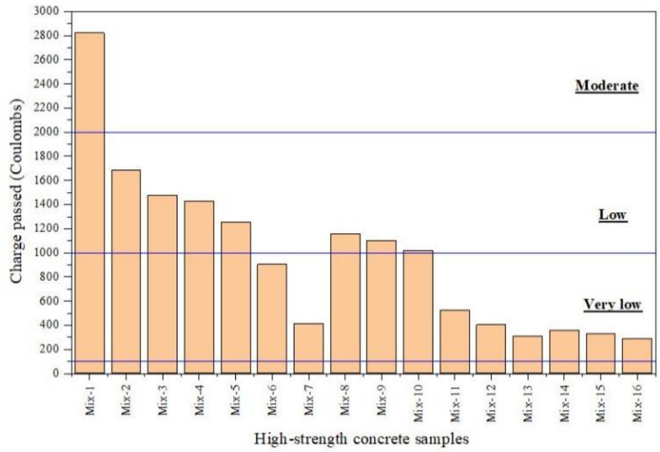


Figure 5. The average values of charge passed of the experimental concrete samples and the level of chloride ion penetrability based on charge passed

The tested results show that, at the same water-binder ratio, the charges passed of Mix-1 of control concrete was significantly higher than that of LC-FA and SF-90 concretes. It can be seen in Table 6 that the average charges passed of the examined concrete containing fly ash and silica fume mixes decreased with increasing FA and SF content. Moreover, according to the classification of ASTM C1202 – 19, the chloride-ion permeability degree of these types of HSC containing sulfate-resisting Portland cement are precisely low and very low (as shown in Figure 5). Furthermore, the charges passed of LC-FA concrete were higher than that of SF-90 concrete. The results of this work, similar to the results presented in published studies [1, 18, 23].

The reduction of charges passed of concrete specimens tested containing the binder, including Low-calcium fly ash and silica fume SF-90 mixes is due to the chloride chemical bonding effect and can be explained by the following reasons:

(i). Usually, chloride ions can react with tricalcium aluminates (C_3A) and C_4AF to from $3CaO.Al_2O_3.CaCl_2.10H_2O$ and $3CaO.Fe_2O_3.Al_2O_3.CaCl_2.10H_2O$ which is stableforms and leads to a decrease of free chlorides available [24].

(ii). The presence of FA and SF-90 leads to an increase in the amount of C_3A due to the higher amount of alumina present in the mix. In addition, FA and SF-90 lead to an increase of calcium silicate hydrate (C-S-H) content that is formed in the pozzolanic reactions, especially SF-90 led to a decrease in the total chloride charges passed through examined concrete.

(iii). The reduction of charges passed is due to the improvement of pore structure by fine particles of fly ash and silica fume that reduces the permeability of hardened concrete [25, 26].

e). Corrosion of reinforced of HSC specimens tested in the medium of 3% NaCl

In Table 6 and Figure 6 were given the time of initial crack of the test specimens for sixteen mixtures tested for the assessment of the corrosion of reinforced in the medium of 3% NaCl solution by standard NT Build 356. It has been observed that for all test mixes with different contents of LC-FA and SF-90, the experimental time's destruction of examined specimens was in the range of 43 - 91 days.

The damage of concrete specimens as a result of this test was shown in Figure 7. In this case, the concrete mixtures containing various amounts of Low-calcium fly ash and silica fume SF-90 are showed significant higher destruction times than the control mixture (mix-1). It is due to the presence of pozzolanic materials, especially silica fume FS-90 increased the volume of the C-S-H gel, as well as the density of concrete structure, and therefore reduced the porosity of its structure and enhanced the strength of the structure, also increased destruction time of test specimens.

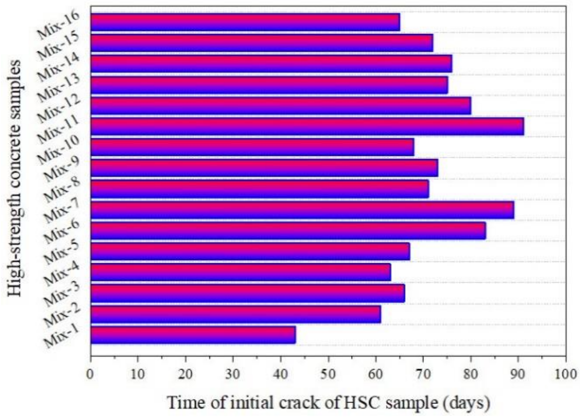


Figure 6. The time of initial crack of concrete tested by standard NT Build 356

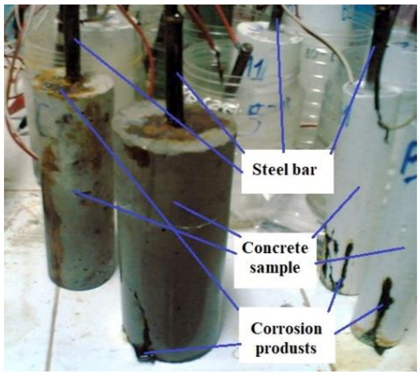


Figure 7. Corrosion failure of the test HPFC specimens

4. Conclusions

The following conclusions may be drawn based on the results obtained from this investigation:

(1) The addition of (20-40)% LC-FA and (5-15)% SF-90 significantly affected the slump of the fresh HSC mixtures containing limestone fine aggregate as a fine aggregate although in these mixes have used 2.0% content of superplasticizer "SR-5000F" and the water- binder ratio of 0.29.

(2) The average densities of all HSC at 28-day were not clearly different when containing Low-calcium fly ash and silica fume SF-90. However, the water absorption of tested concrete samples containing LC-FA and SF-90 was lower than concrete control. This is caused by all hydration products

of Portland cement, LC-FA and SF-90 with water were filled the voids in the cement stone, thus the water absorption of HSC-sample was decreased.

(3) The compressive strength of examined concrete decreased with increasing LC-FA content at all test ages and was lower than concrete control. While the compressive strength of concrete mixtures with SF-90 at 5%, 10% and 15% by mass cement was higher than the mix control and significantly higher than the concrete mixtures containing the amount of (20-30)% LC-FA. Moreover, the mixtures of 20%LC-FA+5%SF, 20%LC-FA+10%SF, 30%LC-FA+10%SF and 20%LC-FA+15%SF at the water- binder ratio of 0.29 have compressive strength at 28 days over 70 MPa. These can be designed as a high strength concrete.

(4) The relations between compressive strength at 28-day and contents of LC-FA and SF-90 were simulated with a correlation coefficient R^2 = 0.8689 and Adjusted R^2 = 0.8034. From these simulation relations would predict the development of compressive strength of HSC-samples for the given LC-FA and SF-90 contents.

(5) Tested concrete containing LC-FA and SF-90 decreased the charge passed and tends to decrease with increasing LC-FA and SF contents. The very low chloride ion penetrability can be obtained when using (20-40)% of low-calcium fly ash and (5-15)% of Silica fume as the binder in mixtures tested. Application of standard NT Build 356 determined the times of initial crack of the test specimens containing sulfate-resisting Portland cement in the range of 43 - 91 days. It is due to the presence of pozzolanic materials increased the volume of the C-S-H gel, as well as the density of concrete structure and enhanced the strength of the structure, thus increased destruction time of specimens used for the assessment of the corrosion of reinforced steel in the concrete.

(6) The results of the current investigation support the use of industrial waste as fly ash and waste limestone from the quarries (Vietnam) as the fine aggregate of green concrete mixtures in the future.

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