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EFFECT OF FLY-ASH AMOUNT AND CEMENT TYPE ON THE CORROSION PERFORMANCE OF THE STEEL EMBEDDED IN CONCRETE

UČINEK KOLIČINE LETEČEGA PEPELA IN VRSTE CEMENTA NA KOROZIJO JEKLA V BETONU

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In this study the corrosion performance of the steel embedded in the concrete produced by using three different types of cement (CEM II/B-M (P-L) 32.5 R, CEM I 42.5 R and CEM I 52.5 R) was investigated. 300 kg/m^3 and 375 kg/m^3 dosages of the cement with (0, 10 and 20) % of fly-ash (FA) replacements of cement were used to produce the concretes. These concretes were cured for 28 d and 180 d. The mechanical properties of the concretes were determined and the corrosion performances of the reinforced-concrete specimens were determined using the impressed voltage test. After the impressed voltage test weight losses occurred because of the corrosion that was determined. The results of this study show that using composite cement and an FA replacement of the cement are useful in combating corrosion.

Keywords: concrete, corrosion, mechanical properties, fly ash

V tej študiji je bilo preiskovano korozijsko vedenje jekla, vgrajenega v beton, izdelan iz treh vrst cementa (CEM II/B-M (P-L) 32,5 R, CEM I 42,5 R in CEM I 52,5 R). Odmerki 300 kg/m^3 in 375 kg/m^3 cementa z (0, 10 in 20) % letečega pepela (FA) kot nadomestila za cement, so bili uporabljeni za izdelavo betona. Beton je bil preskušen po 28 d in po 180 d. Določene so bile mehanske lastnosti betona. Korozijske lastnosti armiranega betona so bile določene s pospešenim korozijskim napetostnim preizkusom. Pri pospešenem napetostnem korozijskem preizkusu se je zaradi korozije pojavilo zmanjšanje mase. Rezultati te študije kažejo, da je za zmanjšanje korozije ugodna uporaba kompozita cementa z letečim pepelom, ki nadomesti cement.

Ključne besede: beton, korozija, mehanske lastnosti, leteči pepel

1 INTRODUCTION

Corrosion of the steel embedded in concrete plays a vital role in the determination of the life and durability of the concrete structures.[1] The durability of reinforced concrete is largely controlled by the capability of the concrete cover to protect the steel reinforcement from corrosion. Chemical protection is provided by the concrete's high alkalinity and physical protection is afforded by the concrete cover acting as a barrier to the access of aggressive species.[2] The corrosion of the steel in concrete is retarded by the passivating ferric-oxide film (γ-FeOOH) formed in the concrete medium (that is highly alkaline with a pH of around 13).[1] Corrosion of the reinforcing-steel bars is initiated to form an inactive thin layer that can be broken when immersed in carbonate, chloride or sulphate solutions.[3] Corrosion of steel produces rust products that have a volume three to eight times greater than that of the original metal. This generates stress and causes cracking and spalling of the concrete cover, which further accelerates corrosion.[4] Various methods have been applied to protect reinforced steel against corrosion; these methods include variation of the concrete formulation, cathodic protection, surface treatment of the rebar and addition of inhibitors and mineral admixtures.[5] It is generally recognized that the incorporation of fly ash (FA) in blended cements helps to protect concrete against the chloride-induced corrosion of steel reinforcement by reducing its permeability, particularly for chloride-ion transportation, and increasing the resistivity of the concrete.[6,7]

In this study, the corrosion performance of the steel embedded in the concrete produced by using three different types of cement was investigated. Cements in 300 kg/m^3 and 375 kg/m^3 dosages and also (0, 10 and 20) % FA replacements of cement were used to produce the concretes. The mechanical properties of the concretes were determined. The impressed voltage test was performed on the reinforced concrete specimens. In conclusion, the best cement type, FA ratios and curing times for the corrosion performance of the steel embedded in concrete were determined.

2 GENERAL OBSERVATIONS ABOUT THE BUILDING STOCK IN TURKEY

According to the studies in various regions of Turkey, the average concrete compressive strength is approximately 10 MPa.[8,9] Several identified improper practices for fabricating an in-situ concrete caused this signifi-

Figure 1: Corrosion of the reinforcement in a damaged column observed after the Van earthquake of 23 October 2011 (Murat Öztürk's archive)
Slika 1: Korozija armature v poškodovanem stebru med potresom 23. 10. 2011 (arhiv Murat Öztürk)

cantly low concrete quality. Important factors include the ignorance of the aggregate gradation, the use of unwashed sea sand and/or river sand, and the use of the aggregate sizes that are too large. One of the most negative factors contributing to a low concrete quality is the use of the sea sand or river sand in a concrete mixture. According to the obtained results, the significantly high chloride content in the sea-sand concrete is an indication of a high tendency for the corrosion of the reinforcement in the reinforced concrete structures. The observations of the building rubbles showed that most rebars had corroded due to the use of the river/sea sand, thereby reducing the efficiency of the longitudinal rebar area and the anchorage (**Figure 1**).

Table 1: Chemical and physical properties of the cements and fly ash
Tabela 1: Kemijske in fizikalne lastnosti cementov in letečega pepela

Chemical Composition, %	Cement Type			FA
	CEM I 52.5 R	CEM I 42.5 R	CEM II/B-M (P-L) 32.5 R	
SiO_2	20.47	20.74	30.88	58.25
Al_2O_3	5.68	5.68	8.01	16.66
Fe_2O_3	3.08	4.12	3.57	12.91
CaO	62.66	63.70	47.78	1.95
MgO	1.1	1.22	1.30	5.08
Na_2O	0.20	0.17	0.12	0.33
K_2O	0.75	0.53	1.33	1.37
SO_3	2.5	2.29	1.67	0.41
Cl	0.010	0.019	0.011	0.002
Loss of ignition	1.9	1.34	6.20	2.09
Insoluble residue	0.7	0.57	0.27	–
Free lime	1.0	1.29	1.31	0.16
Physical Properties				
Specific gravity	3.17	3.14	2.85	2.34
Specific surface, cm^2/g	3700	3450	3580	
Compressive Strength, MPa				
2 days	27	26	13	–
7 days	41	38	27	–
28 days	59	59	43	–

3 EXPERIMENTAL STUDIES

3.1 Materials used

3.1.1 Cement

The experimental studies used the CEM I 42.5 R Portland cement and the CEM II/ B-M (P-L) 32.5 R Portland composite cement, produced by the Eskisehir cement factory according to TS EN 197-1 : 2 000 standards. The CEM II/B-M (P-L) cement contains natural pozzolans and limestone in the ratio of 21–35 % by weight. In addition, the CEM I 52.5 R Portland cement was used. The results of the chemical and physical analyses of these cements, which were provided by the factories, are given in **Table 1**.

3.1.2 FA

In the experiment, the Tunçbilek thermal power plant's FA was used. The chemical composition and the physical properties are given in **Table 1**. Because the SiO_2+Al_2O_3+Fe_2O_3 content exceeds 70 % and the CaO value is under 10 %, the FA of Tunçbilek is of class F (low lime) according to the ASTM C 618 standard.

3.1.3 Aggregates

The Osmaneli sand and the Söğüt Zemzemiye crushed-stone aggregates were used. The maximum particle size of the aggregates was 31.5 mm. According to the results of the experiment, the specific gravities of the sand and the crushed stones I and II are 2620, 2710 and 2710 and the unit weights are (1550, 1720 and 1770) kg/m^3, respectively. (35, 30 and 35) %, of the sand and the crushed stones I and II, respectively, were used in the grain mixture.

3.1.4 Steel reinforcements and the NaCl solution

14-mm-diameter deformed steel reinforcement was used for the preparation of the reinforced concrete specimens to attempt the corrosion tests. According to TS 708 the minimum yield strength of this steel is 420 MPa and the minimum tensile strength is 500 MPa. In the experimental setup for the corrosion testing, an industrial type of the NaCl salt was used for obtaining the solution.

3.2 Mix proportions of the concrete

Three different types of cement, CEM II/B-M(P-L) 32.5R (CII-3), CEM I 42.5R (CI-4) and CEM I 52.5R (CI-5), were used in the concrete mixtures. By using 300

Table 2: Mix proportions of the concrete for 1 m^3
Tabela 2: Delež sestavin v 1 m^3 betona

Cement Type	Dosage	FA %	Cement	Sand	Crushed Stone I	Crushed Stone II	Water	FA
CII-3	375	0	375	611	541	632	188	–
		10	337.5	608	539	629	188	37.5
		20	300	605	537	626	188	75
	300	0	300	669	593	692	150	–
		10	270	667	591	690	150	30
		20	240	665	590	688	150	60
CI-4	375	0	375	622	553	645	188	–
		10	337.5	618	550	642	188	37.5
		20	300	614	547	638	188	75
	300	0	300	678	603	704	150	–
		10	270	675	601	701	150	30
		20	240	672	598	698	150	60
CI-5	375	0	375	623	554	646	188	–
		10	337.5	619	551	643	188	37.5
		20	300	615	548	639	188	75
	300	0	300	679	604	705	150	–
		10	270	676	602	702	150	30
		20	240	673	599	699	150	60

*Superplasticiser (SP) was used as 0.4 % by mass of binder (cement and FA)

kg/m^3 and 375 kg/m^3 dosages of each cement, the concrete specimens were also produced as reference specimens containing 10 % and 20 % of FA. These specimens were cured for two different periods: 28 d and 180 d. Thus, 36 series of the concrete mixture were produced. The mix proportions of the concrete are given in **Table 2**.

3.3 Specimen preparation and testing

3.3.1 Compressive test

The compressive strength test was carried out on the specimens with the cube dimensions of 150 mm × 150 mm × 150 mm. The specimens were demoulded after 24 h and immersed in water at (20 ± 2) °C. The compressive strength tests were made after 28 d and 180 d of curing.

3.3.2 Splitting tensile test

The splitting tensile test was carried out for the cylinder specimens with the dimensions of ϕ150 mm × 300 mm. The specimens were demoulded after 24 hours and immersed in water at (20 ± 2) °C. The splitting tensile tests were carried out after 28 d of curing.

3.3.3 Tests for the ultrasonic pulse velocity and the modulus of dynamic elasticity

The tests of measuring the ultrasonic pulse velocity and the modulus of dynamic elasticity were carried out for the specimens that were prepared for the splitting tensile tests.

3.3.4 Impressed voltage test

The setup for this test included a DC power source, a test specimen and a plastic dish containing a 4 %-NaCl solution, two steel plates and a data logger. The impressed-voltage test setup is shown in **Figure 2**. The reinforced concrete specimens for the accelerated-corrosion tests were the cylinder specimens with the dimensions of ϕ150 mm × 300 mm, in which a 14-mm-diameter steel reinforcement was centrally embedded. A 250-mm part of the steel reinforcement was embedded into each concrete cylinder. The specimens were demoulded after 24 h and immersed in water at (20 ± 2) °C. The impressed voltage tests were carried out after 28 d and 180 d of curing. The steel reinforcement (the working electrode) of the reinforced concrete specimen was connected to the positive terminal and the steel plates (the counter electrodes) were connected to the negative terminal of the DC power source applying 30 V of fixed stress to the system. A similar impressed-voltage test setup has been reported by other researchers.[7,10] Every five minutes the corrosion current of every reservoir was saved using a data logger and the corrosion current-time figures were drawn using the impressed voltage test system.

Figure 2: Setup for the impressed voltage test
Slika 2: Skica pospešenega napetostnega preizkusa

3.3.5 Weight loss method

The method proposed in the ASTM G1-03 standard was used for the determination of the weight loss of a steel bar.[11] After the impressed voltage tests, steel bars were demounted from the reinforced concrete specimens and the weight losses were found by cleaning these steel bars with a Clarke solution, which contained 1000 mL HCL, 24 g Sb_2O_3 and 71.3 g $SnCl_2 \cdot 2H_2O$.

4 RESULTS AND DISCUSSION

4.1 Compressive strength

Changes in the compressive strengths due to the amount of FA are shown in **Figures 3** and **4**. According to the figures for the 28 d and 180 d compressive strengths, the strength results of the concrete produced with the CI-5 cement are higher than those of the others. With the increase in the FA amount in the specimens, the compressive strengths of the specimens cured for 28 d decreased because the mineral admixtures like FA cannot fully complete the pozzolanic reactions.[12] If **Figure 4** is examined, it can be seen that the strength values increase as the dosage increases. Looking at **Figure 4**, by using 10 % of FA instead of the CI-5 and CI-4 cements in the 375 dosed specimens, the compressive strength of the specimens increases respectively by 4.5 % and 15.66 % according to the control specimens and it decreases at the ratio of 6.42 % in the specimens produced with CII-3. If 20 % of FA is used in the specimens, the compressive strength decreases at the ratio of 6.06 % and 12.17 % for the specimen series produced with the CI-5 and CII-3 cements, but increases at the ratio of 5.43 % for the specimen series produced with the CI-4 cement. If **Figures 3** and **4** are compared to each other, it is seen that the compressive strength increases as the curing time increases.

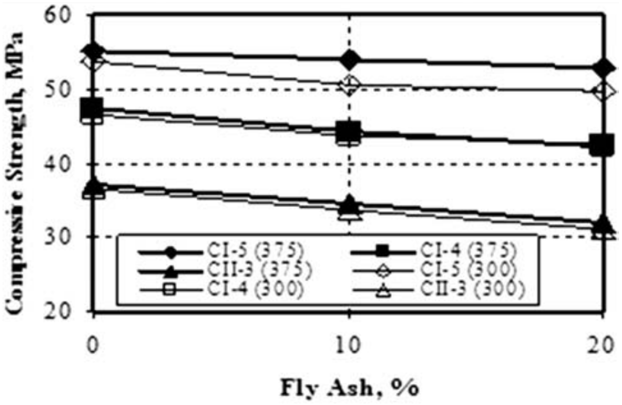

Figure 3: Relationship between the compressive strength and the FA amount in 28-day specimens

Slika 3: Odvisnost med tlačno trdnostjo in deležem letečega pepela (FA) v vzorcu po 28 dneh

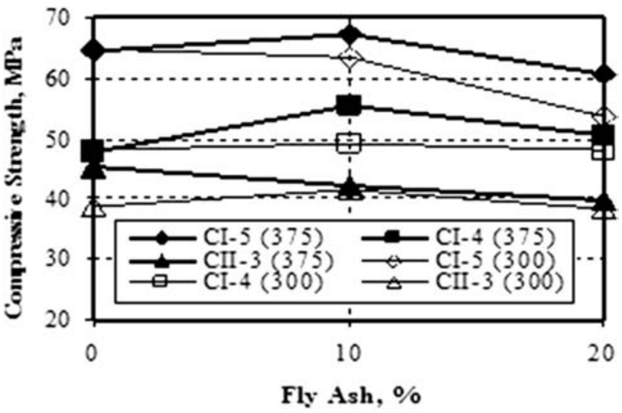

Figure 4: Relationship between the compressive strength and the FA amount in 180-day specimens

Slika 4: Odvisnost med tlačno trdnostjo in deležem letečega pepela (FA) v vzorcu po 180 dneh

4.2 Splitting tensile strength

According to a general assessment from **Figure 5**, the splitting tensile strengths of the specimens produced with the CI-4 and CI-5 cements are very similar to each other. The minimum strengths are found with the specimens produced with the CII-3 cement. As the amount of FA increases in the specimens produced with CII-3, the splitting tensile strength decreases but it increases in the specimens produced with the other cements. According to **Figure 5**, the splitting tensile strength is seen to increase as the dosage of the cement is increased.

4.3 Tests for the ultrasonic pulse velocity and modulus of dynamic elasticity

The ultrasonic pulse velocity and modulus of dynamic elasticity test results are shown in **Table 3**. Considering the ultrasonic pulse velocity of the 375 kg/m[3] and 300 kg/m[3] dosage specimens, it can be seen that the ultrasonic pulse velocity of all the specimens produced with CII-3 are fine. The ultrasonic pulse velocity results of the specimens produced with CI-4 and CI-5 are seen to be better than those of CII-3. Depending on the

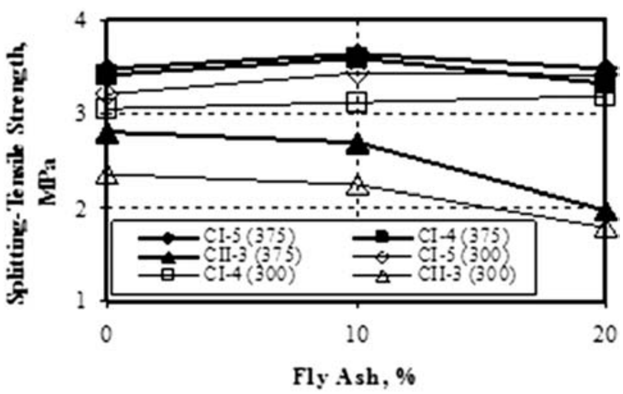

Figure 5: Relationship between the splitting tensile strength and the FA amount

Slika 5: Odvisnost med porušno natezno trdnostjo in deležem letečega pepela (FA) ultrasonic pulse velocity values, the best results are seen to be in the specimens produced with the CI-5 cement and without any FA. According to the assessment in **Table 3**, it can be seen that the modulus of dynamic elasticity decreases as the amount of FA increases. The minimum E_{din} values are for the specimens produced using the CII-3 cement with the dosages of 300 kg/m^3 and 375 kg/m^3. As seen in **Table 3**, for the other series, the E_{din} values are similar.

Table 3: Test results for ultrasonic pulse velocity and modulus of dynamic elasticity
Tabela 3: Rezultati preizkusov za hitrost ultrazvočnega impulza in modul dinamične elastičnosti

Cement Type	FA/%	Ultrasonic pulse velocity /(km/s)		E_{din}/GPa	
		375 Dosage	300 Dosage	375 Dosage	300 Dosage
CII-3	0	4.35	4.52	45.7	49.4
	10	4.46	4.46	47.9	48.0
	20	4.29	4.40	43.6	46.3
CI-4	0	4.62	4.62	52.3	53.1
	10	4.63	4.50	52.3	49.9
	20	4.62	4.60	51.3	51.5
CI-5	0	4.66	4.63	53.5	52.8
	10	4.56	4.56	50.5	50.5
	20	4.65	4.55	52.1	50.5

4.4 Impressed voltage test

After the impressed voltage tests, steel in the reinforced concrete corroded and the specimens were damaged. The damaged specimens are shown in **Figure 6**. Since the volume of the corrosion products (rust) are 2.5–6 times greater than the volume of the steel used in the concrete, these corrosion products lead to higher internal tensile stresses in the hardened concrete. Being exposed to these stresses, the hardened concrete cracks and splits off.[12]

The compressive strength results and damage occurrence times (DOTs) of the accelerated-corrosion specimens are shown in **Table 4**. As seen in **Table 4**, the DOT ranges between 251 h and 394 h. According to **Table 4**, as is the case with the 300 kg/m^3 dosage specimens, an increase in the FA amount leads to a longer DOT. With respect to DOTs, it is observed that the best results are obtained for the specimens produced with CII-3 and 20 % FA cured for 28 d, and the specimens produced with CI-5 and 20 % FA cured for 180 d.

Figure 6: Damaged specimens after the impressed voltage test
Slika 6: Poškodovani vzorci po pospešenem napetostnem preizkusu

A comparison between the 300 kg/m^3 and 375 kg/m^3 dosage specimen results shows that the DOT extends as the cement dosage increases. Generally, if the cement dosage increases, the compressive strength of the concrete increases as well. There is a general relationship between the compressive strength of the concrete and the permeability.[12] According to **Table 4**, the DOT is extended even if the compressive strengths of the concretes produced with the CII-3 cement are low. Actually, the concretes produced with the CII-3 cement that have low compressive strengths are damaged in a shorter time than the concretes produced with the CI-4 and CI-5 cements, because the concretes produced with CII-3 are more porous than the other concretes, as can be understood from the compressive strengths.

Table 4: Compressive strengths and damage occurrence times (DOTs) of the 300 – (375) dosage specimens
Tabela 4: Tlačne trdnosti in časi do pojava napak (DOT) vzorcev z odmerkom 300 – (375)

Cement Type	FA/ %	Compressive Strength, MPa 300 (375)		Damage Occurrence Time Hour – 300 (375)	
		28 days	180 days	28 days	180 days
CII-3	0	36.7 (37.2)	38.9 (45.2)	291 (325)	368 (308)
	10	33.8 (34.7)	41.6 (42.3)	311 (323)	381 (324)
	20	31.2 (32.0)	38.3 (39.7)	325 (366)	394 (373)
CI-4	0	46.5 (47.5)	48.2 (47.9)	279 (287)	303 (306)
	10	43.7 (44.4)	49.2 (55.4)	310 (315)	324 (326)
	20	42.6 (42.2)	48.1 (50.5)	319 (326)	327 (329)
CI-5	0	53.6 (55.2)	64.7 (64.4)	251 (300)	304 (315)
	10	50.7 (54.0)	63.4 (67.3)	268 (316)	343 (368)
	20	49.8 (52.8)	53.6 (60.5)	287 (292)	376 (389)

However, it is known from the previous studies that fly ash, ground granulated blast furnace slag, silica fume and pozzolans bind chloride ions; thus, the chloride permeability decreases.[13–16] The concretes produced with the CII-3 cement are highly porous and permeable due to a high percentage of FA and natural pozzolans that do not pozzolanicly react with water and lime. Therefore, these FA and pozzolan particles react with chloride ions and bind them. In this way, the chloride permeabilities of these concretes are lower than those of the control ones.

Figure 7 shows that the corrosion-time curves of the 28 d cured concretes were produced with a 300 kg/m^3 dosage of the CII-3, CI-4 and CI-5 cements, and 10 % and 20 % FA replacements of the cement. According to the assessment in **Figure 7**, for the concretes produced with the CII-3, CI-4 and CI-5 cements, the curves 2, 3, 5, 6, 8 and 9 show that an increase in the FA amount in the concrete, used as a replacement for the cement, reduces the corrosion currents. According to these results the use

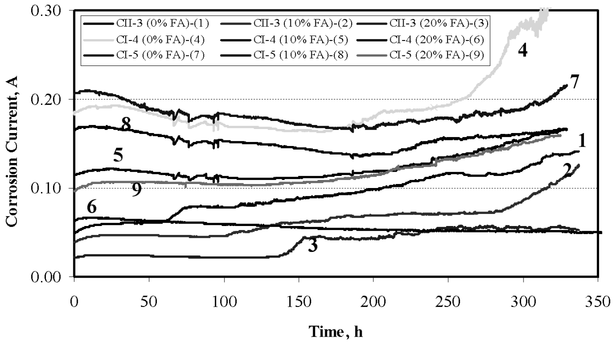

Figure 7: Variation of the corrosion current according to time (a 300-kg/m³ dosage and 28-day specimens)

Slika 7: Spreminjanje korozijskega toka glede na čas (odmerek 300 kg/m³ in vzorec po 28 dneh)

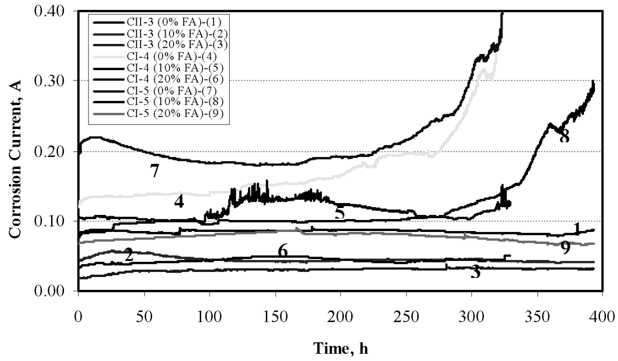

Figure 9: Variation of the corrosion current according to time (a 300-kg/m³ dosage and 180-day specimens)

Slika 9: Spreminjanje korozijskega toka glede na čas (odmerek 300 kg/m³ in vzorec po 180 dneh)

of FA is beneficial. It has been observed that FA binds chloride ions.[15,16] As a result, the corrosion currents decrease as seen in **Figure 7**.

Figure 8 shows the current-time relations for the corrosion of the concretes that are cured for 28 d and produced by using FA as the 10 % and 20 % replacements of the cement weight with a 375 kg/m³ dosage of the CII-3, CI-4 and CI-5 cements. The series produced by using the CII-3 cement gives better test results. However, the best test results are achieved with the concretes produced with a 20 % FA replacement of the CI-4 cement. It is seen that the corrosion current of the specimens is reduced by using the FA replacement for a 375 kg/m³ dosage of the CI-5 cement with the given ratios. By using FA, the corrosion currents are reduced, but better results are achieved than with the other concrete specimens. According to **Figure 8**, the corrosion currents increase with time and it is seen that some series have sudden increases. The corrosion current-time relations are shown in **Figure 9** for the concretes that are cured for 180 d and produced by using FA as the 10 % and 20 % replacements of the cement weight for a 300 kg/m³ dosage of the CII-3, CI-4 and CI-5 cements. Looking at **Figure 9**, with the concretes produced with the CI-4 and CI-5 cements, and without any FA, they are seen to have a corrosion current above 0.1 A. All the other specimens have a corrosion current under 0.1 A at the beginning. The concretes cured for 180 days and produced with a 300-kg/m³ dosage of the CI-4 cement depending on their FA ratio (0 %, 10 % and 20 %) have (0.12, 0.08 and 0.04) A corrosion currents in turn. However, the same series that were cured for 28 d have corrosion currents of (0.18, 0.12 and 0.09) A in turn. According to these results an increase in the curing time reduces the corrosion currents. The corrosion current-time relations are shown in **Figure 10** for the concretes cured for 180 d and produced by using FA as the 10 % and 20 % replacements of the cement weight for the 375 kg/m³ dosage of the CII-3, CI-4 and CI-5 cements. With respect to **Figure 10**, the best results are achieved for the concretes produced with a 20 % FA replacement of the weight of the CII-3 cement.

4.5 Weight loss method

The steel reinforcements cleaned with a Clarke solution are shown in **Figure 11**. The weight losses of the steel reinforcements in various concrete mixtures that were exposed to corrosion are shown in **Figures 12** and **13**. According to a general assessment of these figures,

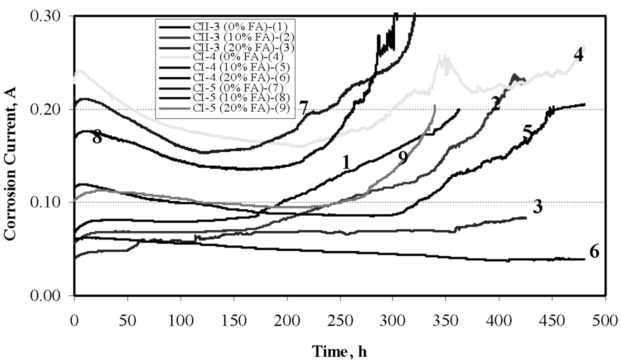

Figure 8: Variation of the corrosion current according to time (a 375-kg/m³ dosage and 28-day specimens)

Slika 8: Spreminjanje korozijskega toka glede na čas (odmerek 375 kg/m³ in vzorec po 28 dneh)

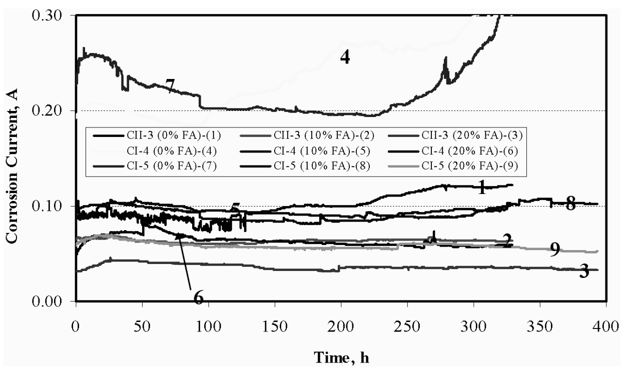

Figure 10: Variation of the corrosion current according to time (a 375-kg/m³ dosage and 180-day specimens)

Slika 10: Spreminjanje korozijskega toka glede na čas (odmerek 375 kg/m³ in vzorec po 180 dneh)

Figure 11: Steel reinforcements cleaned with a Clarke solution
Slika 11: Z raztopino Clarke očiščena jeklena armatura

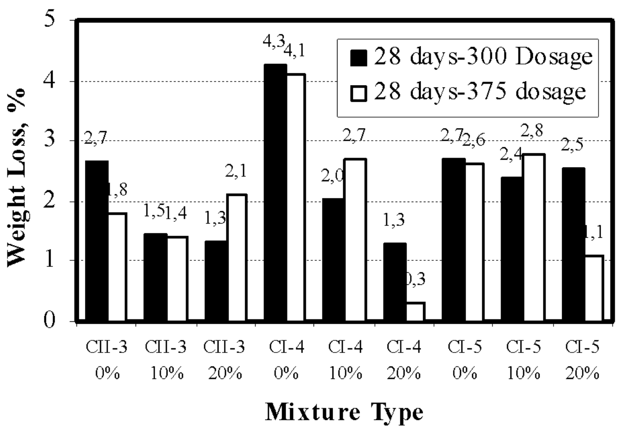

Figure 12: Variation of weight loss by mixture type for 28-day specimens
Slika 12: Razlike v izgubi mase glede na vrsto mešanice v vzorcih po 28 dneh

the weight loss is seen to decrease as the amount of FA, being the concrete replacement of the cement, is increased. Increasing the dosage reduces the weight loss in some series, but increases it in others. As it is seen in **Figure 12**, the maximum weight loss is observed with the concretes that did not have any FA and were produced with CI-4. According to **Figure 13**, the weight

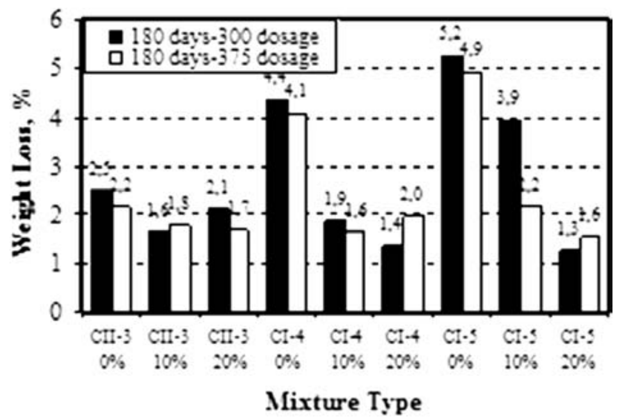

Figure 13: Variation of weight loss by mixture type for 180-day specimens
Slika 13: Razlike v izgubi mase glede na vrsto mešanice v vzorcih po 180 dneh

losses decrease as the amount of FA increases in the concretes. According to the increase in the curing time, by comparing **Figures 12** and **13**, in some series the weight loss of the reinforcements is seen to increase and in some series it decreases.

5 CONCLUSIONS

After the tests it was observed that the mechanical properties of the concretes and the corrosion performances of the steel embedded in the concrete changed with different cement types, dosages, FA amounts used as the replacements for the cement and the curing time.

- The compressive strength of the specimens increased after an increase in the curing time and the cement dosage. The maximum compressive strengths were observed with the concretes that were produced with the CI-5 cement.
- The splitting tensile test results of the specimens that were produced with the CI-4 and CI-5 cements were very similar. The minimum strengths were observed with the specimens that were produced with CII-3.
- According to a general assessment of the results, an increase in the dosage, the curing time and the FA amount used to replace the cement caused an increase in the DOT of the reinforced concrete specimens.
- With respect to the assessment of the DOTs, the most positive results were observed with the specimens that were produced with the CII-3 cement. Compatible results were observed with the specimens that were produced with the other cements and the 20 % FA amount.
- Consequently, the corrosion of the steel embedded in the concrete depends significantly on the cement type, the cement dosage and the curing time. To combat the corrosion of the steel reinforcement in the concrete, the permeability of concrete by water and hazardous ions has to be prevented. This is possible by producing an impermeable concrete. For this reason, impermeable and high-quality concretes have to be produced by using various mineral admixtures such as FA and SF.

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