

Influence of cement type on carbonation of cement mortars and concrete mixtures

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Abstract. The purpose of this research is to investigate the influence of cement type on carbonation. For this reason, mixtures of three different cement mortars and six different concretes have been prepared with three different cements. The cement mortars were produced according to the European Standard EN 196-1. The concrete mixtures belonged in the strength classes C25/30 and C30/37. Accelerated carbonation and natural carbonation measurements on mixtures exposed to open air in northern Greece for 4 years were performed. Service life against carbonation induced corrosion was calculated for all mixtures. It was revealed that the carbonation rate of the concrete mixtures is significantly influenced by the type and the strength category of the cement used. In spite of the fact that all concrete mixtures were produced according to the definitions of the European Standard EN 206, some mixtures do not fulfill the requirement for 50 years of service life against carbonation induced corrosion if the choice of the cement type is not carefully examined.

1 Introduction

According to Eurocode 2 (ELOT EN1992) the requirement for the use of durable concrete may lead to the choice of concrete with a greater strength class than required by the structural design. The Concrete Technology Regulation of 2016 as well as the National Appendix ELOT EN 206 define the minimum requirements of the concretes used depending on the environmental exposure category of the structures that are constructed with them. The relevant tables distinguish the concretes exposed to environments with chlorides that come from the sea (exposure class XS) depending on the type of cement used for their preparation. However, the same does not apply to the exposure class XC (reinforcement corrosion due to carbonation of concrete) where the two regulations essentially adopt - with minimal differences - the requirements of the European Standard EN 206-13. In the present research, the effect of the type of cement on the carbonation resistance of concrete is investigated. Three types of cements were used to make cement mortars and concretes of different strength classes. All specimens were exposed to a natural carbonation environment for up to four years. The results show the significant effect of cement type on the resistance of concrete against carbonation, the choice of unsuitable type of cement can significantly reduce the lifetime against carbonation, even if the strength class of concrete remains stable and the relevant requirements of the standard are achieved.

2 Experimental program

Six different mixtures of conventional concrete and three different mixtures of cement mortars were produced. Concrete mixtures belonged to the strength classes C25/30 and C30/37 (EN206-1, 2000). All mixtures were prepared using CEM I 42.5R, CEM II 42.5 (A-M) N and CEM II 32.5 (B-M) N cements. The mixtures were prepared and tested in the fresh state. The coarse aggregates consisted of crushed granite with a maximum size of 32mm. The fine-grained aggregates used were crushed and natural silicate sand. High range, water reducing, carboxylic ether, polymer admixture was added in different dosages to achieve the desired workability. The chemical analysis of the cements used is shown in Table 1.

Standard sand was used in the cement mortar mixtures while gravel (2-16 mm) and crushed stone (8-32 mm) were used in the concrete mixtures which came from crushing natural rock in a crusher.

The proportions as well as the properties of the fresh mixes are presented for all the concretes and cement mortars prepared in Tables 2 and 3.

2.1 Compressive strength

The specimens that were prepared to measure compressive strength at different ages were prisms 40x40x160mm for cement mortars and 150mm edge cubes for concretes. All samples were stored in a

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maintenance chamber ($T = 20\text{ }^{\circ}\text{C}$, $\text{RH} > 98\%$) until the age of the tests.

Table 1. Chemical analysis of cements

	CEMI 42,5 R	CEM II 42,5 (A-M)N	CEM II 32,5 (B-M)N
SiO ₂	20,86	23,85	28
Al ₂ O ₃	5,38	5,22	9
Fe ₂ O ₃	2,73	4,13	5,5
CaO	60,88	58,2	48
MgO	2,31	3,2	2,2
SO ₃	3,13	3,3	3,2
K ₂ O	1,93	0,68	1,5
Na ₂ O	-	0,32	0,5
TiO ₂	-	0,24	-
P ₂ O ₅	-	0,06	-
SrO	-	0,03	-
Cr ₂ O ₃	-	0,02	-
ZnO	-	0,01	-
MnO	-	-	-
specific weight	3,1	3,1	3,15

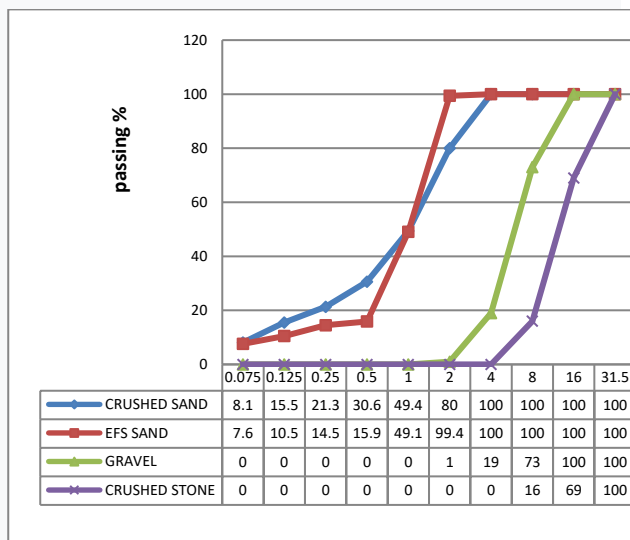


Fig.1. Grading curve of aggregates

2.2 Accelerated carbonation

The specimens that were used to measure the accelerated carbonation depth were prisms 40x40x160mm for cement mortars and 60x100mm cylindrical specimens for concretes. These specimens were stored in the above liquid chamber for 3 days and then stored in an indoor laboratory environment until the age of 28 days. At the age of 28 days, they were transferred to the accelerated carbonation chamber ($T = 20\text{ }^{\circ}\text{C}$, relative humidity=55%, $\text{CO}_2=1\%$). The specimens remained in this chamber until the age of each measurement.

Table 2. Mix design and characteristics of C25/30 and 30/37 strength classes concretes

Mix design	C 25/30 CEM I 42.5	C 30/37 CEM I 42.5	C 25/30 CEM I 42.5	C 30/37 CEM I 42.5	C 25/30 Mixe d	C 30/37 Mixe d
kg/m ³	C1	C2	C3	C4	C5	C6
CEM I 42,5	300	350	300	350	0	0
CEM II 42,5	0	0	0	0	150	200
CEM II 32,5	0	0	0	0	150	150
River Sand	400	400	400	400	400	400
Crush Sand	500	500	500	500	500	500
Gravel	270	270	270	270	270	270
Crush Stone	630	630	630	630	630	630
Water	180	175	180	175	180	175
Superplasticizer	1,17	1,4	1,17	1,4	1,17	1,4
W/C	0,6	0,5	0,6	0,5	0,6	0,5
Slump (cm)	16	17	22	15	18,5	21

Table 3. Mix design and characteristics of cement mortars

Mix design	CEMI 42.5	CEMII 42.5	CEMII 32.5
gr/1,7lt	M1	M2	M3
CEM I 42,5	450	0	0
CEM II 42,5	0	450	0
CEM II 32,5	0	0	450
Sand	1350	1350	1350
Water	225	225	225
W/C	0,5	0,5	0,5
Expansion (cm)	13,5	13,5	14

2.3 Natural carbonation

The specimens that were used to measure the natural carbonation depth were the same as in accelerated carbonation(prisms 40x40x160mm for cement mortars and 60x100mm cylindrical specimens for concretes).These specimens were stored in the

maintenance chamber ($T = 20\text{ }^{\circ}\text{C}$, $\text{RH} > 98\%$) for 3 days and then stored in an indoor laboratory environment until the age of 28 days. At the age of 28 days they were transferred to the outdoor laboratory environment. The specimens remained outdoors until the age of each measurement.

3 Experimental results and discussion

3.1 Compressive strength.

The compressive strength was measured for all concrete mixtures at the ages of 2, 7 and 28 days. These values are shown in Table 4.

Table 4. Compressive strength of concrete mixtures

(Mpa)	C1	C2	C3	C4	C5	C6
fc_2	26,4	30	23,9	24	18,1	22,7
fc_7	41,7	50,4	32,7	36,1	24,3	34,5
fc_{28}	46,1	58,7	39,7	46,7	34,0	43,3

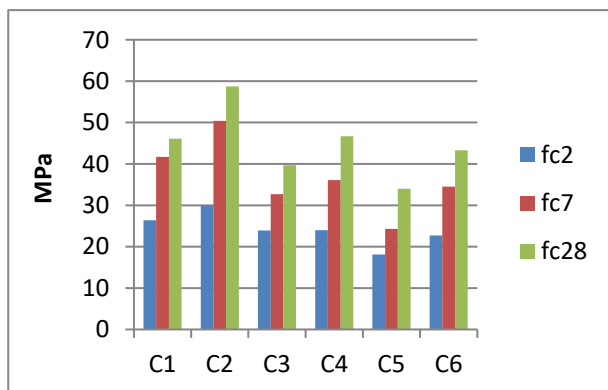


Fig.2. Compressive strength of concrete mixtures

The compressive strength was measured for all cement mortars at the ages of 2, 7, 14 and 28 days. These values are shown in Table 5.

Table 5. Compressive strength of cement mortars

(Mpa)	M1	M2	M3
fc_2	25,7	18,8	11,8
fc_7	38,4	30,0	21,9
fc_{14}	52,6	40,6	30,0
fc_{28}	54,4	48,1	42,3

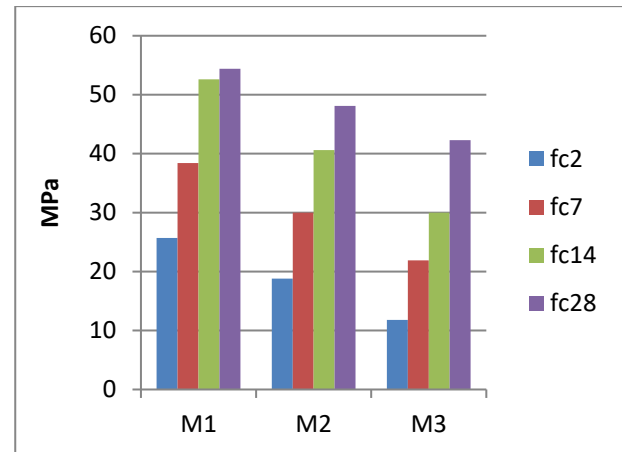


Fig.3. Compressive strength of cement mortars

From the values of the above tables, it appears that the use of cement type 42,5 increases the compressive strength considerably. At the age of 28 days, all cement mixes have compressive strengths within the acceptable limits.

3.2 Carbonation depth

The carbonation depth was measured by spraying the freshly broken surfaces of the samples with a phenolphthalein indicator according to the procedure described in Standard EN 14630. The carbonation depth of all mixtures is shown in Tables 6 and 7.

Table 6. Accelerated carbonation depth of concretes

Carbonation (mm)	C1	C2	C3	C4	C5	C6
28 days	3,5	3,0	4,3	3,1	8,1	4,5
56 days	5,3	4,6	7,1	4,8	12,6	7,4

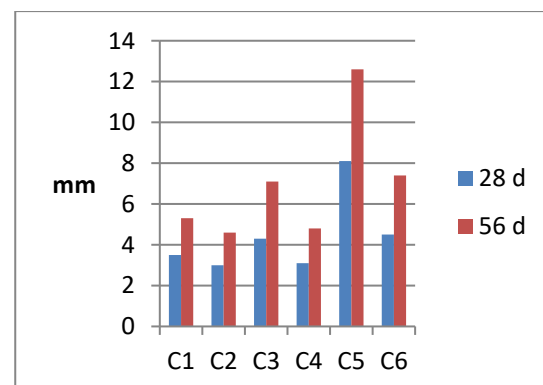


Fig.4. Accelerated carbonation depth of concretes

Table 7. Accelerated carbonation depth of cement mortars

Carbonation (mm)	M1	M2	M3
28 days	2,5	2,3	5,8
56 days	3,5	3	8,1
90 days	4,3	3,8	10,3
120 days	4,8	4,3	11,7
180 days	5,8	5,3	14,0

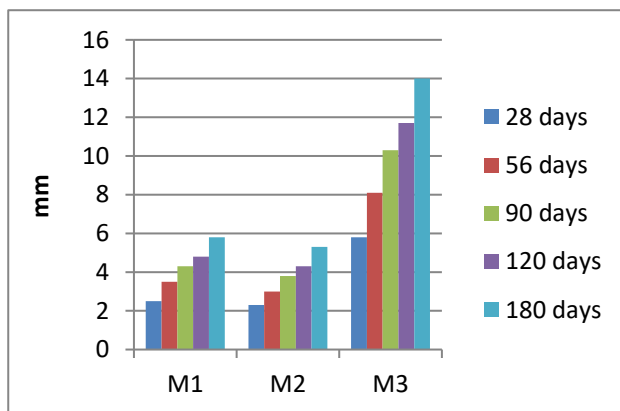


Fig.5. Accelerated carbonation depth of cement mortars

Table 8. Natural carbonation depth of concretes

Carbonation (mm)	C1	C2	C3	C4	C5	C6
6 months	3,0	2,5	3,3	2,9	5,9	3,0
9 months	4,2	3,4	4,5	4,1	7,9	4,3
12 months	5,2	4,1	5,5	5,0	9,5	5,2
24 months	8,5	6,8	9,0	8,2	14,7	8,4
36 months	10,5	8,4	11,1	10,1	17,8	10,3

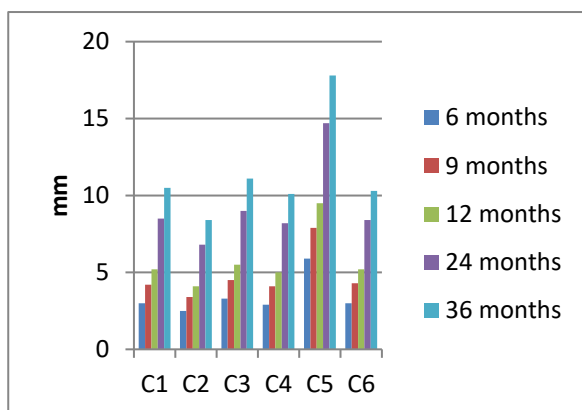


Fig.6. Natural carbonation depth of concretes

Table 9. Natural carbonation depth of cement mortars

Carbonation (mm)	M1	M2	M3
3 months	0,5	0,6	1,5
6 months	0,9	0,8	2,5
9 months	1,0	0,9	2,9
12 months	1,1	1,0	3,3
18 months	1,3	1,2	3,9
24 months	1,4	1,2	4,4
30 months	1,5	1,3	4,9
36 months	1,6	1,4	5,3
42 months	1,7	1,5	5,6
48 months	1,8	1,6	5,8

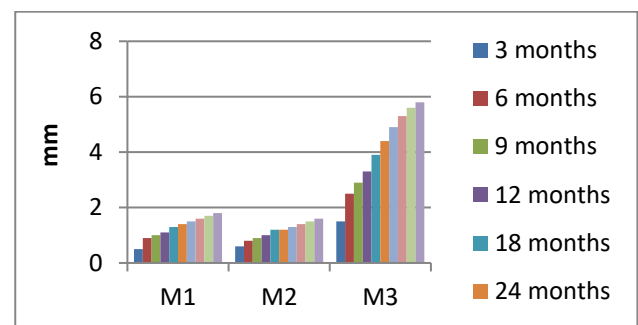


Fig.7. Natural carbonation depth of cement mortars

Several models are used to describe the relationship between carbonation depth (x) and concrete age (t). The most widely used one is given below:

$$x = k \cdot t^{0.5} \quad (1)$$

where k is the carbonation coefficient.

The carbonation coefficient k and correlation between carbonation depth of concretes and the age of structure is shown in Table 10 and Figure 9. Similarly, coefficient k and relationship between carbonation depth of cement mortars and the age of structure is shown in Table 11 and Figure 10.

The coefficient is derived from linear regression of at least three values (at least five in the present study).

Table 10. Coefficient k of concretes

	C1	C2	C3	C4	C5	C6
k	5,678	4,548	6,025	5,474	9,949	5,622

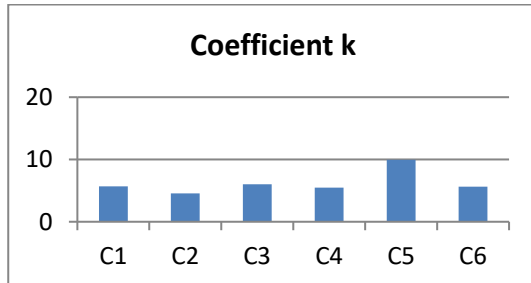


Fig.8. Coefficient k of concretes

Table 11. Coefficient k of cement mortars

	M1	M2	M3
k	0,861	0,725	2,916

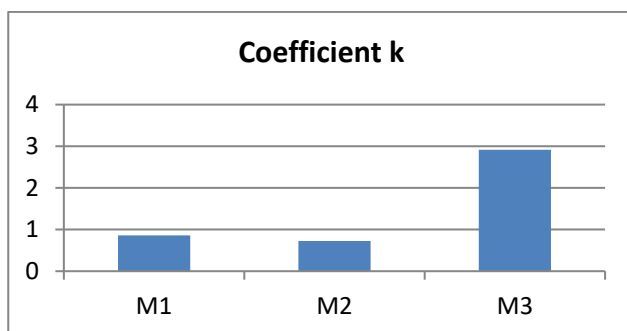


Fig.9. Coefficient k of cement mortars

The scenario that follows is about a construction exposed to natural carbonation. The reinforcement overlap is 35 mm according to EN206. The time needed for carbonation to reach the reinforcement in each one of the 6 produced concretes is showed in Table 12.

Table 12. Time needed to reach the specified carbonation depth (years)

Life Time	C1	C2	C3	C4	C5	C6
years	38,0	59,2	33,7	40,9	12,4	38,8

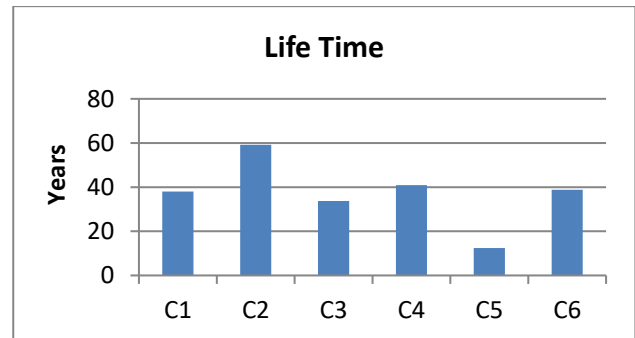


Fig.10. Time needed to reach the specified carbonation depth (years)

4 Conclusions

The use of type I 42.5 and II 42.5 cements seems, with the results so far, to improve the behavior of concrete against carbonation. Specifically, where type I 42.5 is used, the results seem to be optimal, followed by the mixtures with II 42.5 and then the mixtures where type II 32.5 cements were used. It was clearly shown that the type of cement is crucial for the service life of concrete structures against carbonation induced corrosion. Only concrete produced with CEM I 42.5 cement achieved the target service life of 50 years required by the codes. It is therefore suggested to take this parameter into account in the next revision of EN 206.

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