ROMANIA

Ministry of Education

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Research report no. 3 of the Doctoral Thesis

Experimental research for determining the optimal terms for the establishing the concrete characteristics made with cements with mineral additions

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CONTENT

The research program developed in the Research report no. 3 of the doctoral thesis consisted in the determination of the performance of the concrete prepared with mineral additions and the concretes prepared with cements with additions, in order to assess the influence of additions and cements with additions on the strength and durability characteristics of the concrete.

Two research programs were designed in the Research report no. 3 of the doctoral thesis, the first program consisted in the analysis of compressive strength for concrete over 28 days. The experimental values were compared with computed strength values for four types of concrete with slag cement in accordance with SR EN 1992-1-1 [33] and the draft revision, prSR EN 1992-1- 1 [60].

In the second program, two concrete compositions (reference concrete) were designed using two types of composite cements (CEM II/A-S 42.5R and CEM III/A 42.5N-LH) and two concrete mixes (candidate concrete) with similar percentages of mineral addition (10% and 37% slag) and showed the differences between the results obtained between these two types of concrete, reference concrete and candidate concrete, for certain durability characteristics, by applying prescriptive and performance methods.

1. IDENTIFYING THE REFERENCE TIME FOR DETERMINING THE COMPRESSIVE STRENGTH OF CONCRETE CONTAINING DIFFERENT TYPES OF CEMENTS

The compressive strength of the concrete measured at 28 days is the criterion for assessing the concrete class, and these values will be acceptable precise indications for other physical and mechanical characteristics of the concrete. In addition to the factors the compressive strength of concrete varies on (such as: the characteristics and proportion of constituents, the placement conditions and subsequent treatment and testing conditions), the concrete class should also depend on the type of cement contained and the concrete strength evolution over time.

Due to the fact that concretes with composite cements have a slower evolution of compressive strength and a significant strength increase after 28 days, concretes with different types of cements and mineral admixtures were tested for compression after 28 days in order to determine the reference time for such tests – and thus the concrete's class.

The experimental results showed that the compressive strength of the concrete and its evolution over time are influenced by a series of parameters, calculating formulae being thus proposed in the designing codes. Additional cementing materials introduced within the cement or concrete (such as: siliceous or calcite flying ashes, ground granulated furnace slag or calcareous filler), give the concrete mechanical properties that are different to those of concrete prepared with Portland cement.

These mineral additions within the concrete, due to their chemical, physical and mineralogical properties, have an influence on the hydrating reactions, on the evolution of the structure of the pores and on the composition of the solutions in the pores, causing alterations in the concrete's microstructure, thus influencing the performance of the material inside the concrete structures exposed to environmental conditions. This study refers to the influences of these mineral additions on the evolution in time of concrete's strengths prepared with different types of cements.

1.1. Theoretical presentation of European Standard SR EN 1992-1-1 and the new Draft prEN 1992-1-1.

Although based on principles in use for a long period of time, the current provisions of European Standard SR EN 1992-1-1 [1] - describing the evolution over time of the compressive strength of concrete - lead to results sometimes different from reality.

The following formulae are used to determine the strength for concrete of ages other than 28 days :

$f_{ck}(t) = f_{cm}(t) - 8$ MPa for $3 < t < 28$ days (1)

$f_{ck}(t) = f_{ck}$ for $t \geq 28$ days (2)

where the average compressive strength at age "t" is estimated by the formulae:

$f_{cm}(t) = \beta_{cc}(t) \times f_{cm}$ (3)

$\beta_{cc}(t) = \exp\{s[1-(28/t)^{1/2}]\}$ (4)

where : $f_{cm}(t)$ is the average compressive strength of concrete at "t" days of age;

f_{cm} - average compressive strength of concrete at 28 days;

$\beta_{cc}(t)$ - coefficient depending on the concrete's age;

t - concrete's age, in days;

s - coefficient depending on the type of cement.

s=0.20 for CEM 42.5R, CEM 52.5N and CEM 52.5R (class R)

s=0.25 for CEM 32.5R and CEM 42.5N (class N)

s=0.38 for CEM 32.5N (class S)

The current standard considers only the cement's strength class within the concrete – by using "s" coefficient, the temperature and subsequent treatment conditions

- and average compressive strength of the concrete at 28 days. This new project, aiming to update the European standard prEN 1992-1-1 [2] (drafted in October 2017), brings in new values for “s” coefficient and the possible taking into consideration the reference time of 28 to 90 days for determining the evolution in time of concrete's compressive strength.

Based on this, in our proposal of revising prEN 1992-1-1 [2] standard, the characteristics for compressive strength of concrete (which defines the strength classes) is to be determined at a reference time generally considered to be 28 days, or between 28-91 days for applications where strength develops slowly. Thus, according to this revising project, the average compressive strength of concrete at different ages f_{cm} (t) can be estimated by the following formulae:

$f_{ck}(t) = f_{cm}(t) - 8$ MPa for $t < t_{ref}$ (days) (5)

$f_{cm}(t) = \beta_{cc}(t) \times f_{cm}$ (6)

$\beta_{cc}(t) = \exp\{s[1-(t_{ref}/t)^{1/2}](28/t_{ref})^{1/2}\}$ (7)

where: $f_{cm}(t)$ - is the average compressive strength of concrete at “t” days of age;

f_{cm} - average compressive strength of concrete at age 28 days;

$\beta_{cc}(t)$ - coefficient depending on the age of the concrete;

t - age of concrete, in days;

t_{ref} - age of concrete at which the concrete strength is determined in days;

s - coefficient depending on the type of cement.

Table 1. - Values of coefficient *s* for different cements and classes of concrete (prEN 1992-1-1 [2])

Concrete class	High early strength Class R	Ordinary early strength Class N	Low early strength Class L
	Cement of strength CEM 42.5R, CEM 52.5N and CEM 52.5R	Cement of strength CEM 32.5R, CEM 42.5N	Cement of strength CEM 32.5N
C35 and below	0.3	0.35	0.4
C40-C55	0.2	0.25	0.35
C60 and above	0.1	0.17	0.3

The different approaches between the two editions of the standard reveal that evolution of concrete's strength depends over time, taking into consideration that - in case of some compositions with types of cement with slow evolving strength - other time of reference can be acceptable rather than the 28 days one.

In order to analyze the conditions for applying the proposed formula for this new version of the prEN 1992-1-1 [2] standard, a series of concretes with cements containing different percentages of granular furnace slag (with/without flying ash) were tested at different ages. The experimental program aimed to determine the average compressive strength of concretes prepared with four types of cements (one - normal hardening, and three - fast hardening) with different w/c ratios.

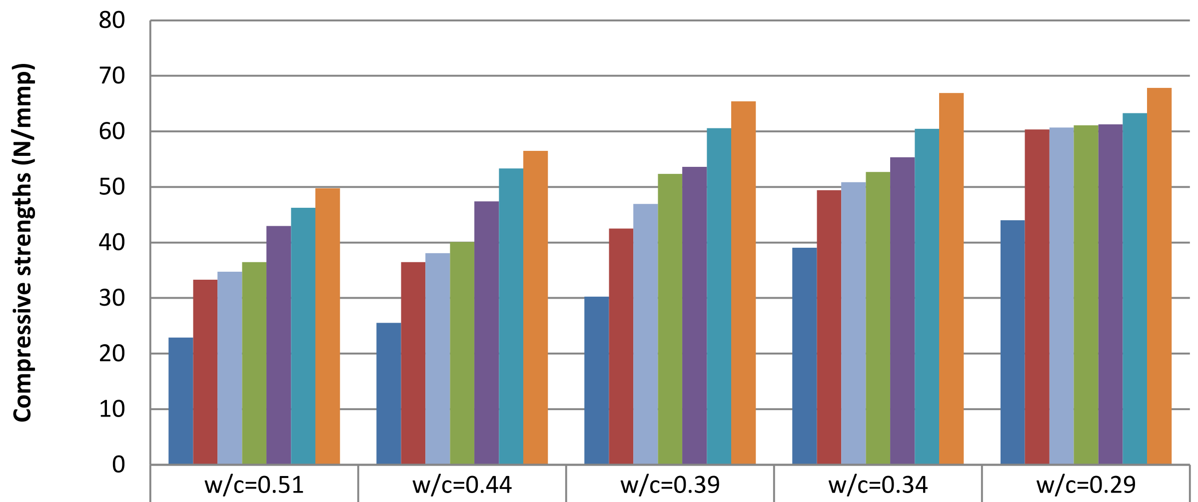
- **Concrete with CEM II/B-S 32.5R (65-79% clinker, 21-35% slag)**

The compositions of concretes with CEM II/B-S 32.5R are shown in Table 2.

Table 2. - Composition and properties of fresh concrete prepared with CEM II/B-S 32.5R

Concrete class	w/c ratio	Cement dosage (kg/m^3)	Maximum diameter of the aggregate (mm)	Admixture	Settlement (mm)
C12/15	0.73	260	40	superplasticizer admixture	145
C16/20	0.67	280	40		140
C20/25	0.60	300	40		150
C25/30	0.53	320	40	superplasticizer admixture	150
C30/37	0.49	340	40		140
C30/37	0.47	380	40		140
C35/45	0.42	420	40	superplasticizer and air-entrain admixture	150
C35/45	0.35	460	40	superplasticizer admixture	150

Figures 1 and 1' show the experimental results for average compressive strength measured at different ages for these seven concrete compositions containing CEM II/B-S 32.5R. The evolution of compressive strengths of concrete with CEM II/B-S 32.5R was also analyzed over time by comparing the results experimentally obtained versus the computed strength values as per the designing prescriptions in SR EN 1992-1-1: 2004 [1] and as per the Project for revising EN 1992-1-1 [2] (taking into account in this case, different reference ages - 28, 56 and 90 days).



	w/c=0.51	w/c=0.44	w/c=0.39	w/c=0.34	w/c=0.29
7 days	22.88	25.55	30.22	39.03	43.99
28 days	33.32	36.44	42.51	49.4	60.37
56 days	34.73	38.08	46.96	50.87	60.7
90 days	36.44	40.07	52.37	52.67	61.11
180 days	42.96	47.4	53.62	55.33	61.26
360 days	46.22	53.33	60.59	60.44	63.26
720 days	49.78	56.52	65.44	66.89	67.85

Figure 1. - The variation of compressive strength over time - for concretes containing CEM II/B-S 32.5R with different w/c ratios

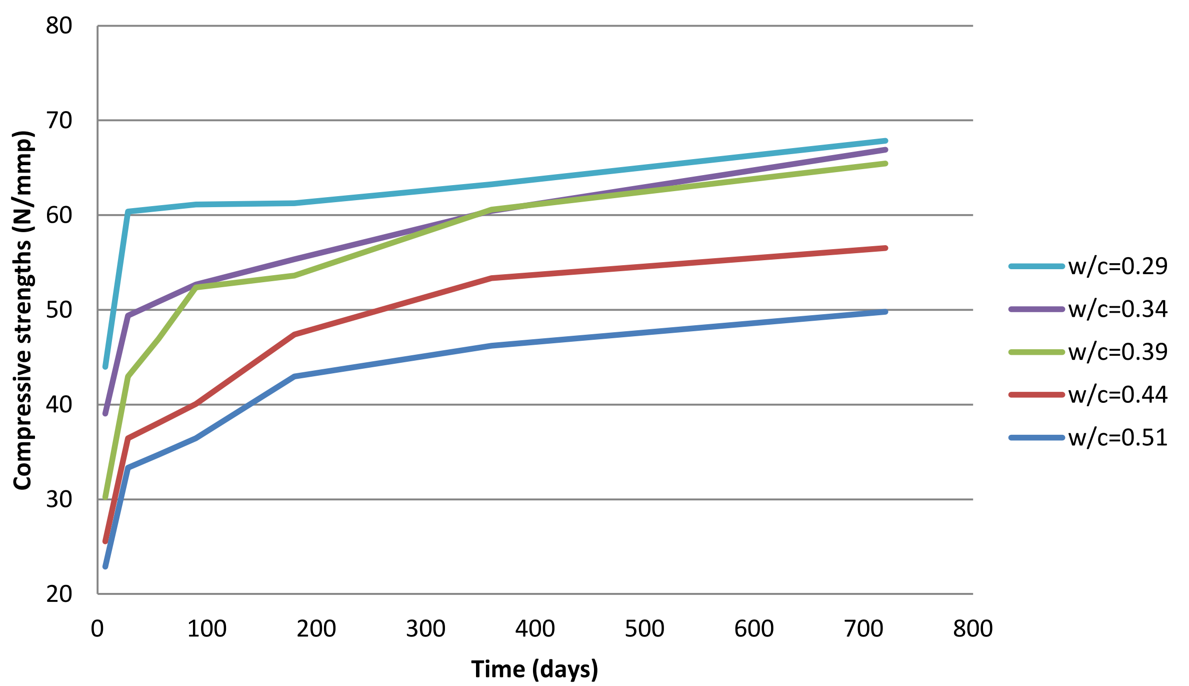


Figure 1'. - The variation of compressive strength over time - for concretes with CEM II/B-S 32.5R and with different w/c ratios

Table 3. - Compressive strength over time - determined experimentally and also calculated - for concrete with CEM II/B-S 32.5R with a w/c ratio of 0.51 [3], [4], [5].

Age of concrete	f_{cm} experimental values (**w/c = 0.51**)	f_{cm} (EC 2) calculated values	f_{cm} (prEC2*ref28) calculated values	f_{cm} (prEC 2*ref 56) calculated values	f_{cm} (prEC 2*ref 90) calculated values
7 days	22.88				
28 days	33.32				
56 days	34.73	β = 1.076 35.85	β = 1.108 36.92		
90 days	36.44	β = 1.117 37.22	β = 1.167 38.90	β = 1.054 36.59	
180 days	42.96	β = 1.163 38.77	β = 1.236 41.19	β = 1.116 38.75	β = 1.059 38.58
360 days	46.22	β = 1.198 39.90	β = 1.287 42.89	β = 1.162 40.34	β = 1.103 40.17
720 days	49.78	β = 1.222 40.73	β = 1.324 44.13	β = 1.195 41.51	β = 1.135 41.34
		β_{max}=1.284 42.78	β_{max}=1.419 47.28	β_{max}= 1.281 44.48	β_{max}=1.216 44.29

Denotations:

f_{cm} (EC 2) - the average compressive strength at an age of over 28 days, calculated as per SR EN 1992-1-1: 2004 [1], with a reference time of 28 days;

f_{cm} (prEC 2*ref 28) - the average compressive strength at an age of over 28 days, calculated as per prEN 1992-1-1 [2] draft review, with a reference time of 28 days;

f_{cm} (prEC 2*ref 56) - the average compressive strength at an age of over 28 days, calculated as per prEN 1992-1-1 [2] draft review, with a reference time of 56 days;

f_{cm} (prEC 2*ref 90) - the average compressive strength at an age of over 28 days calculated as per prEN 1992-1-1 [2] draft review, with a reference time of 90 days;

Table 4. - Compressive strength over time - determined experimentally and also calculated - for concrete with CEM II/B-S 32.5R with a w/c ratio of 0.44 [3], [4], [5].

Age of concrete	f_{cm} experimental values (**w/c = 0.44**)	f_{cm} (EC 2) calculated values	f_{cm} (prEC2*ref28) calculated values	f_{cm} (prEC 2*ref 56) calculated values	f_{cm} (prEC 2*ref 90) calculated values
7 days	25.75				
28 days	36.44				
56 days	38.08	β = 1.076 39.21	β = 1.108 40.37		
90 days	40.07	β = 1.117 40.70	β = 1.167 42.54	β = 1.054 40.12	
180 days	47.40	β = 1.163 42.40	β = 1.236 45.04	β = 1.116 42.48	β = 1.059 42.43
360 days	53.33	β = 1.198 43.64	β = 1.287 46.90	β = 1.162 44.24	β = 1.103 44.18

Age of concrete	f_{cm} experimental values (**w/c = 0.44**)	f_{cm} (EC 2) calculated values	f_{cm} (prEC2*ref28) calculated values	f_{cm} (prEC 2*ref 56) calculated values	f_{cm} (prEC 2*ref 90) calculated values
720 days	56.52	β = 1.222 44.54	β = 1.324 48.26	β = 1.195 45.52	β = 1.135 45.46
		$β_{max}$=1.284 46.79	$β_{max}$=1.419 51.71	$β_{max}$= 1.281 48.77	$β_{max}$=1.216 48.71

Table 5. - Compressive strength over time - determined experimentally and also calculated - for concrete with CEM II/B-S 32.5R with a w/c ratio of 0.39 [3], [4], [5].

Age of concrete	f_{cm} experimental values (**w/c = 0.39**)	f_{cm} (EC 2) calculated values	f_{cm} (prEC2*ref28) calculated values	f_{cm} (prEC 2*ref 56) calculated values	f_{cm} (prEC 2*ref 90) calculated values
7 days	30.22				
28 days	42.51				
56 days	46.96	β = 1.076 45.74	β = 1.108 47.10		
90 days	52.37	β = 1.117 47.48	β = 1.167 49.63	β = 1.054 49.48	
180 days	53.62	β = 1.163 49.46	β = 1.236 52.55	β = 1.116 52.39	β = 1.059 55.45
360 days	60.59	β = 1.198 50.91	β = 1.287 54.71	β = 1.162 54.55	β = 1.103 57.74
720 days	65.44	β = 1.222 51.96	β = 1.324 56.30	β = 1.195 56.13	β = 1.135 59.41
		$β_{max}$=1.284 54.58	$β_{max}$=1.419 60.32	$β_{max}$= 1.281 60.14	$β_{max}$=1.216 63.66

Table 6. - Compressive strength over time - determined experimentally and also calculated - for concrete with CEM II/B-S 32.5R with a w/c ratio of 0.34 [3], [4], [5].

Age of concrete	f_{cm} experimental values (**w/c = 0.34**)	f_{cm} (EC 2) calculated values	f_{cm} (prEC2*ref28) calculated values	f_{cm} (prEC 2*ref 56) calculated values	f_{cm} (prEC 2*ref 90) calculated values
7 days	39.03				
28 days	49.40				
56 days	50.87	β = 1.076 45.74	β = 1.108 54.73		
90 days	52.67	β = 1.117 55.17	β = 1.167 57.67	β = 1.054 53.60	
180 days	55.33	β = 1.163 57.47	β = 1.236 61.06	β = 1.116 56.75	β = 1.059 55.77
360 days	60.44	β = 1.198 59.16	β = 1.287 63.58	β = 1.162 59.09	β = 1.103 58.07
720 days	66.89	β = 1.222 60.38	β = 1.324 65.43	β = 1.195 60.81	β = 1.135 59.75
		$β_{max}$=1.284 63.43	$β_{max}$=1.419 70.10	$β_{max}$= 1.281 65.15	$β_{max}$=1.216 64.02

Table 7. - Compressive strength over time - determined experimentally and also calculated - for concrete with CEM II/B-S 32.5R with a w/c ratio of 0.29 [3], [4], [5].

Age of concrete	f_{cm} experimental values (**w/c = 0.29**)	f_{cm} (EC 2) calculated values	f_{cm} (prEC2*ref28) calculated values	f_{cm} (prEC 2*ref 56) calculated values	f_{cm} (prEC 2*ref 90) calculated values
7 days	43.99				
28 days	60.37				
56 days	60.70	β = 1.076 64.96	β = 1.108 66.88		
90 days	61.11	β = 1.117 67.43	β = 1.167 70.47	β = 1.054 63.95	
180 days	61.26	β = 1.163 70.24	β = 1.236 74.62	β = 1.116 67.72	β = 1.059 64.70
360 days	63.26	β = 1.198 72.30	β = 1.287 77.70	β = 1.162 70.51	β = 1.103 67.37
720 days	67.85	β = 1.222 73.79	β = 1.324 79.95	β = 1.195 72.56	β = 1.135 69.33
		$β_{max}$=1.284 77.52	$β_{max}$=1.419 85.67	$β_{max}$= 1.281 77.74	$β_{max}$=1.216 74.28

Tables 3-7 show that the values of β coefficient in SR EN 1992-1-1:2004 [1] are different from those proposed by the revised European Standard prEN1992-1-1 [2], and therefore the calculated values of compressive strengths of concrete vary in relation to the average compressive strength at 28 days.

Figures 2-6 show the evolution over time of compressive strength (both real and estimated), for the seven concrete compositions.

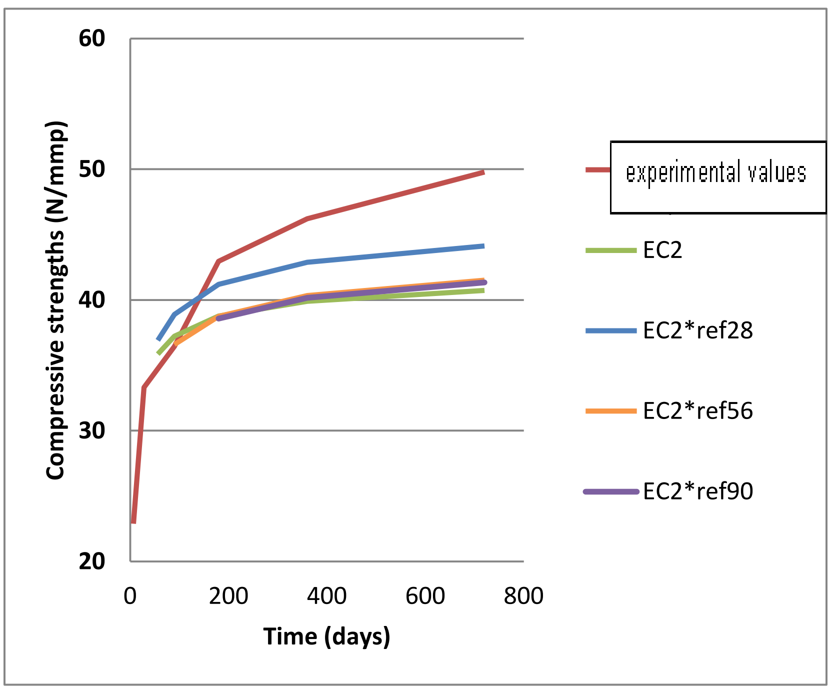


Figure 2. - Compressive strength of concrete with CEM II/B-S 32.5R with a w/c ratio of 0.51, depending on the age.

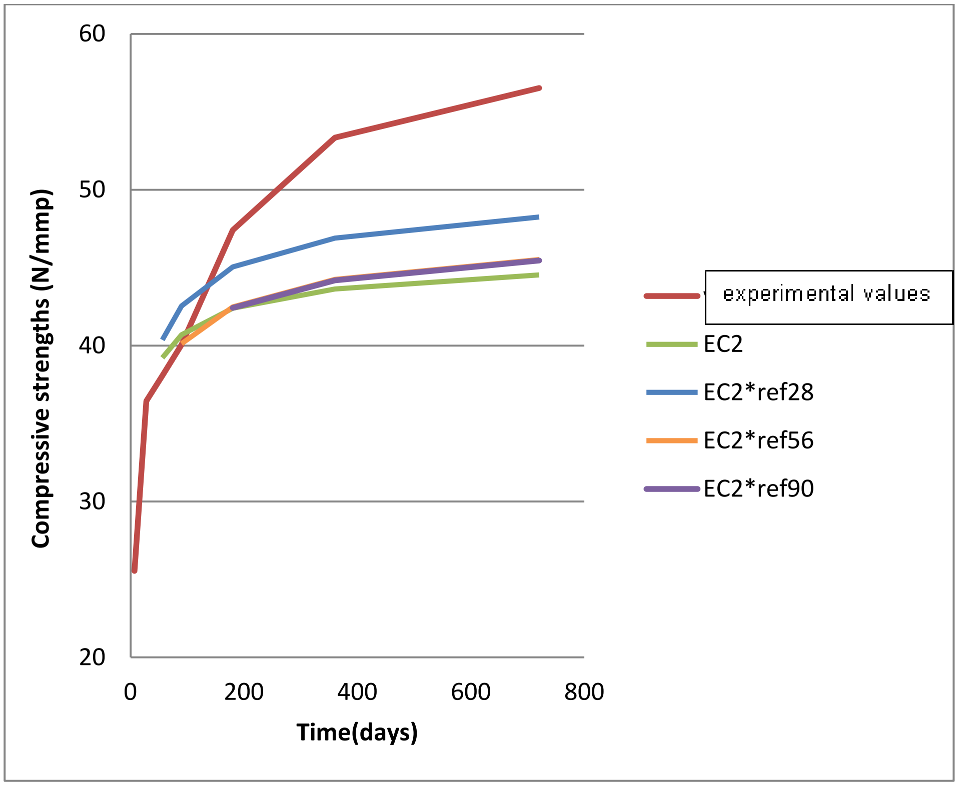


Figure 3. - Compressive strength of concrete with CEM II/B-S 32.5R with a w/c ratio of 0.44, depending on the age.

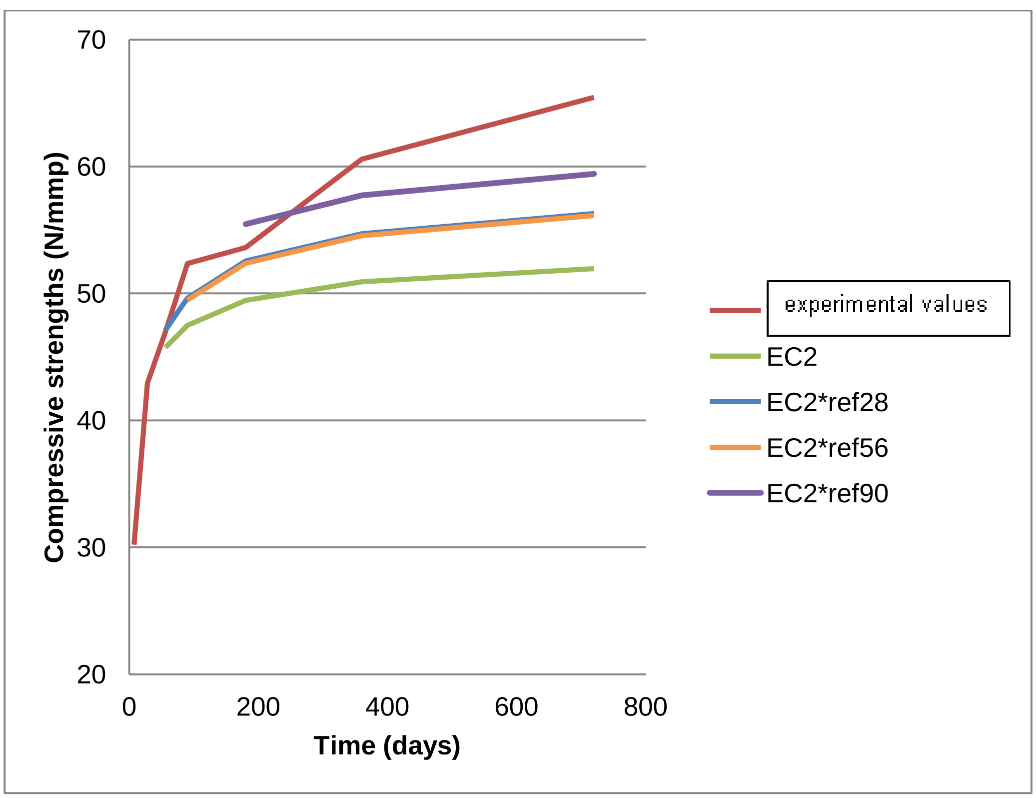


Figure 4. - Compressive strength of concrete with CEM II/B-S 32.5R with a w/c ratio of 0.39, depending on the age.

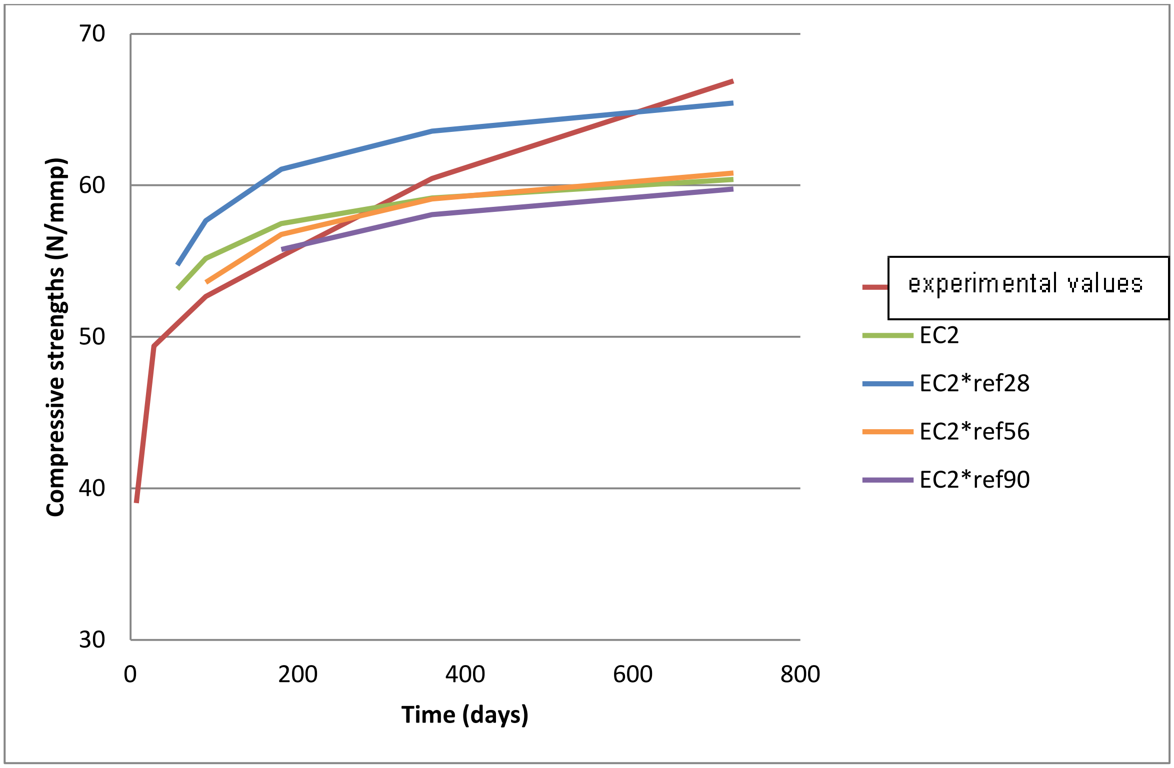


Figure 5. - Compressive strength of concrete with CEM II/B-S 32.5R with a w/c ratio of 0.34, depending on the age.

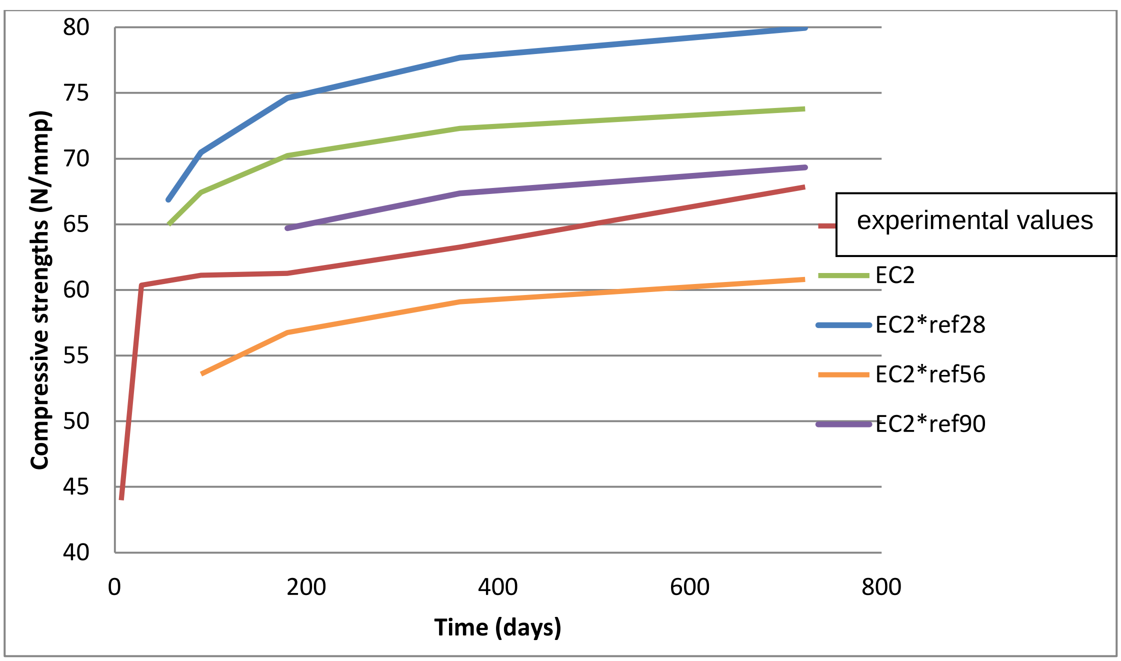
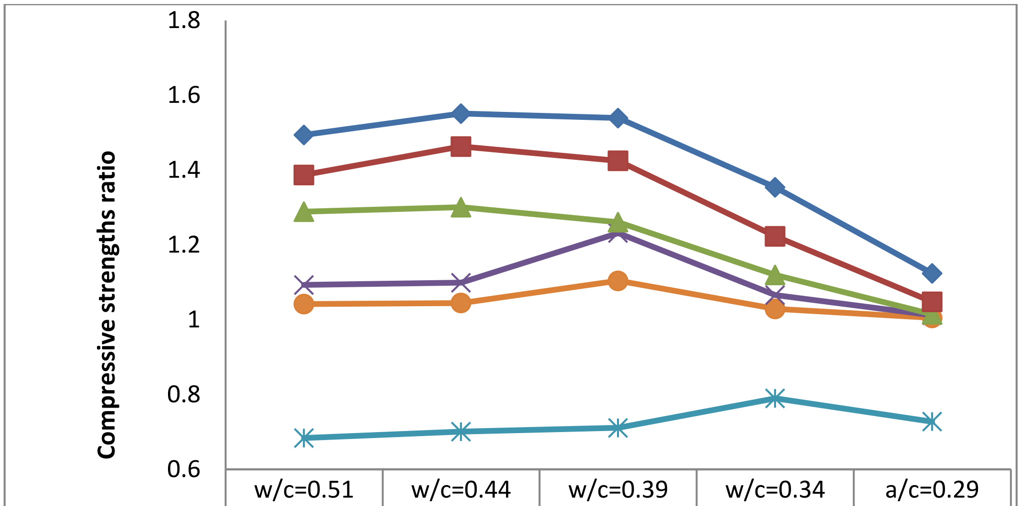


Figure 6. - Compressive strength of concrete with CEM II/B-S 32.5R with a w/c ratio of 0.29, depending on the age.

Figure 7 show the ratios between of compressive strengths for concrete prepared with different type of cements at different proposed reference times.



	w/c=0.51	w/c=0.44	w/c=0.39	w/c=0.34	a/c=0.29
fc7/fc28	0.684	0.701	0.711	0.79	0.728
fc56/fc28	1.042	1.045	1.104	1.029	1.005
fc90/fc28	1.093	1.099	1.232	1.066	1.012
fc180/fc28	1.289	1.301	1.261	1.12	1.015
fc360/fc28	1.387	1.463	1.425	1.223	1.048
fc720/fc28	1.494	1.551	1.539	1.354	1.124

Figure 7.- Ratios between compressive strengths for concrete made with CEM II/B-S 32.5R at a proposed reference time of 28 days.

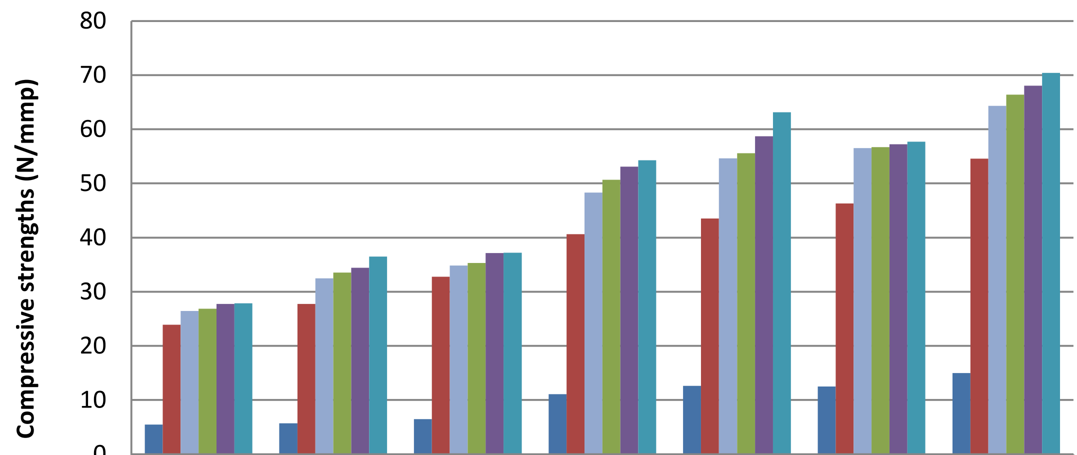
- **Concrete with CEM II/B-S 32.5N (65-79% clinker, 21-35% slag)**

The compositions of concretes with CEM II/B-S 32.5N are shown in Table 8.

Table 8. - Composition and properties of fresh concrete prepared with CEM II/B-S 32.5N

Concrete class	w/c ratio	Cement dosage (kg/m^3)	Maximum diameter of the aggregate (mm)	Admixture	Settlement (mm)
C12/15	0.73	260	40	superplasticizer admixture	145
C16/20	0.67	280	40		140
C20/25	0.60	300	40		150
C25/30	0.53	320	40	superplasticizer admixture	150
C30/37	0.49	340	40		140
C30/37	0.47	380	40		140
C35/45	0.42	420	40	superplasticizer and air-entrain admixture	150
C35/45	0.35	460	40	superplasticizer admixture	150

Figures 8 and 8' show the experimental results for average compressive strength measured at different ages for these seven concrete compositions containing CEM II/B-S 32.5N. The evolution of compressive strengths of concrete with CEM II/B-S 32.5N was also analyzed over time by comparing the results experimentally obtained versus the computed strength values as per the designing prescriptions in SR EN 1992-1-1: 2004 [1] and as per the Project for revising EN 1992-1-1 [2] (taking into account in this case, different reference ages - 28, 56 and 90 days).



	w/c=0.73	w/c=0.67	w/c=0.60	w/c=0.53	w/c=0.49	w/c=0.47	w/c=0.42
2 days	5.45	5.68	6.46	11.1	12.61	12.53	15
28 days	23.91	27.75	32.78	40.61	43.5	46.32	54.54
60 days	26.43	32.45	34.83	48.33	54.63	56.5	64.29
90 days	26.87	33.51	35.3	50.68	55.55	56.7	66.36
180 days	27.77	34.44	37.11	53.11	58.73	57.21	68.03
360 days	27.89	36.49	37.18	54.26	63.13	57.71	70.39

Figure 8. - The variation of compressive strength over time - for concretes containing CEM II/B-S 32.5N with different w/c ratios

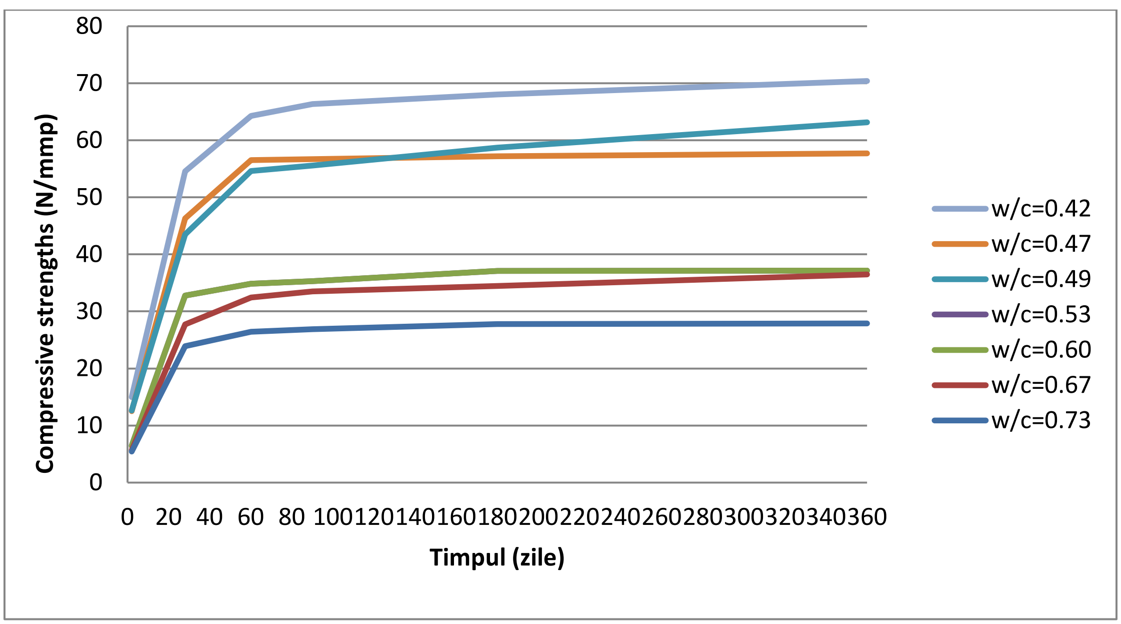


Figure 8'. - The variation of compressive strength over time - for concretes with CEM II/B-S 32.5N and with different w/c ratios

Table 9. - Compressive strength over time - determined experimentally and also calculated - for concrete with CEM II/B-S 32.5N with a w/c ratio of 0.73 [3], [4], [5].

Age of concrete	f_{cm} experimental values (**w/c = 0.73**)	f_{cm} (EC 2) calculated values	f_{cm} (prEC2*ref28) calculated values	f_{cm} (prEC 2*ref 56) calculated values	f_{cm} (prEC 2*ref 90) calculated values
2 days	5.45				
28 days	23.91				
60 days	26.43	β = 1.128 26.97	β = 1.135 27.14		
90 days	26.87	β = 1.183 28.28	β = 1.194 28.53	β = 1.051 27.19	
180 days	27.77	β = 1.259 30.09	β = 1.274 30.46	β = 1.122 29.66	β = 1.068 28.68
360 days	27.89	β = 1.315 31.45	β = 1.334 31.90	β = 1.176 31.07	β = 1.118 30.04
		β_{max}=1.462 34.96	β_{max}=1.492 35.67	β_{max}=1.314 34.73	β_{max}=1.250 33.58

Table 10. - Compressive strength over time - determined experimentally and also calculated - for concrete with CEM II/B-S 32.5N with a w/c ratio of 0.67 [3], [4], [5].

Age of concrete	f_{cm} experimental values (**w/c = 0.67**)	f_{cm} (EC 2) calculated values	f_{cm} (prEC2*ref28) calculated values	f_{cm} (prEC 2*ref 56) calculated values	f_{cm} (prEC 2*ref 90) calculated values
2 days	5.68				
28 days	27.75				
60 days	32.45	β = 1.128 31.30	β = 1.135 31.50		
90 days	33.51	β = 1.183 32.82	β = 1.194 33.12	β = 1.051 34.12	
180 days	34.44	β = 1.259 34.93	β = 1.274 35.35	β = 1.122 36.42	β = 1.068 35.77
360 days	36.49	β = 1.315 36.50	β = 1.334 37.03	β = 1.176 38.14	β = 1.118 37.46
		β_{max}=1.462 40.58	β_{max}=1.492 41.40	β_{max}=1.314 42.65	β_{max}=1.250 41.88

Table 11. - Compressive strength over time - determined experimentally and also calculated - for concrete with CEM II/B-S 32.5N with a w/c ratio of 0.60 [3], [4], [5].

Age of concrete	f_{cm} experimental values (**w/c = 0.60**)	f_{cm} (EC 2) calculated values	f_{cm} (prEC2*ref28) calculated values	f_{cm} (prEC 2*ref 56) calculated values	f_{cm} (prEC 2*ref 90) calculated values
2 days	6.46				
28 days	32.78				
60 days	34.83	β = 1.128 36.97	β = 1.135 37.21		
90 days	35.30	β = 1.183	β = 1.194	β = 1.051	

		38.78	39.12	36.62	
180 days	37.11	β = 1.259 41.26	β = 1.274 41.76	β = 1.122 39.09	β = 1.068 37.68
360 days	37.18	β = 1.315 43.11	β = 1.334 43.74	β = 1.176 40.94	β = 1.118 39.46
		β_{max}=1.462 47.93	β_{max}=1.492 48.90	β_{max}=1.314 45.77	β_{max}=1.250 44.12

Table 12. - Compressive strength over time - determined experimentally and also calculated - for concrete with CEM II/B-S 32.5N with a w/c ratio of 0.53 [3], [4], [5].

Age of concrete	f_{cm} experimental values (**w/c = 0.53**)	f_{cm} (EC 2) calculated values	f_{cm} (prEC2*ref28) calculated values	f_{cm} (prEC 2*ref 56) calculated values	f_{cm} (prEC 2*ref 90) calculated values
2 days	11.10				
28 days	40.61				
60 days	48.33	β = 1.128 45.80	β = 1.135 46.09		
90 days	50.68	β = 1.183 48.04	β = 1.194 48.47	β = 1.051 50.18	
180 days	53.11	β = 1.259 51.12	β = 1.274 51.74	β = 1.122 54.24	β = 1.068 54.10
360 days	54.26	β = 1.315 53.41	β = 1.334 54.18	β = 1.176 56.81	β = 1.118 56.66
		β_{max}=1.462 59.38	β_{max}=1.492 60.58	β_{max}=1.314 63.52	β_{max}=1.250 63.35

Table 13. - Compressive strength over time - determined experimentally and also calculated - for concrete with CEM II/B-S 32.5N with a w/c ratio of 0.49 [3], [4], [5].

Age of concrete	f_{cm} experimental values (**w/c = 0.49**)	f_{cm} (EC 2) calculated values	f_{cm} (prEC2*ref28) calculated values	f_{cm} (prEC 2*ref 56) calculated values	f_{cm} (prEC 2*ref 90) calculated values
2 days	12.61				
28 days	43.50				
60 days	54.63	β = 1.128 49.06	β = 1.135 49.38		
90 days	55.55	β = 1.183 51.46	β = 1.194 51.92	β = 1.051 57.44	
180 days	58.73	β = 1.259 54.75	β = 1.274 55.42	β = 1.122 61.32	β = 1.068 59.30
360 days	63.13	β = 1.315 57.21	β = 1.334 58.04	β = 1.176 64.22	β = 1.118 62.10
		β_{max}=1.462 63.61	β_{max}=1.492 64.89	β_{max}=1.314 71.79	β_{max}=1.250 69.43

Table 14. - Compressive strength over time - determined experimentally and also calculated - for concrete with CEM II/B-S 32.5N with a w/c ratio of 0.47 [3], [4], [5].

Age of concrete	f_{cm} experimental values (**w/c = 0.47**)	f_{cm} (EC 2) calculated values	f_{cm} (prEC2*ref28) calculated values	f_{cm} (prEC 2*ref 56) calculated values	f_{cm} (prEC 2*ref 90) calculated values
2 days	12.53				
28 days	46.32				
60 days	56.50	β = 1.128 52.25	β = 1.135 52.58		
90 days	56.70	β = 1.183 54.79	β = 1.194 55.28	β = 1.051 59.40	
180 days	57.21	β = 1.259 58.30	β = 1.274 59.01	β = 1.122 63.41	β = 1.068 60.53
360 days	57.71	β = 1.315 58.30	β = 1.334 59.01	β = 1.176 63.41	β = 1.118 63.39
		β_{max}=1.462 67.73	β_{max}=1.492 69.10	β_{max}=1.314 74.25	β_{max}=1.250 70.87

Table 15. - Compressive strength over time - determined experimentally and also calculated - for concrete with CEM II/B-S 32.5N with a w/c ratio of 0.42 [3], [4], [5].

Age of concrete	f_{cm} experimental values (**w/c = 0.42**)	f_{cm} (EC 2) calculated values	f_{cm} (prEC2*ref28) calculated values	f_{cm} (prEC 2*ref 56) calculated values	f_{cm} (prEC 2*ref 90) calculated values
2 days	15.00				
28 days	54.54				
60 days	64.29	β = 1.128 61.52	β = 1.135 61.91		
90 days	66.36	β = 1.183 64.52	β = 1.194 65.09	β = 1.051 67.59	
180 days	68.03	β = 1.259 68.65	β = 1.274 69.49	β = 1.122 72.16	β = 1.068 70.84
360 days	70.39	β = 1.315 71.73	β = 1.334 72.77	β = 1.176 75.57	β = 1.118 74.19
		β_{max}=1.462 79.75	β_{max}=1.492 81.36	β_{max}=1.314 84.49	β_{max}=1.250 82.94

Figures 9-15 show the evolution over time of compressive strength (both real and estimated), for the seven concrete compositions.

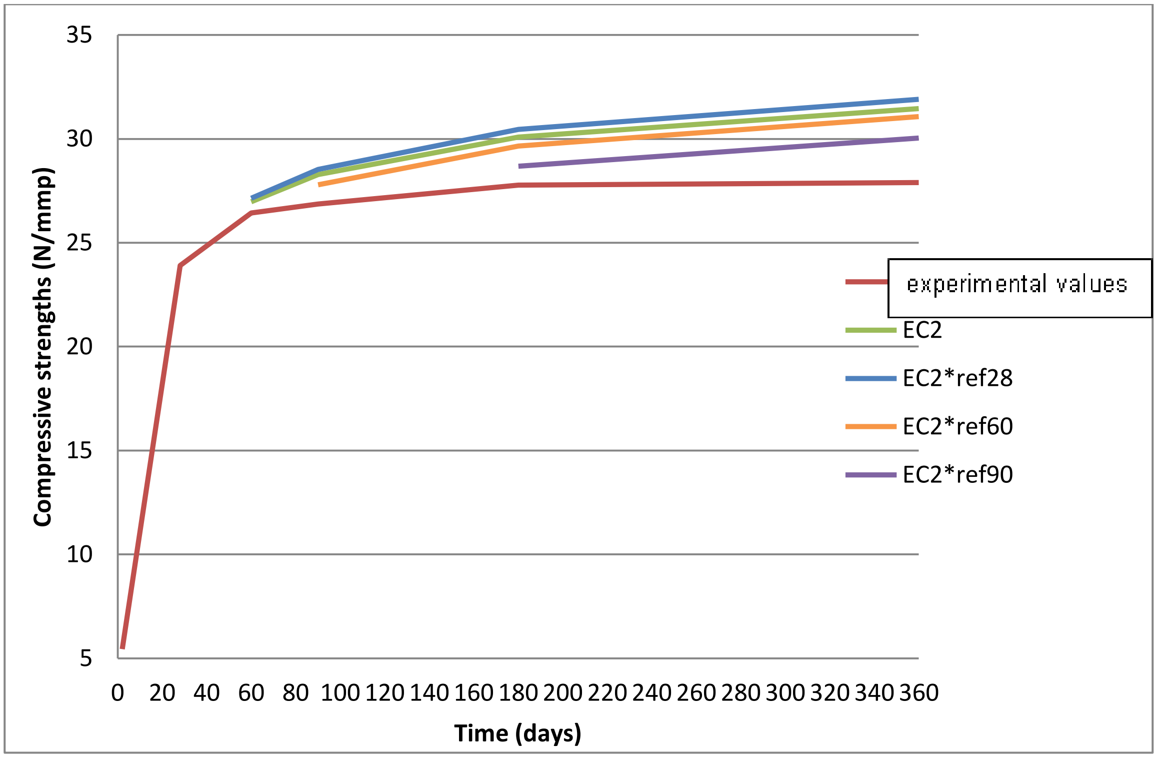


Figure 9. - Compressive strength of concrete with CEM II/B-S 32.5N with a w/c ratio of 0.73, depending on the age.

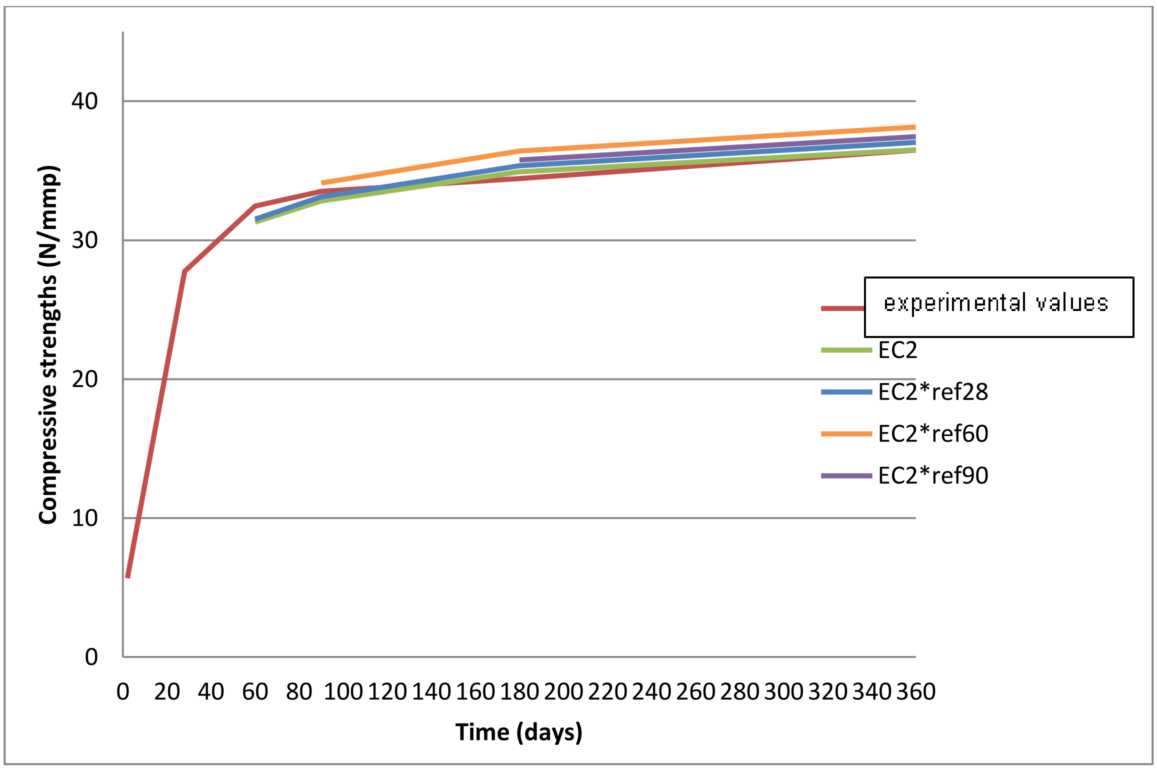


Figure 10. - Compressive strength of concrete with CEM II/B-S 32.5N with a w/c ratio of 0.67, depending on the age.

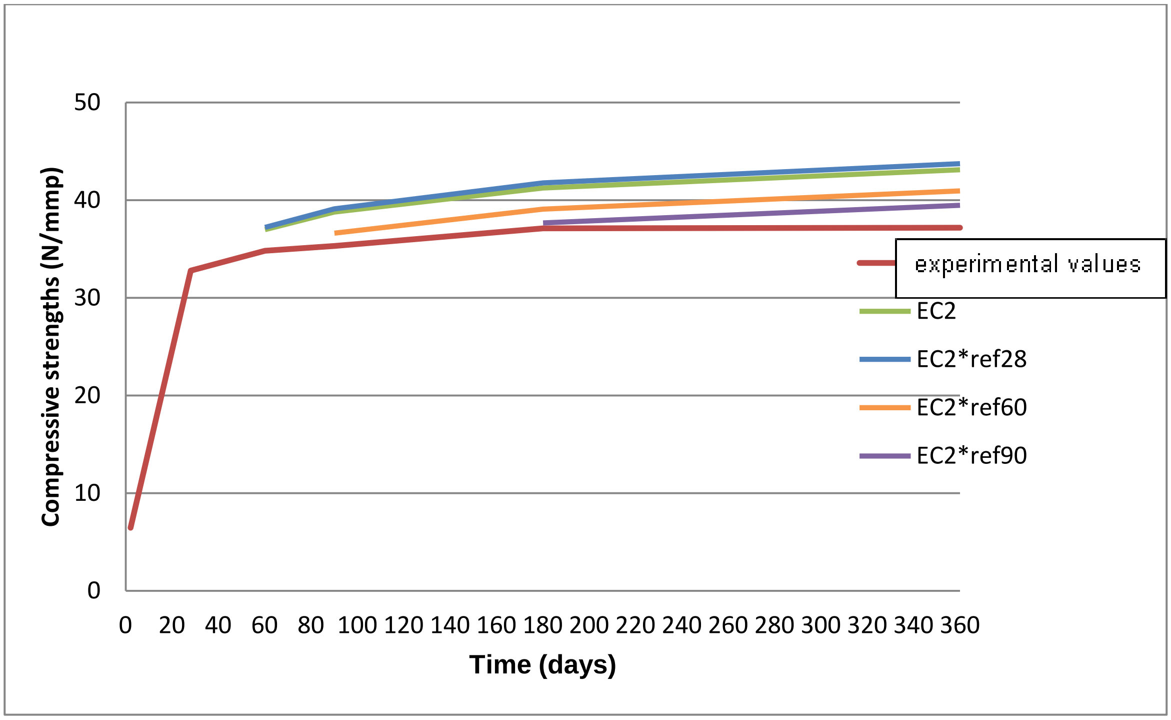


Figure 11. - Compressive strength of concrete with CEM II/B-S 32.5N with a w/c ratio of 0.60, depending on the age.

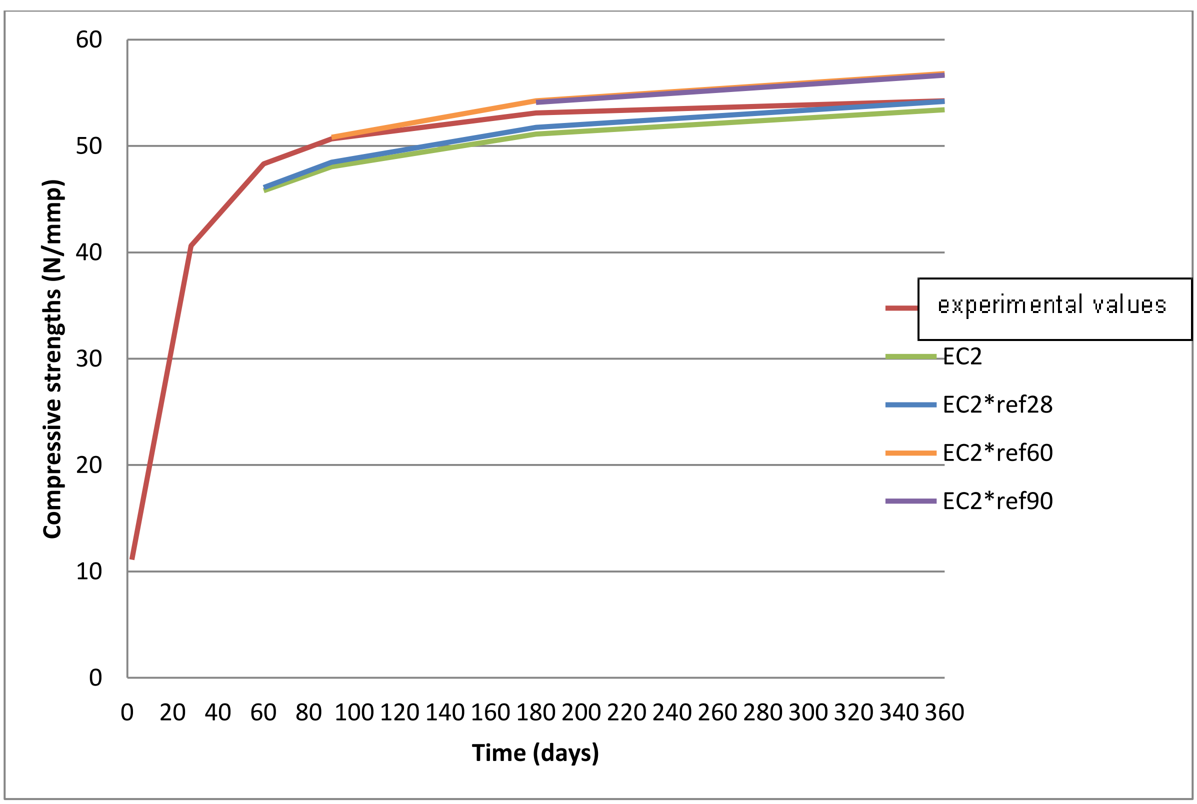


Figure 12. - Compressive strength of concrete with CEM II/B-S 32.5N with a w/c ratio of 0.53, depending on the age.

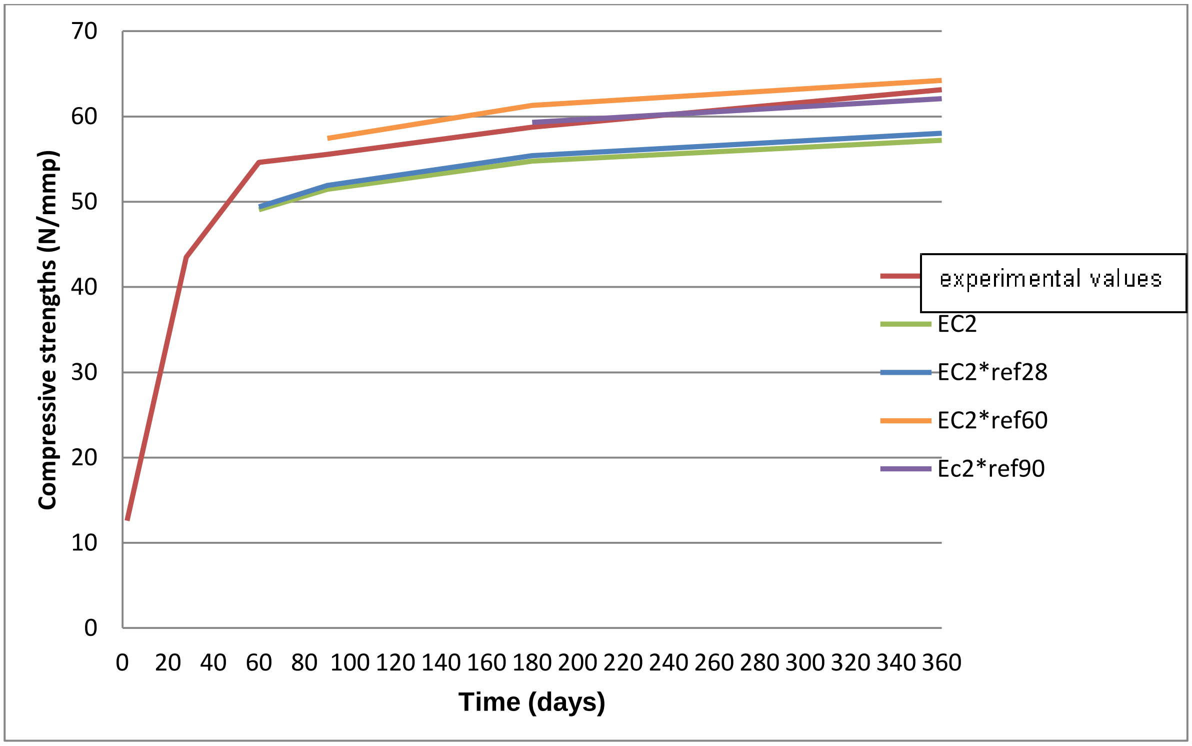


Figure 13. - Compressive strength of concrete with CEM II/B-S 32.5N with a w/c ratio of 0.49, depending on the age.

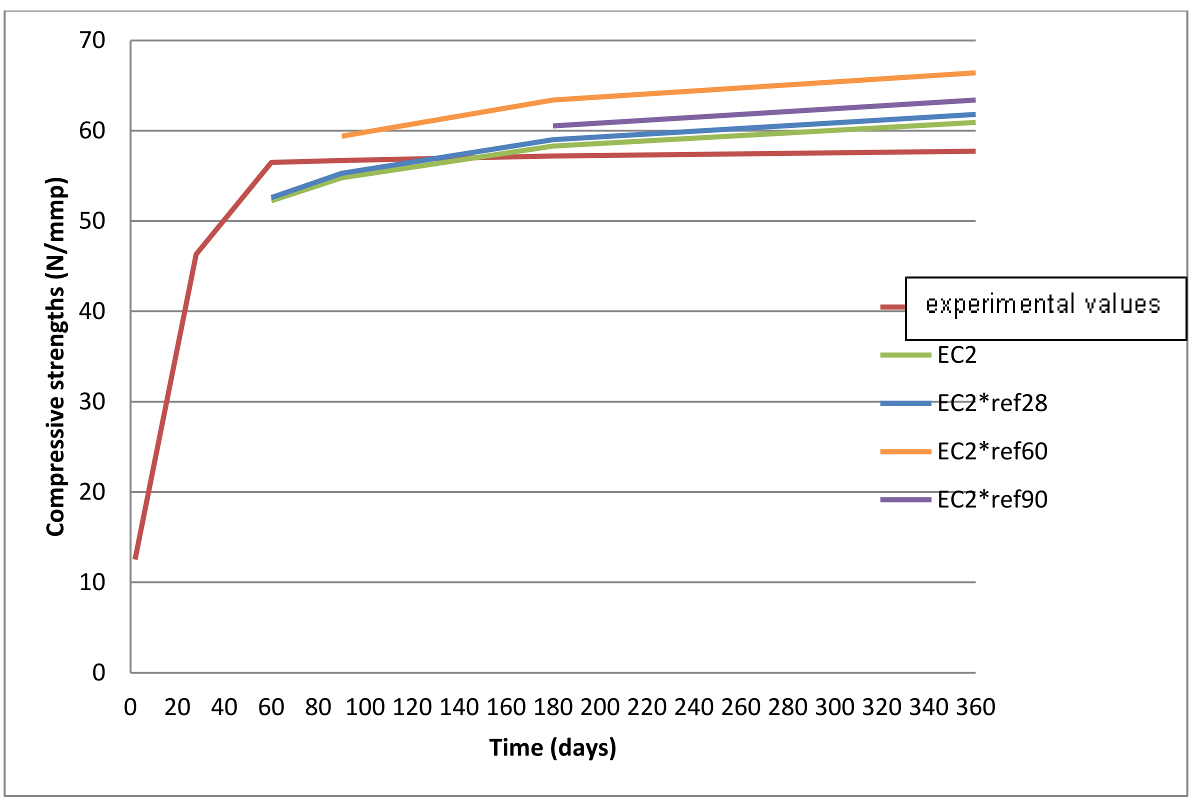


Figure 14. - Compressive strength of concrete with CEM II/B-S 32.5N with a w/c ratio of 0.47, depending on the age.

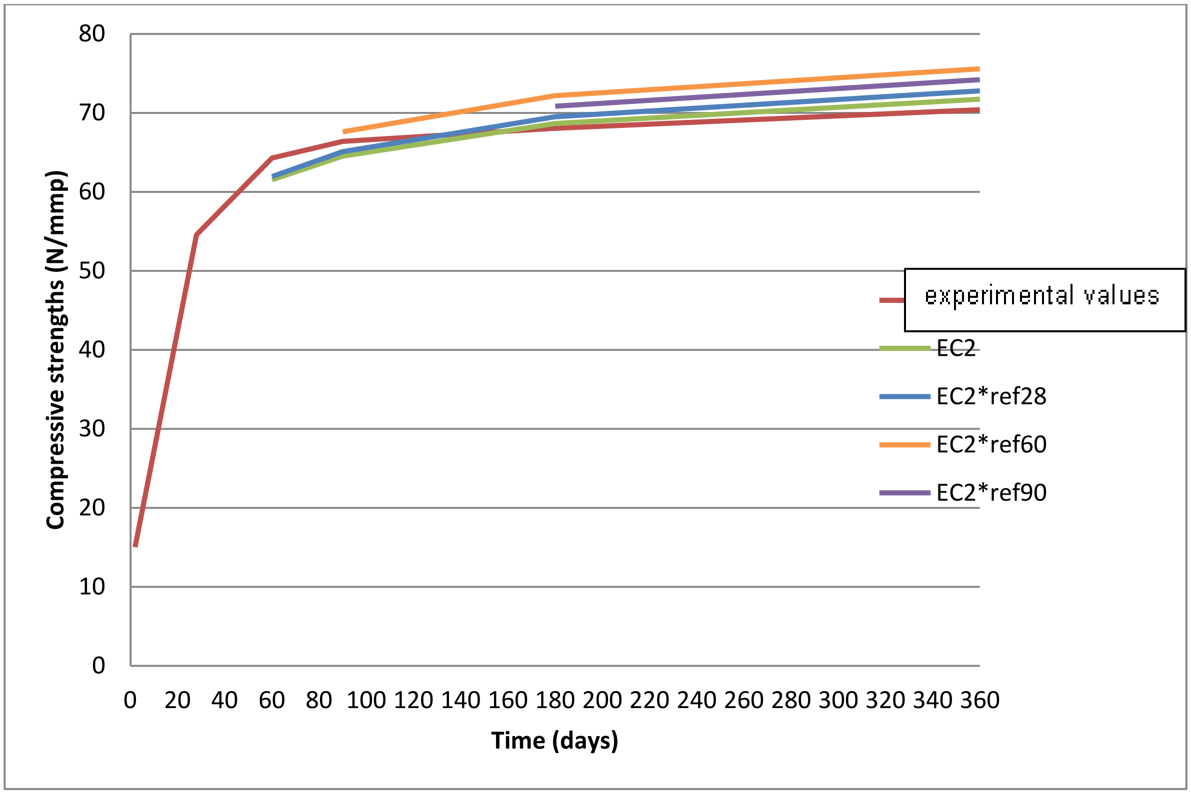
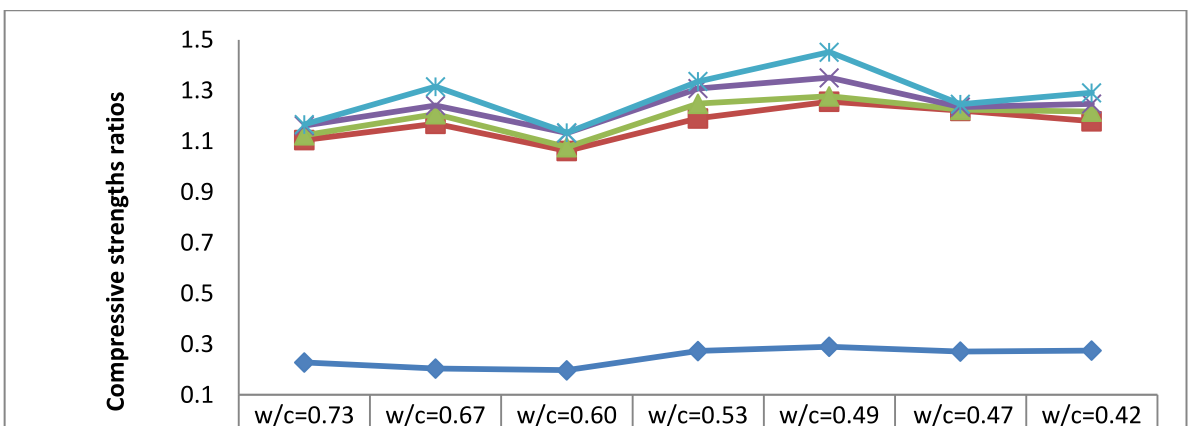


Figure 15. - Compressive strength of concrete with CEM II/B-S 32.5N with a w/c ratio of 0.42, depending on the age.

Figure 16 show the ratios between of compressive strengths for concrete prepared with different type of cements at different proposed reference times.



	w/c=0.73	w/c=0.67	w/c=0.60	w/c=0.53	w/c=0.49	w/c=0.47	w/c=0.42
fc2/fc28	0.228	0.204	0.197	0.273	0.29	0.271	0.275
fc60/fc28	1.105	1.169	1.062	1.19	1.256	1.22	1.179
fc90/fc28	1.124	1.207	1.077	1.248	1.277	1.224	1.217
fc180/fc28	1.161	1.241	1.132	1.308	1.35	1.235	1.247
fc360/fc28	1.166	1.315	1.134	1.336	1.451	1.246	1.291

Figure 16.- Ratios between compressive strengths for concrete made with CEM II/B-S 32.5N at a proposed reference time of 28 days.

- **Concrete with CEM II/B-M (S-V) 32.5R (65-79% clinker, 21-35% slag+ fly ash)**

The compositions of concretes with CEM II/B-M (S-V) 32.5R are shown in Table 16.

Table 16. - Composition and properties of fresh concrete prepared with CEM II/B-M (S-V) 32.5R

Concrete class	w/c ratio	Cement dosage (kg/m^3)	Maximum diameter of the aggregate (mm)	Admixture	Settlement (mm)
C16/20	0.49	325	32	superplasticizer admixture	110
C20/25	0.43	370	32		115
C25/30	0.39	420	32		120
C30/37	0.37	470	32		120

Figures 17 and 17' show the experimental results for average compressive strength measured at different ages for these four concrete compositions containing CEM II/B-M (S-V) 32.5R. The evolution of compressive strengths of concrete with CEM II/B-M (S-V) 32.5R was also analyzed over time by comparing the results experimentally obtained versus the computed strength values as per the designing prescriptions in SR EN 1992-1-1: 2004 [1] and as per the Project for revising EN 1992-1-1 [2] (taking into account in this case, different reference ages - 28, 56 and 90 days).

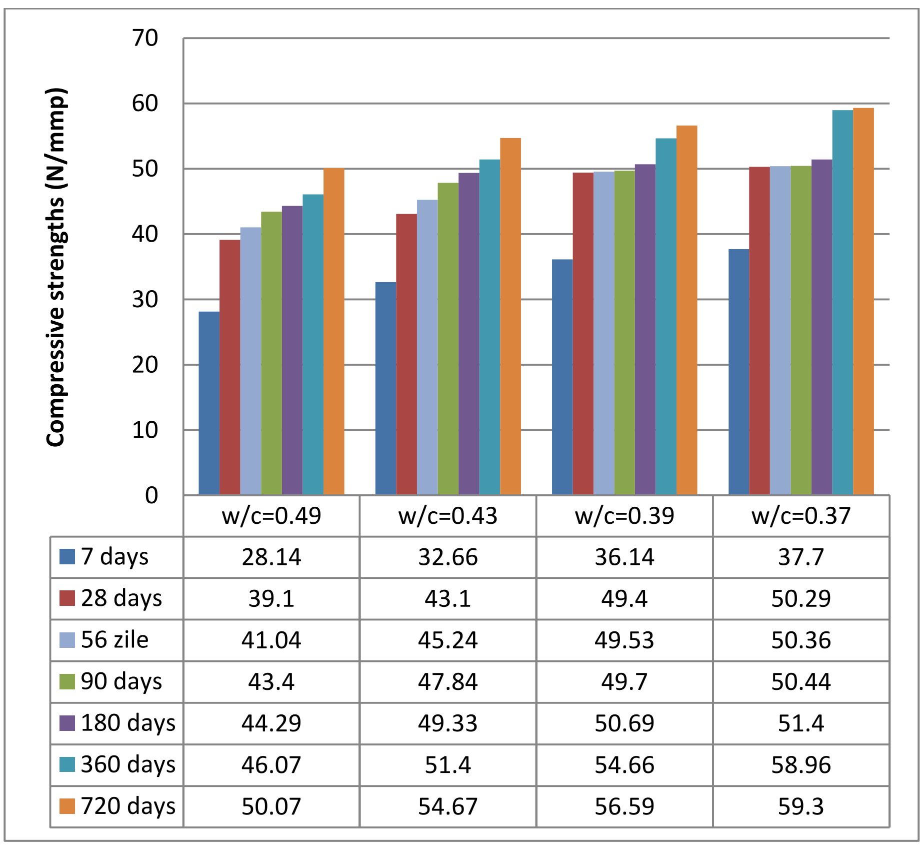


Figure 17. - The variation of compressive strength over time - for concretes containing CEM II/B-M (S-V) 32.5R with different w/c ratios

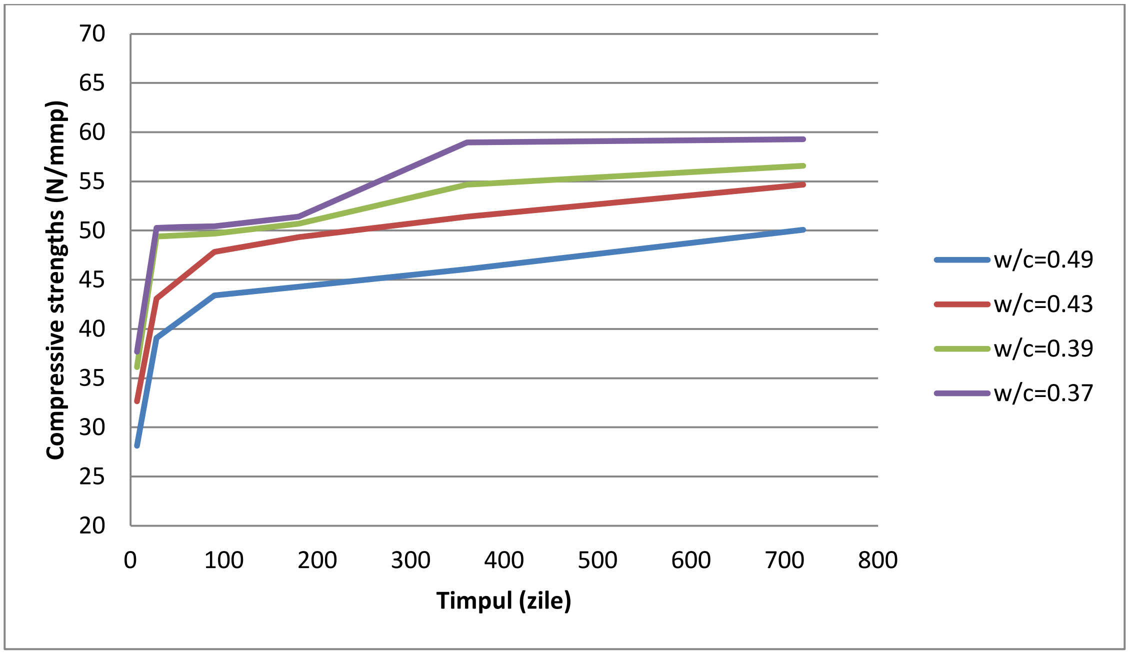


Figure 17'. - The variation of compressive strength over time - for concretes with CEM II/B-M (S-V) 32.5R and with different w/c ratios

Table 17. - Compressive strength over time - determined experimentally and also calculated - for concrete with CEM II/B-M (S-V) 32.5R with a w/c ratio of 0.49 [3], [4], [5]

Age of concrete	f_{cm} experimental values (**w/c = 0.49**)	f_{cm} (EC 2) calculated values	f_{cm} (prEC2*ref28) calculated values	f_{cm} (prEC 2*ref 56) calculated values	f_{cm} (prEC 2*ref 90) calculated values
7 days	28.14				
28 days	39.10				
56 days	41.04	β = 1.076 42.07	β = 1.108 43.32		
90 days	43.40	β = 1.117 43.67	β = 1.167 45.64	β = 1.054 43.24	
180 days	44.29	β = 1.163 45.49	β = 1.236 48.33	β = 1.116 45.78	β = 1.059 45.95
360 days	46.07	β = 1.198 46.82	β = 1.287 50.32	β = 1.162 47.67	β = 1.103 47.85
720 days	50.07	β = 1.222 49.79	β = 1.324 51.78	β = 1.195 49.06	β = 1.135 49.24
		β_{max}=1.284 50.20	β_{max}=1.419 55.48	β_{max}=1.281 52.56	β_{max}=1.216 52.75

Table 18. - Compressive strength over time - determined experimentally and also calculated - for concrete with CEM II/B-M (S-V) 32.5R with a w/c ratio of 0.43 [3], [4], [5]

Age of concrete	f_{cm} experimental values (**w/c = 0.43**)	f_{cm} (EC 2) calculated values	f_{cm} (prEC2*ref28) calculated values	f_{cm} (prEC 2*ref 56) calculated values	f_{cm} (prEC 2*ref 90) calculated values

7 days	32.66				
28 days	43.10				
56 days	45.24	β = 1.076 46.37	β = 1.108 47.75		
90 days	47.84	β = 1.117 48.14	β = 1.167 50.31	β = 1.054 47.66	
180 days	49.33	β = 1.163 50.14	β = 1.236 53.27	β = 1.116 50.47	β = 1.059 50.65
360 days	51.40	β = 1.198 51.61	β = 1.287 55.47	β = 1.162 52.55	β = 1.103 52.74
720 days	54.67	β = 1.222 52.68	β = 1.324 57.08	β = 1.195 54.08	β = 1.13451 54.27
		β_{max}=1.284 55.34	β_{max}=1.419 61.16	β_{max}=1.281 57.94	β_{max}=1.216 58.15

Table 19. - Compressive strength over time - determined experimentally and also calculated - for concrete with CEM II/B-M (S-V) 32.5R with a w/c ratio of 0.39 [3], [4], [5]

Age of concrete	f_{cm} experimental values (**w/c = 0.39**)	f_{cm} (EC 2) calculated values	f_{cm} (prEC2*ref28) calculated values	f_{cm} (prEC 2*ref 56) calculated values	f_{cm} (prEC 2*ref 90) calculated values
7 days	36.14				
28 days	49.40				
56 days	49.53	β = 1.076 53.15	β = 1.108 54.73		
90 days	49.70	β = 1.117 55.17	β = 1.167 57.67	β = 1.054 52.16	
180 days	50.69	β = 1.163 57.47	β = 1.236 61.06	β = 1.116 55.26	β = 1.059 52.62
360 days	54.66	β = 1.198 59.16	β = 1.287 63.58	β = 1.162 57.54	β = 1.103 54.79
720 days	56.59	β = 1.222 60.38	β = 1.324 65.43	β = 1.195 59.21	β = 1.135 56.38
		β_{max}=1.284 63.43	β_{max}=1.419 70.10	β_{max}=1.281 63.44	β_{max}=1.216 60.41

Table 20. - Compressive strength over time - determined experimentally and also calculated - for concrete with CEM II/B-M (S-V) 32.5R with a w/c ratio of 0.37 [3], [4], [5]

Age of concrete	f_{cm} experimental values (**w/c = 0.37**)	f_{cm} (EC 2) calculated values	f_{cm} (prEC2*ref28) calculated values	f_{cm} (prEC 2*ref 56) calculated values	f_{cm} (prEC 2*ref 90) calculated values
7 days	37.70				
28 days	50.29				
56 days	50.36	β = 1.076 54.11	β = 1.108 55.72		
90 days	50.44	β = 1.117 56.17	β = 1.167 58.71	β = 1.054 53.06	
180 days	51.40	β = 1.163 58.51	β = 1.236 62.16	β = 1.116 56.18	β = 1.059 53.41

Age of concrete	f_{cm} experimental values (**w/c = 0.37**)	f_{cm} (EC 2) calculated values	f_{cm} (prEC2*ref28) calculated values	f_{cm} (prEC 2*ref 56) calculated values	f_{cm} (prEC 2*ref 90) calculated values
360 days	58.96	β = 1.198 60.22	β = 1.287 64.73	β = 1.162 58.50	β = 1.103 55.61
720 days	59.30	β = 1.222 61.47	β = 1.324 66.60	β = 1.195 60.20	β = 1.135 57.22
		$β_{max}$=1.284 64.57	βmax=1.419 71.36	$β_{max}$=1.281 64.50	βmax=1.216 61.31

Tables 17-20 show that the values of β coefficient in SR EN 1992-1-1:2004 [1] are different from those proposed by the revised European Standard prEN1992-1-1 [2], and therefore the calculated values of compressive strengths of concrete vary in relation to the average compressive strength at 28 days.

Figures 18-21 show the evolution over time of compressive strength (both real and estimated), for the four concrete compositions.

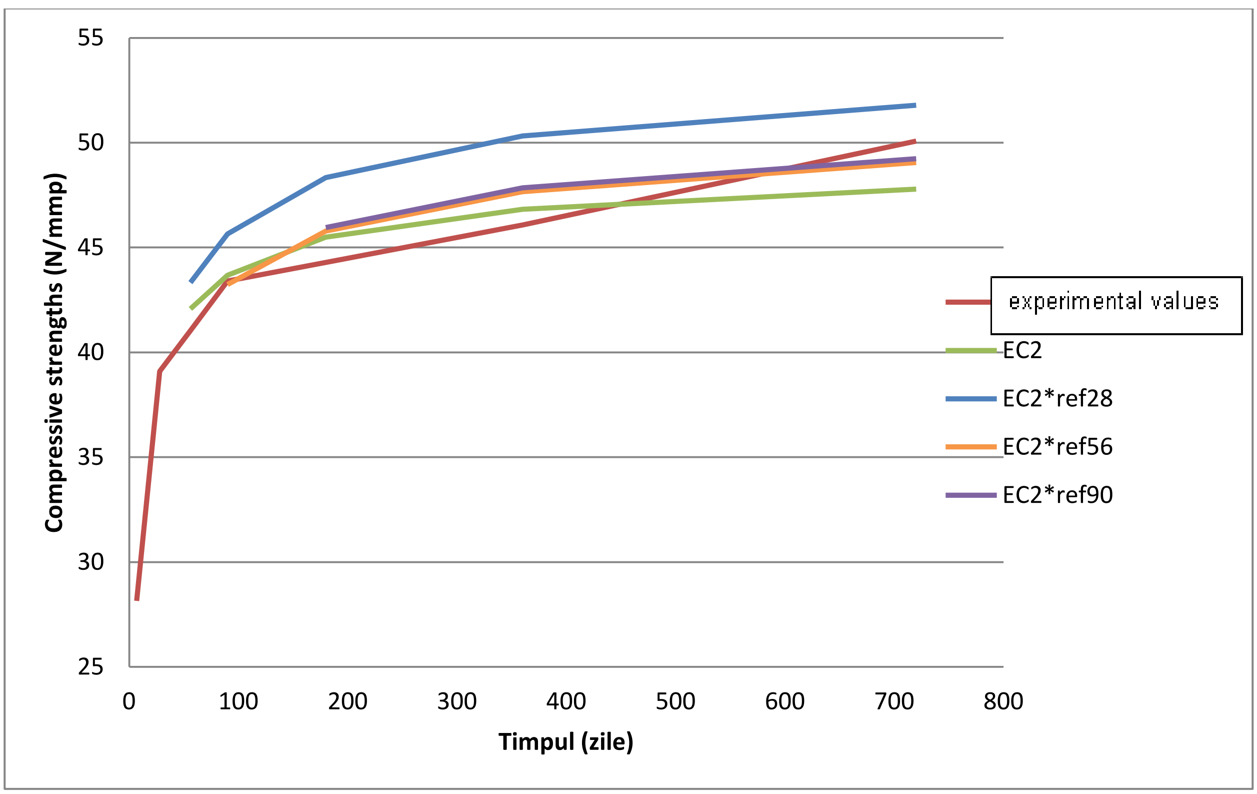


Figure 18. - Compressive strength of concrete with CEM II/B-M (S-V) 32.5R with a w/c ratio of 0.49, depending on the age.

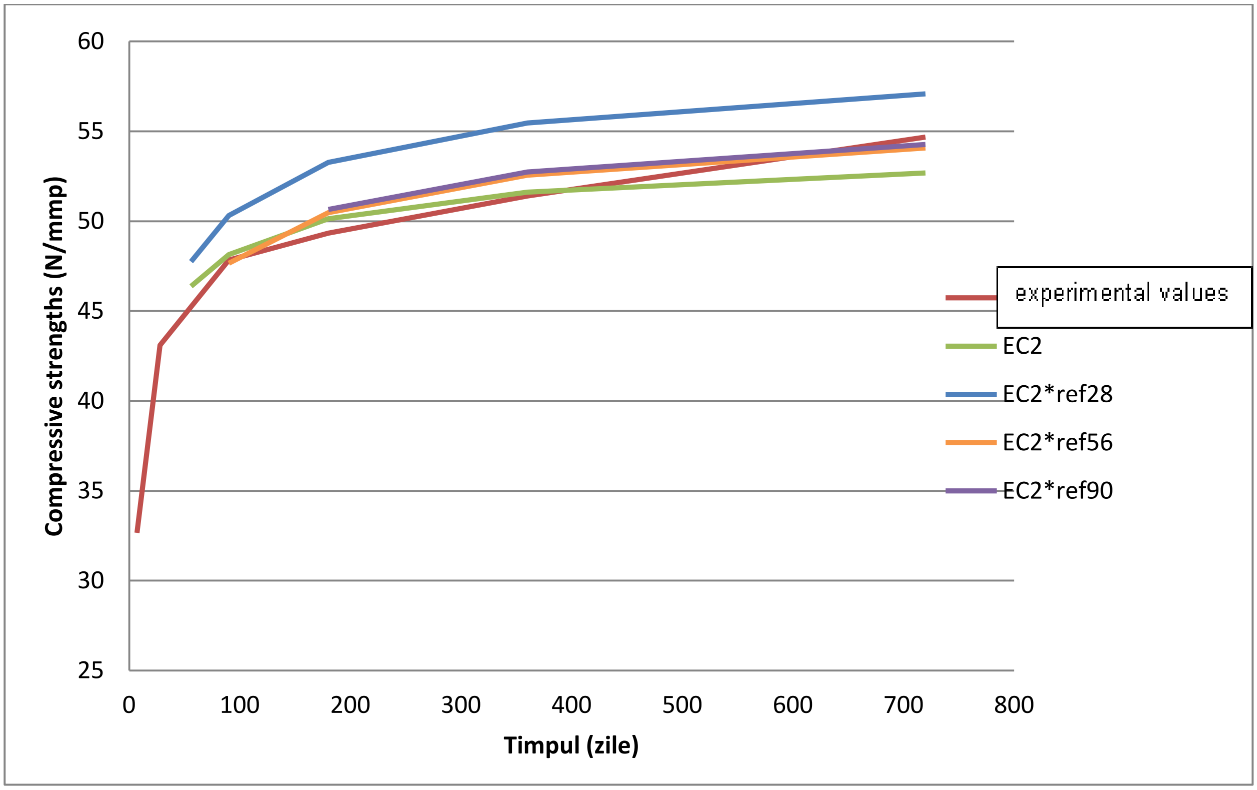


Figure 19. - Compressive strength of concrete with CEM II/B-M (S-V) 32.5R with a w/c ratio of 0.43, depending on the age.

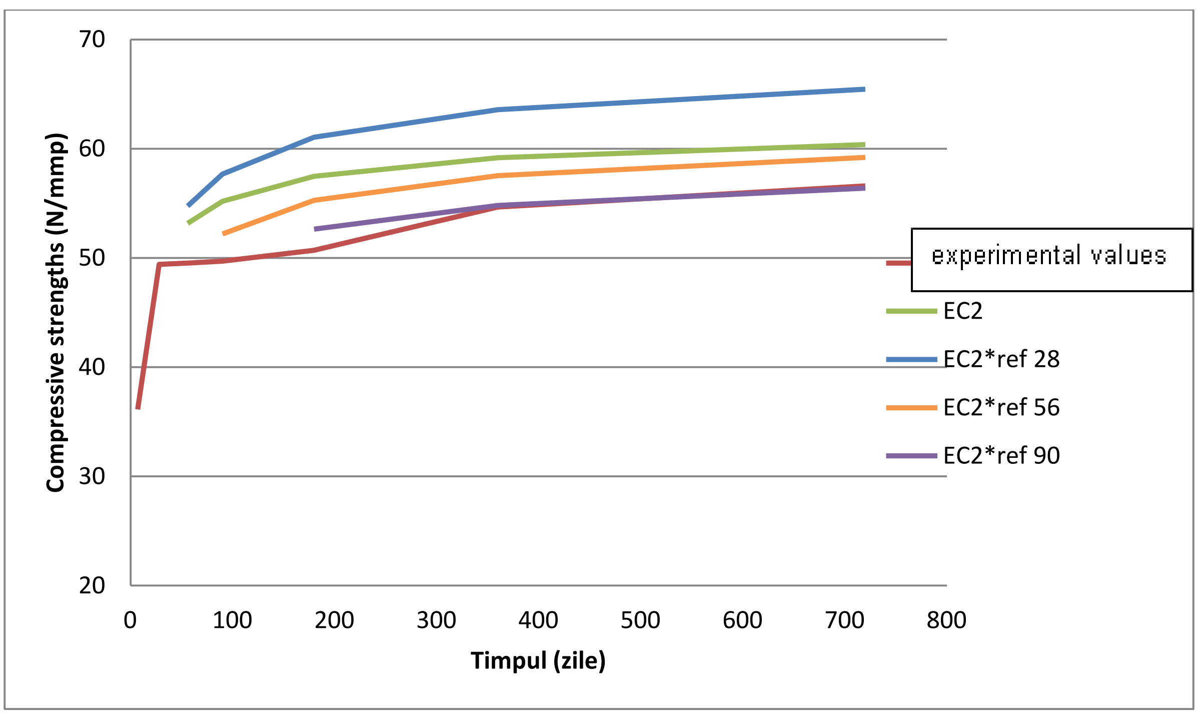


Figure 20. - Compressive strength of concrete with CEM II/B-M (S-V) 32.5R with a w/c ratio of 0.39, depending on the age.

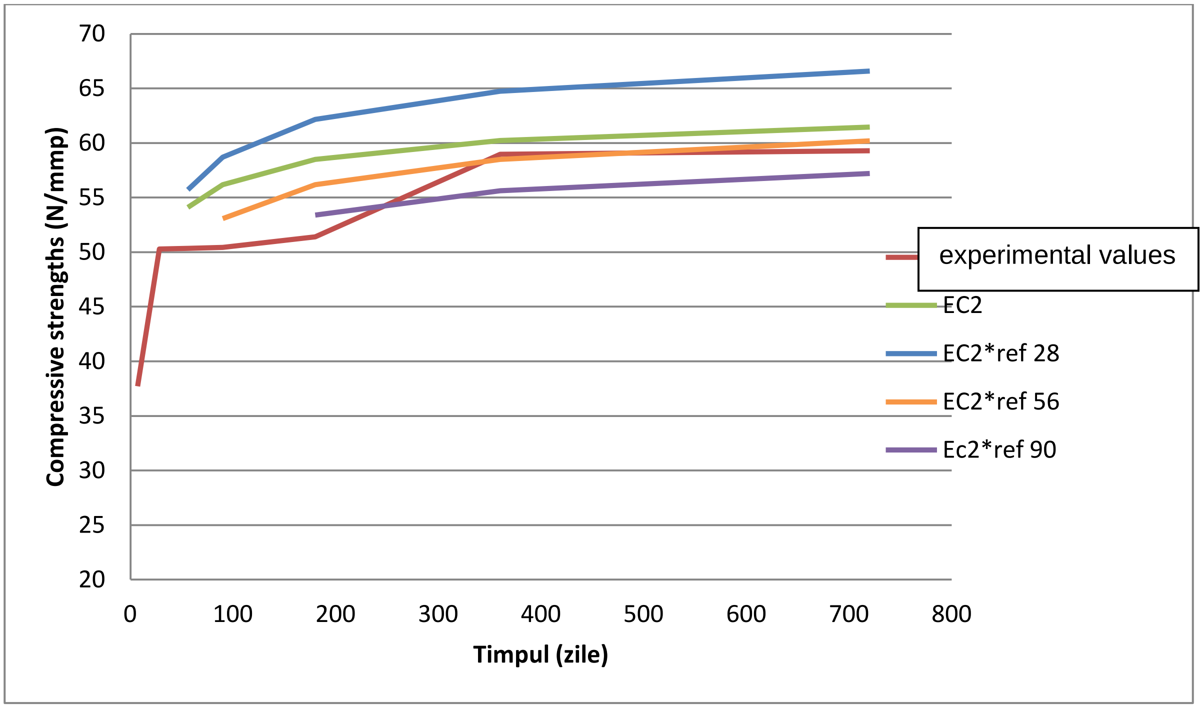
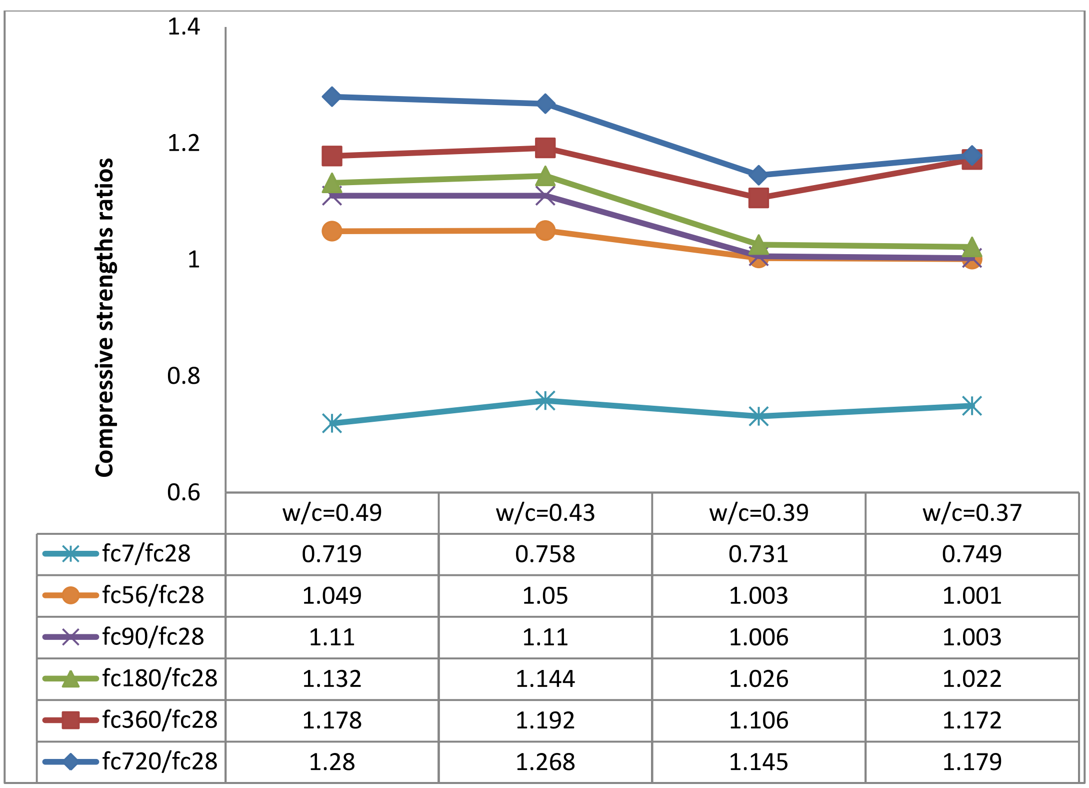


Figure 21. - Compressive strength of concrete with CEM II/B-M (S-V) 32.5R with a w/c ratio of 0.37, depending on the age.

Figure 22 show the ratios between of compressive strengths for concrete prepared with different type of cements at different proposed reference times.



	w/c=0.49	w/c=0.43	w/c=0.39	w/c=0.37
fc7/fc28	0.719	0.758	0.731	0.749
fc56/fc28	1.049	1.05	1.003	1.001
fc90/fc28	1.11	1.11	1.006	1.003
fc180/fc28	1.132	1.144	1.026	1.022
fc360/fc28	1.178	1.192	1.106	1.172
fc720/fc28	1.28	1.268	1.145	1.179

Figure 22.- Ratios between compressive strengths for concrete made with CEM II/B-M (S-V) 32.5R at a proposed reference time of 28 days.

- **Concrete with CEM III/A 32.5R (35-64% clinker, 36-65% slag)**

The compositions of concretes with CEM III/A 32.5R are shown in Table 21.

Table 21. - Composition and properties of fresh concrete prepared with CEM III/A 32.5R

Concrete class	w/c ratio	Cement dosage (kg/m^3)	Maximum diameter of the aggregate (mm)	Admixture	Settlement (mm)
C16/20	0.47	320	32	superplasticizer admixture	115
C20/25	0.41	370	32		110
C25/30	0.37	420	32		110
C30/37	0.35	470	32		110

Figures 23 and 23' show the experimental results for average compressive strength measured at different ages for these four concrete compositions containing CEM III/A 32.5R. The evolution of compressive strengths of concrete with CEM III/A 32.5R was also analyzed over time by comparing the results experimentally obtained versus the computed strength values as per the designing prescriptions in SR EN 1992-1-1: 2004 [1] and as per the Project for revising EN 1992-1-1 [2] (taking into account in this case, different reference ages - 28, 56 and 90 days).

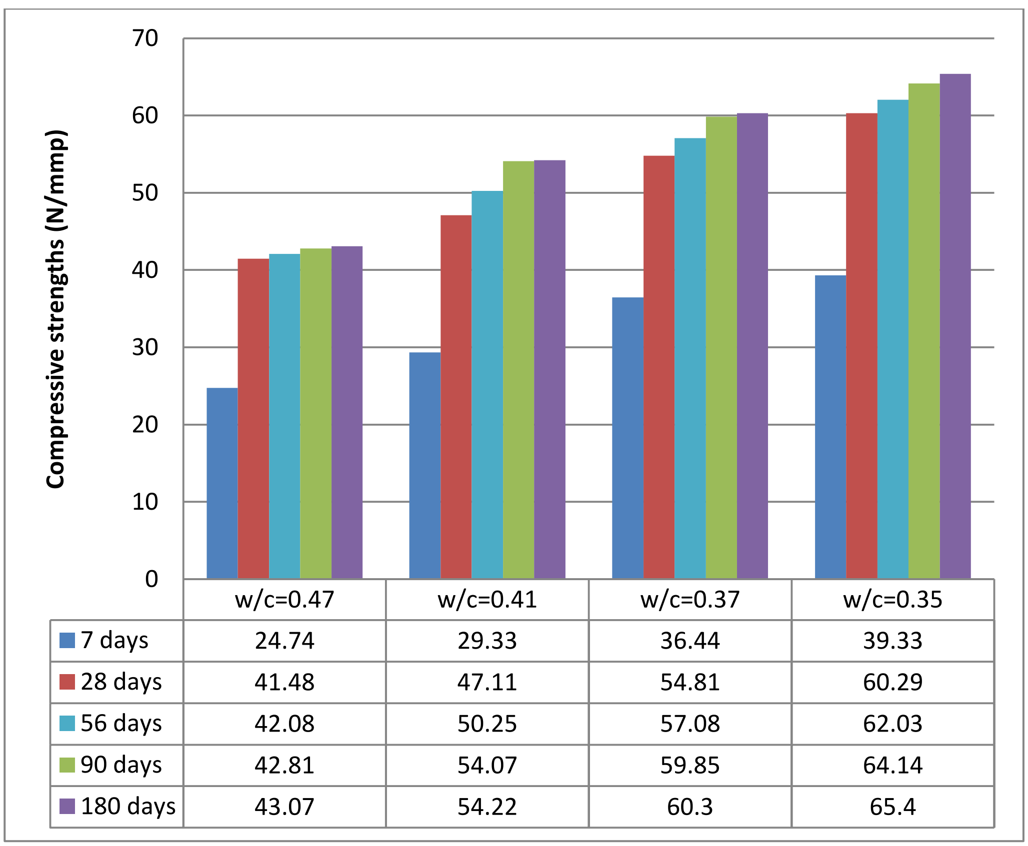


Figure 23. - The variation of compressive strength over time - for concretes containing CEM III/A 32.5R with different w/c ratios

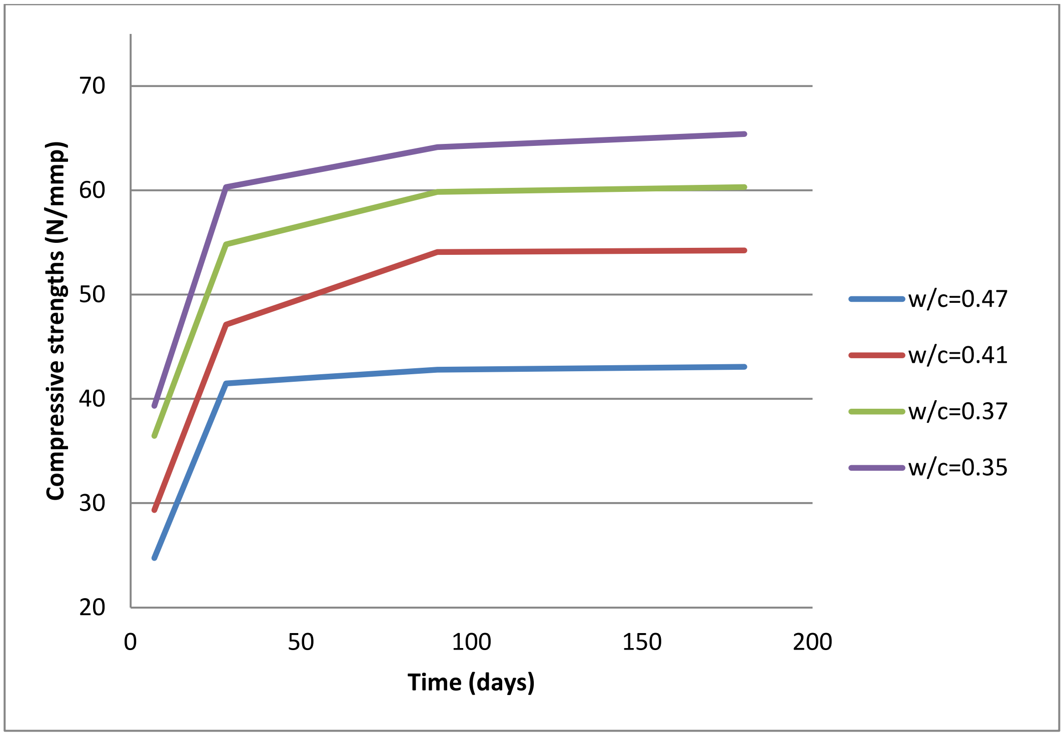


Figure 23'. - The variation of compressive strength over time - for concretes with CEM III/A 32.5R and with different w/c ratios

Table 22. - Compressive strength over time - determined experimentally and also calculated - for concrete with CEM III/A 32.5R with a w/c ratio of 0.47 [3], [4], [5]

Age of concrete	f_{cm} experimental values (**w/c = 0.47**)	f_{cm} (EC 2) calculated values	f_{cm} (prEC2*ref28) calculated values	f_{cm} (prEC 2*ref 56) calculated values	f_{cm} (prEC 2*ref 90) calculated values
7 days	24.74				
28 days	41.48				
56 days	42.08	β = 1.076 44.63	β = 1.108 45.96		
90 days	42.81	β = 1.117 46.33	β = 1.167 48.42	β = 1.054 44.34	
180 days	43.07	β = 1.163 48.26	β = 1.236 51.27	β = 1.116 46.94	β = 1.059 45.33
		$β_{max}$=1.284 53.26	$β_{max}$=1.419 58.86	$β_{max}$=1.281 53.89	$β_{max}$=1.216 52.04

Table 23. - Compressive strength over time - determined experimentally and also calculated - for concrete with CEM III/A 32.5R with a w/c ratio of 0.41 [3], [4], [5]

Age of concrete	f_{cm} experimental values (**w/c = 0.41**)	f_{cm} (EC 2) calculated values	f_{cm} (prEC2*ref28) calculated values	f_{cm} (prEC 2*ref 56) calculated values	f_{cm} (prEC 2*ref 90) calculated values
7 zile	29.33				

28 zile	47.11				
56 zile	50.25	β = 1.076 50.69	β = 1.108 52.19		
90 zile	54.07	β = 1.117 52.62	β = 1.167 54.99	β = 1.054 52.94	
180 zile	54.22	β = 1.163 54.81	β = 1.236 58.23	β = 1.116 56.06	β = 1.059 57.25
		β_{max}=1.284 60.49	β_{max}=1.419 66.85	β_{max}=1.281 64.36	β_{max}=1.216 65.72

Table 24. - Compressive strength over time - determined experimentally and also calculated - for concrete with CEM III/A 32.5R with a w/c ratio of 0.37 [3], [4], [5]

Age of concrete	f_{cm} experimental values (**w/c = 0.37**)	f_{cm} (EC 2) calculated values	f_{cm} (prEC2*ref28) calculated values	f_{cm} (prEC 2*ref 56) calculated values	f_{cm} (prEC 2*ref 90) calculated values
7 zile	36.44				
28 zile	54.81				
56 zile	57.08	β = 1.076 58.97	β = 1.108 60.72		
90 zile	59.85	β = 1.117 61.22	β = 1.167 63.98	β = 1.054 60.14	
180 zile	60.30	β = 1.163 63.77	β = 1.236 67.75	β = 1.116 63.68	β = 1.059 63.37
		β_{max}=1.284 70.38	β_{max}=1.419 77.78	β_{max}=1.281 73.11	β_{max}=1.216 72.75

Table 25. - Compressive strength over time - determined experimentally and also calculated - for concrete with CEM III/A 32.5R with a w/c ratio of 0.35 [3], [4], [5]

Age of concrete	f_{cm} experimental values (**w/c = 0.35**)	f_{cm} (EC 2) calculated values	f_{cm} (prEC2*ref28) calculated values	f_{cm} (prEC 2*ref 56) calculated values	f_{cm} (prEC 2*ref 90) calculated values
7 zile	39.33				
28 zile	60.29				
56 zile	62.03	β = 1.076 64.87	β = 1.108 66.80		
90 zile	64.14	β = 1.117 67.33	β = 1.167 70.38	β = 1.054 65.36	
180 zile	65.40	β = 1.163 70.14	β = 1.236 74.52	β = 1.116 69.20	β = 1.059 67.91
		β_{max}=1.284 77.41	β_{max}=1.419 85.55	β_{max}=1.281 79.45	β_{max}=1.216 77.97

Tables 22-25 show that the values of β coefficient in SR EN 1992-1-1:2004 [1] are different from those proposed by the revised European Standard prEN1992-1-1 [2], and therefore the calculated values of compressive strengths of concrete vary in relation to the average compressive strength at 28 days.

Figures 24-27 show the evolution over time of compressive strength (both real and estimated), for the four concrete compositions.

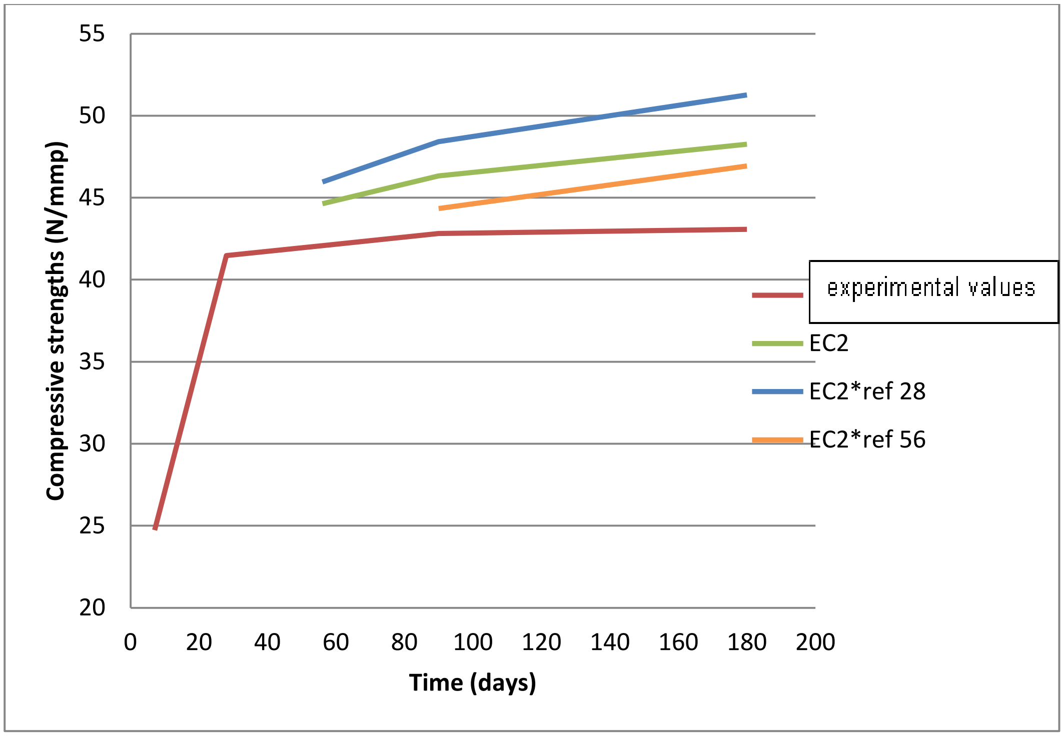


Figure 24. - Compressive strength of concrete with CEM III/A 32.5R with a w/c ratio of 0.47, depending on the age.

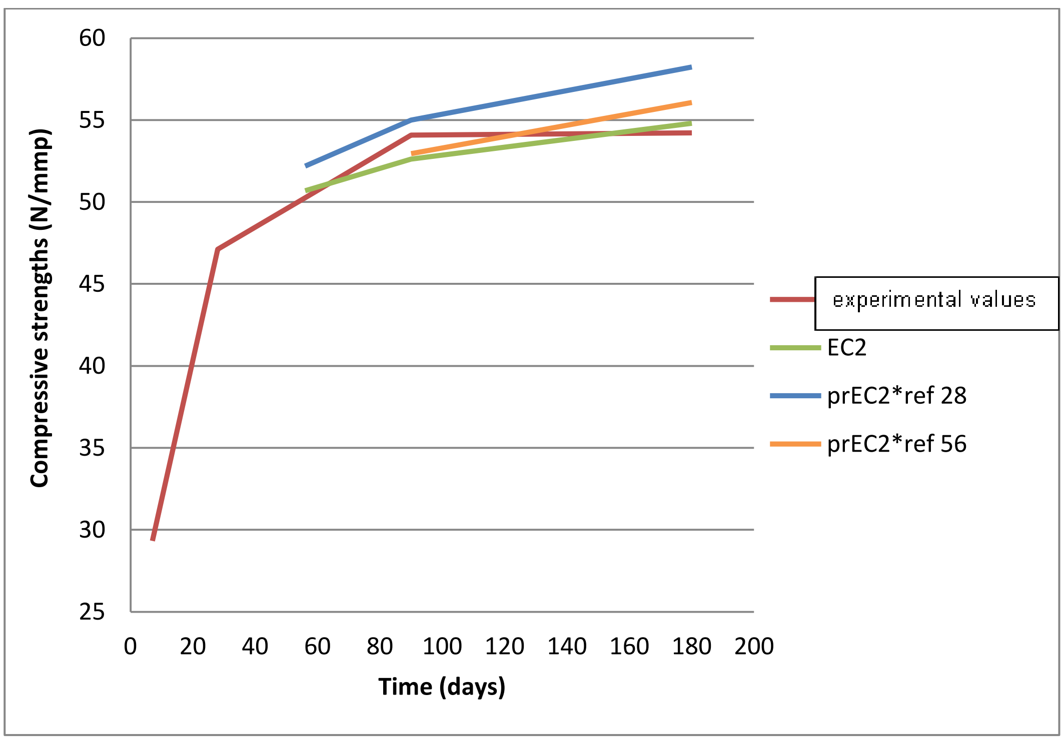


Figure 25. - Compressive strength of concrete with CEM III/A 32.5R with a w/c ratio of 0.41, depending on the age.

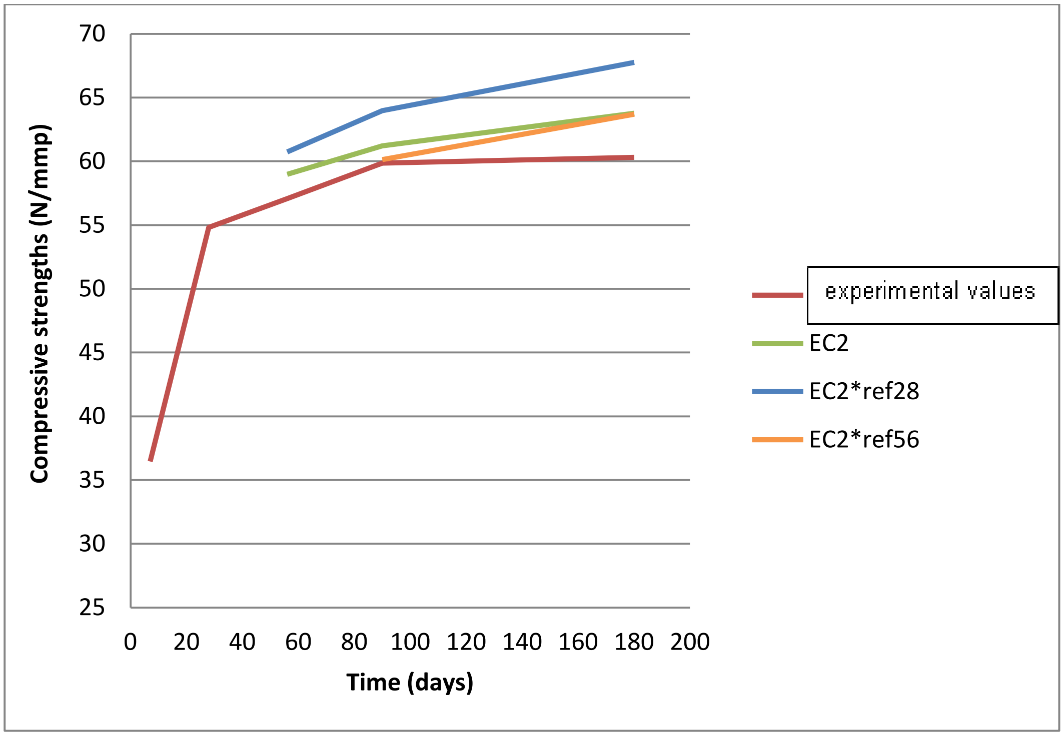


Figure 26. - Compressive strength of concrete with CEM III/A 32.5R with a w/c ratio of 0.37, depending on the age.

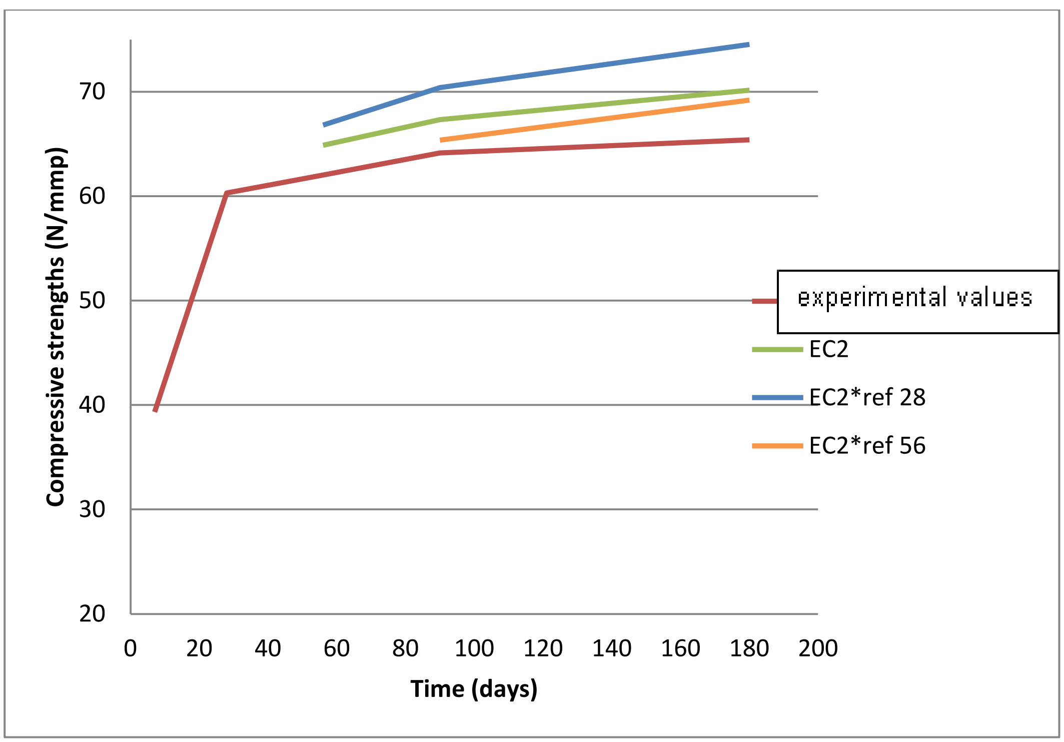
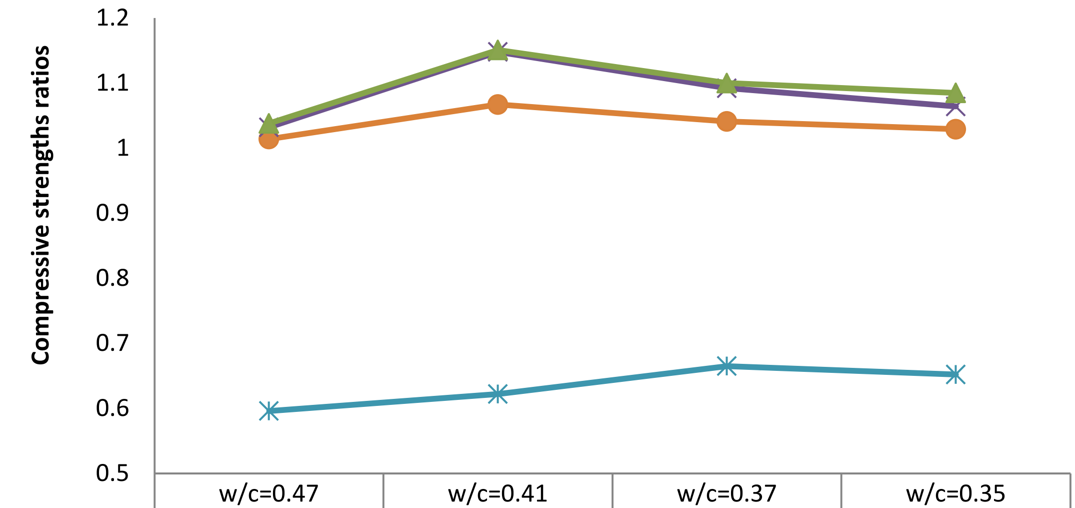


Figure 27. - Compressive strength of concrete with CEM III/A 32.5R with a w/c ratio of 0.35, depending on the age.

Figure 28 show the ratios between of compressive strengths for concrete prepared with different type of cements at different proposed reference times.



	w/c=0.47	w/c=0.41	w/c=0.37	w/c=0.35
fc7/fc28	0.596	0.622	0.665	0.652
fc56/fc28	1.014	1.067	1.041	1.029
fc90/fc28	1.032	1.148	1.092	1.064
fc180/fc28	1.038	1.151	1.1	1.085

Figure 28.- Ratios between compressive strengths for concrete made with CEM III/A 32.5R at a proposed reference time of 28 days.

1.2. Conclusions:

1) The studies shown in this research report are an introduction in the field of analyzing the compression strength calculated for concrete of over 28 days of age, with a view to exemplifying and applying the knowledge from the new proposal issued in October 2017 in order to update the European standard prEN 1992-1-1 [2], to ensure the safety requirements for the exploitation of structures built with reinforced concrete prepared with cements containing mineral additions.

2) The reference time for determining concrete's class may be between 28 and 90 days in accordance with the draft revision prEN1992-1-1 [2].

3) The value of the ”s”-coefficient, used for determining the compression strength of concrete at ages other than 28 days, is calculated as per the proposal of reviewing prEN1992-1-1 [2], according to the type of cement and the concrete's class – unlike the current edition, where ”s” depends only on the type of cement (the strength at young ages and at 28 days).

4) This study presents the results of the experimental research on concrete prepared with four types of cements containing slag in different proportions, one of type N and three of type R, with similar w/c ratios, (where the concrete should have reached similar strengths).

5) The results obtained regarding the evolution over time of the compressive strengths show that the value of „s” can not be considered the same based only on considerations in relation with the type of the cement characterized by its strength (eg 32.5R or N). For example, in the case of the concrete with CEM II/B-S 32.5R, there is a major difference between the actual evolution of strength and the one determined by using the formula proposed in the Draft for reviewing prEN1992-1-1 [2]. Also, in the case of concrete prepared with CEM II/B-S 32.5N cement, by applying the formula the reference age, should be 28 days. But there is an obvious difference between the results obtained at 28 days and 56 days respectively.

6) Therefore, a separate analysis is needed to experimentally determine the reference time/age for establishing the concrete's class, mainly depending on ratios between the strengths obtained at 56 days and 90 days, and 28 days respectively, and studying the evolution of concrete strength over time. If we obtain a strength at 56 or 90 an increase higher than 15% against the one at 28 days, and include in another concrete class (criterion f_{ck} + 4), then a reference time higher than 28 days is proposed. Knowing the value of the reference time calculated this way, the formula proposed as per the Draft for revising prEN1992-1-1 [2] can be applied. Nevertheless, in such cases, trials/tests are recommended to be performed in order to determine the compression strength up to 1 year of age and to compare the actual evolution to the one obtained by applying the formula, In case of important differences, the „s” coefficient in the formula should be revised.

2. APPLICATION OF SOME EVALUATION METHODS ASSOCIATED WITH THE PERFORMANCE OF MATERIALS TO DETERMINE THE AREAS OF USE OF CONCRETE

The use of admixtures in the preparation of cement and concrete is already a widespread solution at national and European level. There is often the issue of promoting new compositions with varying percentages and types of additions for certain applications and exposure environments, the main issue being to ensure good behavior over time and to ensure a proper working life.

The study presents the applications of performance-related methods used at European level to check the possibility of using new compositions in certain exposure environments. These methods stand for useful tools in completing the water/cement equivalent ratio method,expected to provide similar time behaviors to a reference composition. The article presents the carbonation resistance and frost-thawing resistance of concrete based on the results of experimental research carried out by the author.

The research presents an analysis of the application of various methods related to concrete performance taking as a case study the results of some experimental research on concrete with cement with addition, CEM II/A-S 42,5R and CEM III/A 42.5N-LH respectively concrete with additions with the same proportions, CEM I 42.5R + 10% slag and CEM I 42.5R + 37% slag.

This anaysis starts from the application of the prescriptive k-value concept [6] which is based on the comparison of the performances of a concrete prepared with cement «A» with those of a concrete in which part of the cement «A» has been replaced with an addition, i.e. the replacement A / C ratio with equivalent ratio A/C + k x addition.

The aim was to examine whether the application of this concept can "cover" in achieving equivalent performances. That is why the principles of the equivalent durability procedure has also been applied in different proposals at European level [7] or for some national documents in Europe [8].

The experimental researches consisted in the determination of the performance of concrete prepared with type II/AS 42,5R cement (concrete prepared with or type III/A 42,5N-LH cement) and of a concrete made of CEM I 42,5R with the addition of 10% slag (or a concrete made of CEM I 42,5R with the addition of 37% slag) in terms of compressive strength and carbonation resistance and freeze-thaw resistance.

2.1. The determination of the *k*-value concept

The first stage of the experimental research consisted in determining the *k*-value concept [9], [10]. Table 26 shows the composition of concrete prepared with CEM I 42,5R cement, and Table 27,28 shows the compositional characteristics of concrete prepared with cement CEM I 42,5R and 10% slag and respectively of concrete prepared with cement CEM I 42,5R and 37% slag.

Table 26. - Compositions of the concrete prepared with CEM I 42,5R

Cement dosage (kg/m^3)	Water (l)	Admixture (l)	Aggregate (kg)	0-4 mm type	4-8 mm type	8-16 mm type
270	171	2.55	1893	757	379	757
300	159	2.83	1855	742	371	742
340	154	3.21	1801	720	360	721
370	158	3.49	1780	712	356	712
430	167	4.06	1705	682	341	682

Table 27. - Compositions of the concrete prepared with CEM I 42,5R and 10% slag

Cement dosage (kg/m^3)	Slag dosage (kg/m^3)	Water (l)	Admixture (l)	Aggregate (kg)	0-4 mm type	4-8 mm type	8-16 mm type
243	27	160	2.55	1893	757	379	757

270	30	156	2.83	1855	742	371	742
306	34	143	3.21	1801	720	360	721
333	37	153	3.49	1780	712	356	712
387	43	153	4.06	1705	682	341	682

Tabelul 28. – Compositions of the concrete prepared with CEM I 42,5R and 37% slag

Cement dosage (kg/m^3)	Slag dosage (kg/m^3)	Water (l)	Admixture (l)	Aggregate (kg)	0-4 mm type	4-8 mm type	8-16 mm type
170	100	157	2.55	1893	757	379	757
189	111	146	2.83	1855	742	371	742
214	126	142	3.21	1801	720	360	721
233	137	150	3.49	1780	712	356	712
271	159	148	4.06	1705	682	341	682

Table 29. The characteristics of fresh concretes prepared with CEM I 42,5R

Cement dosage (kg/m^3)	A/C	Settlement (mm)	Density (kg/m^3)
270	0.64	150	2379
300	0.54	150	2405
340	0.46	150	2439
370	0.44	150	2400
430	0.40	150	2433

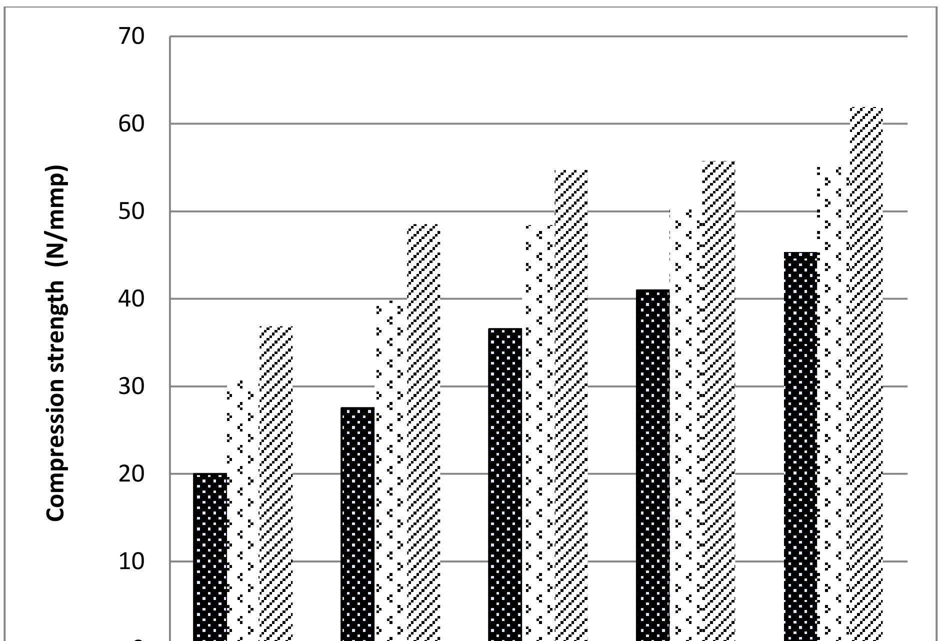
Table 30. - The characteristics of fresh concretes prepared with CEM I 42,5R and 10% slag

Cement dosage (kg/m^3)	Slag dosage (kg/m^3)	A/C	Settlement (mm)	Density (kg/m^3)	Comments
243	27	0.60	110	2398	noncohesive concrete
270	30	0.53	135	2424	noncohesive concrete
306	34	0.43	125	2446	-
333	37	0.42	145	2414	-
387	43	0.37	105	2418	-

Table 31. - The characteristics of fresh concretes prepared with CEM I 42,5R and 37% slag

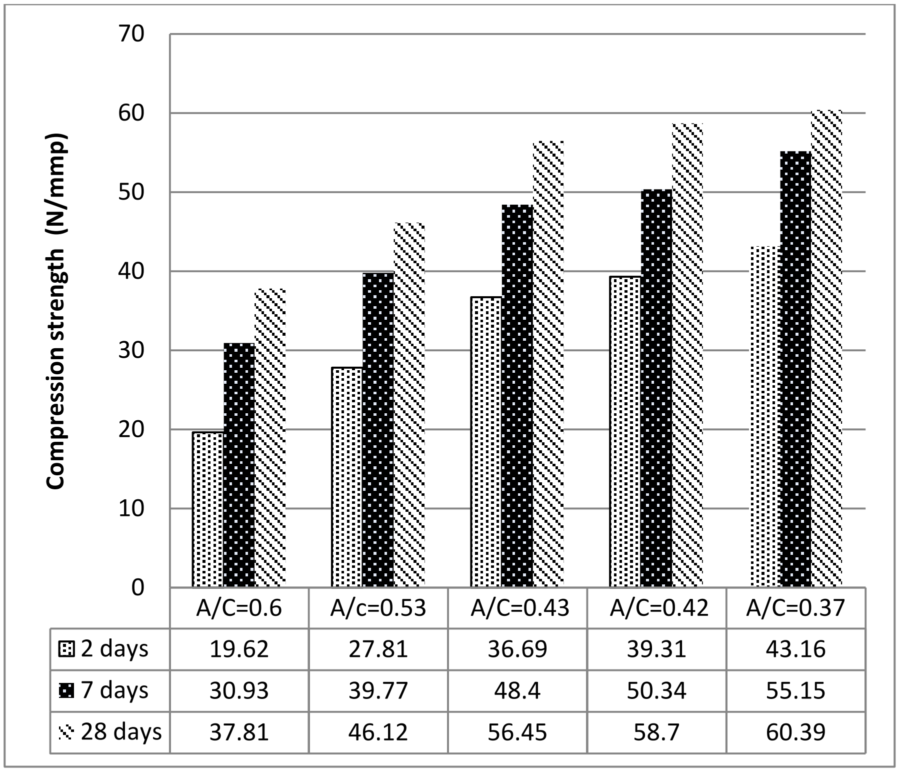
Cement dosage (kg/m^3)	Slag dosage (kg/m^3)	A/C	Settlement (mm)	Density (kg/m^3)	Comments
170	100	0.59	120	2424	noncohesive concrete
189	111	0.50	150	2420	noncohesive concrete
214	126	0.43	145	2445	noncohesive concrete
233	137	0.41	150	2421	-
271	159	0.35	145	2443	-

The figures 29-31 show the variation of the compressive strength according to the A/C ratio.



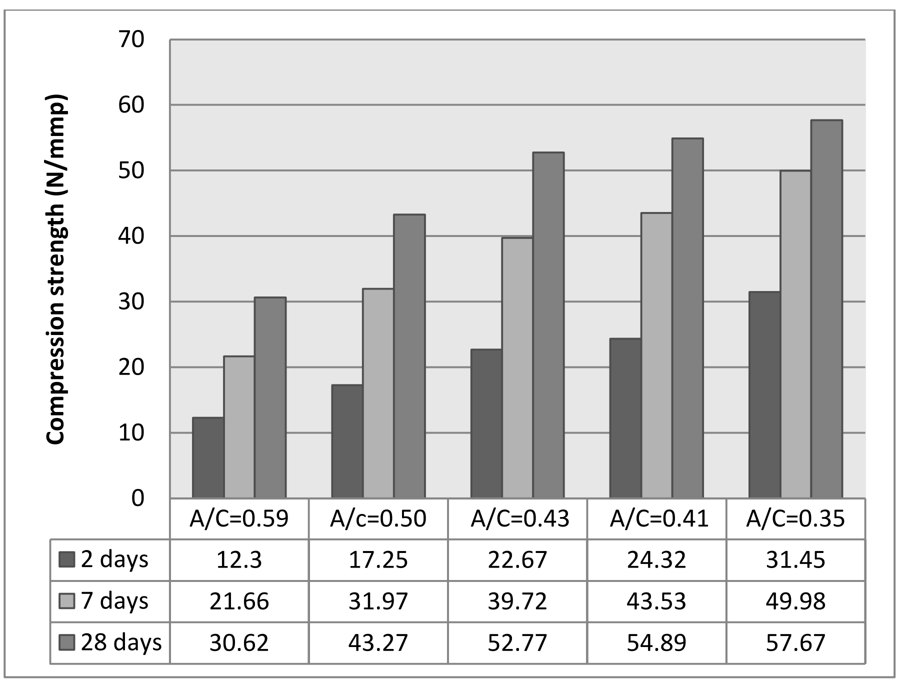
	A/C=0.64	A/c=0.54	A/C=0.46	A/C=0.44	A/C=0.4
2 days	19.96	27.51	36.55	40.96	45.32
7 days	30.93	39.77	48.4	50.34	55.15
28 days	36.85	48.51	54.72	55.74	61.9

Fig. 29. - The compressive strength values of concretes prepared with CEM I 42,5R



	A/C=0.6	A/c=0.53	A/C=0.43	A/C=0.42	A/C=0.37
2 days	19.62	27.81	36.69	39.31	43.16
7 days	30.93	39.77	48.4	50.34	55.15
28 days	37.81	46.12	56.45	58.7	60.39

Fig. 30. - The compressive strength values of concretes prepared with CEM I 42,5R and 10% slag



	A/C=0.59	A/c=0.50	A/C=0.43	A/C=0.41	A/C=0.35
2 days	12.3	17.25	22.67	24.32	31.45
7 days	21.66	31.97	39.72	43.53	49.98
28 days	30.62	43.27	52.77	54.89	57.67

Fig. 31. - The compressive strength values of concretes prepared with CEM I 42,5R and 37% slag

The diagrams presents in fig. 32-34 [10] were used to determine the coefficients A_0, B_0 for the reference concrete and A_a and B_a respectively for the concrete with addition.

The following results were obtained:

$f_0 = 100.6-98.92\ \omega_0$

$f_a = 99.28-100.8\ \omega_a$ (10% slag)

For the concrete with 10% slag addition, applying the relation (1):

$$k = \frac{(A_a - A_0)(1+a/c)}{B_a \text{ x } a/c} \text{x} \frac{1}{\omega_0} + \left[\frac{B_0(1+a/c)}{B_a} - 1\right] \text{x} \frac{1}{a/c} \quad (8)$$

where:
ω_0 - water / cement ratio of reference concrete without additions;
ω_a - water / cement ratio of cement with additions, $\omega_a = w_a/c_a$;
w_a - water quantity of concrete with additions (kg/m^3);
c_a - the amount of cement in the concrete with additions (kg/m^3);
a/c - addition / cement;
a - the amount of additions (kg/m^3)
f_a, f_0 – the compressive strengths of concrete (N/mm^2);
A_0, A_a, B_0, B_a - coefficients of the linear relation between the A/C ratios and the compressive strength of the concrete for the reference concrete and the concrete with additions.
The result is:

$k = -0.132/\omega_0 + 0.812$ (concrete with 10% slag) (9)

$k = -0.0473/\omega_0 + 0.524$ (concrete with 37% slag) (10)

Applying the relation (9) and (10) for different water/cement ratios ω_0 = 0.45; 0.5; 0.60, 0.65, a minimum value of the coefficient *k* of approx. 0.5, the k-value concept values varying between 0.52 and 0.62 [10].

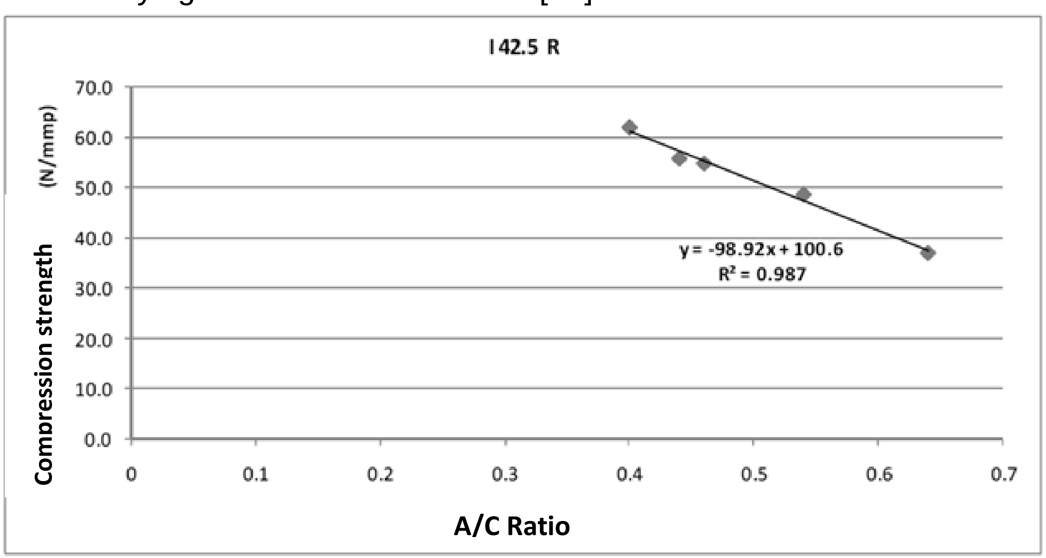


Fig. 32. - The compressive strength values at 28 days of concrete prepared with CEM I 42,5R [10]

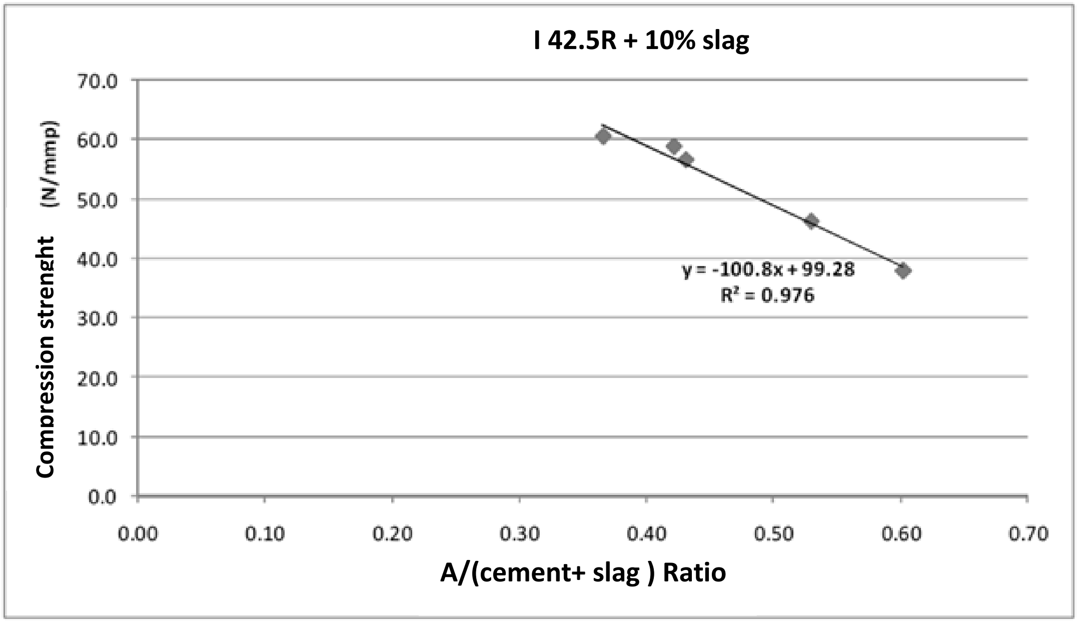


Fig. 33. - The compressive strength values after 28 days of concrete prepared with CEM I 42,5R and 10% slag [10]

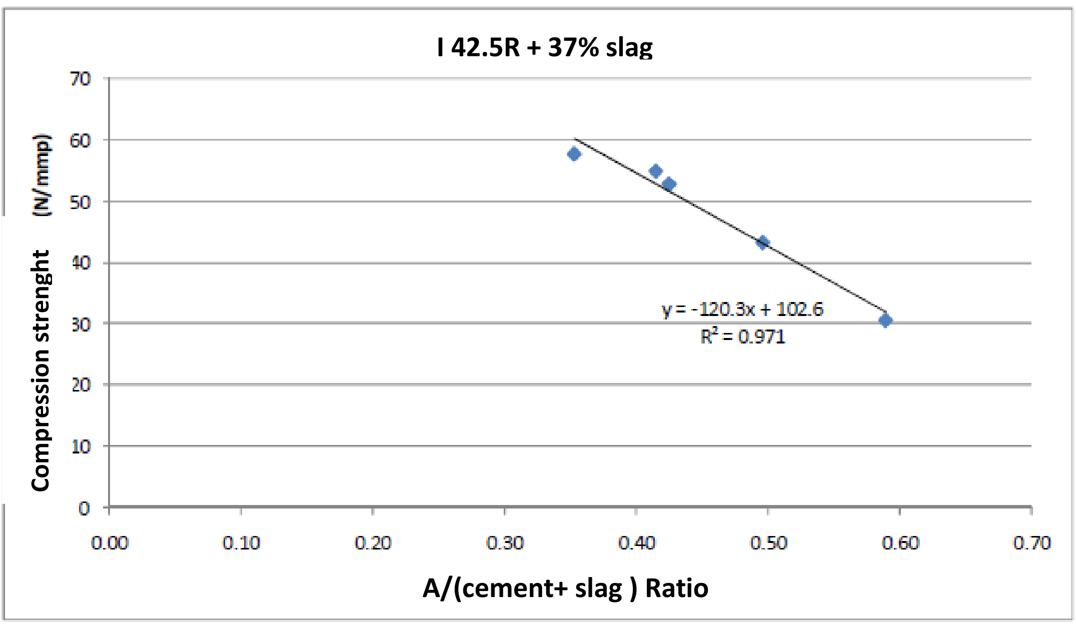


Fig. 34. - The compressive strength values after 28 days of concrete prepared with CEM I 42,5R and 37% slag [10]

2.2. Concrete compositions

Concrete compositions made with cement CEM II/A-S 42.5R and CEM I 42.5R and 10% slag, coefficient k = 0.5

Concrete mixtures were proposed for two prescribed compressive classes of C 16/20 with an equivalent ratio A/C = 0.65 and C20/25a with an equivalent ratio with an A/C = 0.50, having the compositions and characteristics shown in Tables 32 and 33 for which the strength and durability characteristics have been determined. The determination of the required amount of slag resulted from the choice of a cement dosage (260 kg/m^3 for C16/20 and 330 kg/m^3 for class C20/25a respectively) and considering the coefficient k = 0.5.

Concrete class C 16/20

- Concrete with cement type II/A-S 42,5R (10% slag) was prepared with cement dosage of 260 kg/m^3 and with A/C ratio of 0.65
- Concrete with 10% slag (k = 0.5) was prepared

c_1 +0.5 • 0.1 c_1 = 260 kg/m^3 c_1 = 248 kg/m^3, slag = 25 kg/m^3

Concrete class C 20/25a

- Concrete with cement type II/A-S 42,5R (10% slag) was prepared with cement dosage of 330 kg/m^3 and with A/C ratio of 0.5

- It was prepared concrete with 10% slag (k = 0.5)

c_1 +0.5 • 0.1 c_1 = 330 kg/m^3; c_1 = 314 kg/m^3, slag = 31 kg/m^2

Concrete compositions made with cement CEM III/A 42.5N-LH and CEM I 42.5R and 37% slag, coefficient k = 0.5

Concrete mixtures were proposed for two prescribed compressive classes of C 16/20 with an equivalent ratio A/C = 0.65 and C20/25a with an equivalent ratio with an A/C = 0.50, having the compositions and characteristics shown in Tables 32 and 33 for which the strength and durability characteristics have been determined. The determination of the required amount of slag resulted from the choice of a cement dosage (260 kg/m^3 for C16/20 and 330 kg/m^3 for class C20/25a respectively) and considering the coefficient k = 0.5.

Concrete class C 16/20

- Concrete with cement type III/A 42,5N-LH (37% slag) was prepared with cement dosage of 260 kg/m^3 and with A/C ratio of 0.65
- Concrete with 10% slag (k = 0.5) was prepared

c_1 +0.5 • 0.1 c_1 = 260 kg/m^3 c_1 = 219 kg/m^3, slag = 81 kg/m^3

Concrete class C 20/25a

- Concrete with cement type III/A 42,5N-LH (37% slag) was prepared with cement dosage of 330 kg/m^3 and with A/C ratio of 0.5

- It was prepared concrete with 10% slag (k = 0.5)

c_1 +0.5 • 0.1 c_1 = 330 kg/m^3; c_1 = 278 kg/m^3, slag = 103 kg/m^2

2.2.1. Fresh concrete

Table 32. - Compositions and characteristics of C16/20 concrete that was prepared with an A/C equivalent ratio to 0.65

Cement type /	Cement dosage (kg/m^3)	Slag dosage (kg/m^3)	Water (l)	Super plasticizer admixture (l)	Aggregate (kg)	0-4 mm type	4-8 mm type	8-16 mm type	Settlement (mm)	Density (kg/m^3)
CEM	248	25	166	2.57	1908	763	382	763	195	2361

I+10% slag									
CEM I+37% slag	219	81	166	2.83	1884	754	377	754	155	2372
CEM II/ A-S	260	0	166	2.45	1920	768	384	768	200	2338
CEM III/A	260	0	166	2.45	1920	768	384	768	200	2369

Table 33. - Compositions and characteristics of C25/30a concrete that was prepared with an A/C equivalent ratio to 0.5

Cement type	Cement dosage (kg/m^3)	Slag dosage (kg/m^3)	Water (l)	Super plasticizer admixture (l)	Air-entraining admixture (l)	Aggregate (kg)	0-4 mm type	4-8 mm type	8-16 mm type	Settlement (mm)	Density (kg/m^3)	Air (%)
CEM I+10% slag	314	31	161	3.26	0.691	1856	742	372	742	210	2192	10
CEM I+37% slag	278	103	161	3.59	0.762	1825	730	365	730	210	2151	10
CEM II/ A-S	330	0	161	3.11	0.66	1870	748	374	748	205	2180	9.2
CEM III/A	330	0	161	3.11	0.66	1870	748	374	748	235	2335	8.9

2.2.2. The compressive strength

The compressive strength after 28 days is considered appropriate for preliminary tests if the compressive strength values of the concrete obtained are greater than f_{ck} + 6...12 ($f_{cm} \geq f_{ck}$+6...12 according to SR EN 206 [1]), where f_{ck} is the characteristic strength corresponding to the concrete class and for current tests, if the average strength values are greater than f_{ck} + 4 ($f_{cm} \geq f_{ck}$ + 4 according to SR EN 206 [1]).

The results of the compression tests are presented in Tables 34 and 35.

Table 34. - The compressive strength values of concrete C16 / 20 prepared with an A/C equivalent ratio = 0.65

Cement type	Cement dosage (kg/m^3)	Slag dosage (kg/m^3)	Compressive strength (N/mm^2)				f_{cm2}/ f_{cm28}	The concrete class obtained	
			2 days		28 days			Current tests	Preliminary tests
CEM I+10% slag	248	25	18.07	18.50	26.16	26.16	0.71	C16/20	C16/20
			19.40		25.84				
			18.03		26.48				
CEM I+37% slag	219	81	17.32	17.43	26.14	25.76	0.67	C16/20	C16/20
			17.29		26.64				
			17.67		24.49				
CEM II/ A-S	260	0	16.74	16.77	27.40	28.81	0.58	C16/20	C16/20
			16.39		29.44				
			17.18		29.60				

CEM III/A	260	0	12.18 12.22 11.08	11.83	25.38 26.85 26.70	26.31	0.45	C16/20	C16/20

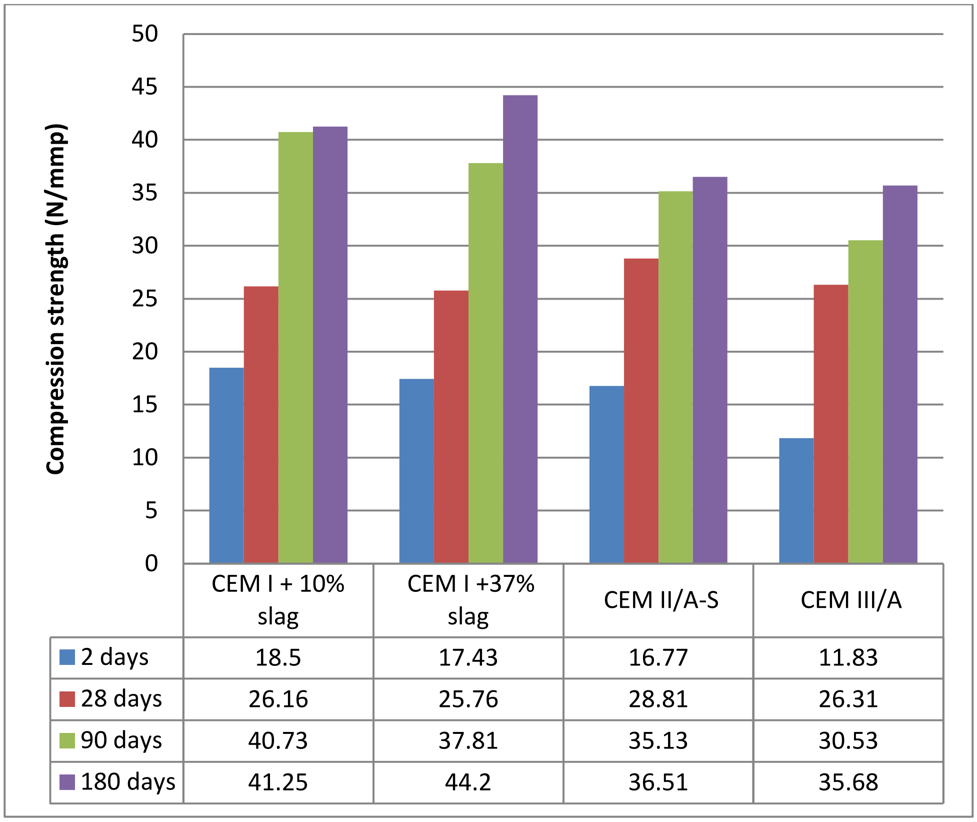


Figure 35. - The variation of compressive strength over time - for C16/20 concretes with ratio a/c = 0.65 depending on cement type

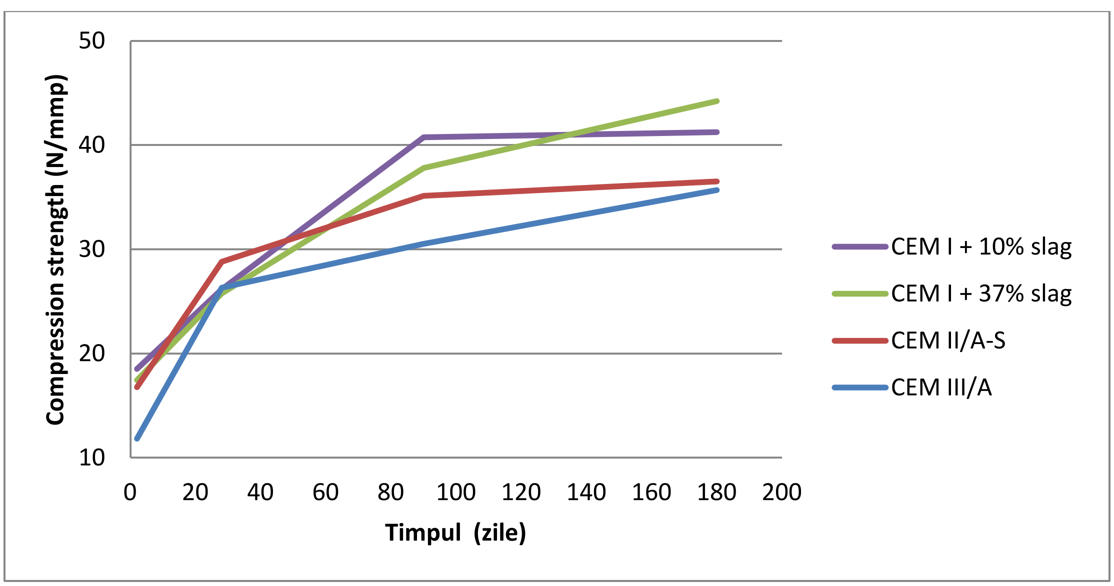


Figure 35'. - The variation of compressive strength over time - for C16/20 concretes with ratio a/c = 0.65 depending on cement type

Table 35. - Compressive strength values of concrete C20/25a prepared with an A/C equivalent ratio = 0.5

Cement type	Cement dosage (kg/m^3)	Slag dosage (kg/m^3)	Compressive strength (N/mm^2)				f_{cm2}/f_{cm28}	The concrete class obtained	
			2 days		28 days			Current tests	Preliminary tests
CEM I+10% slag	314	31	19.07	18.45	31.92	31.49	0.58	C20/25a	C20/25a
			18.15		31.57				
			18.14		30.97				
CEM I+37% slag	278	103	18.36	18.10	34.51	32.86	0.55	C20/25a	C20/25a
			18.09		31.99				
			17.84		32.08				
CEM II/ A-S	330	0	18.32	17.95	29.18	29.84	0.60	C20/25a	C16/20
			18.17		30.86				
			17.35		29.47				
CEM III/A	330	0	12.72	13.14	30.23	30.69	0.43	C20/25a	C16/20
			13.29		31.01				
			13.40		30.84				

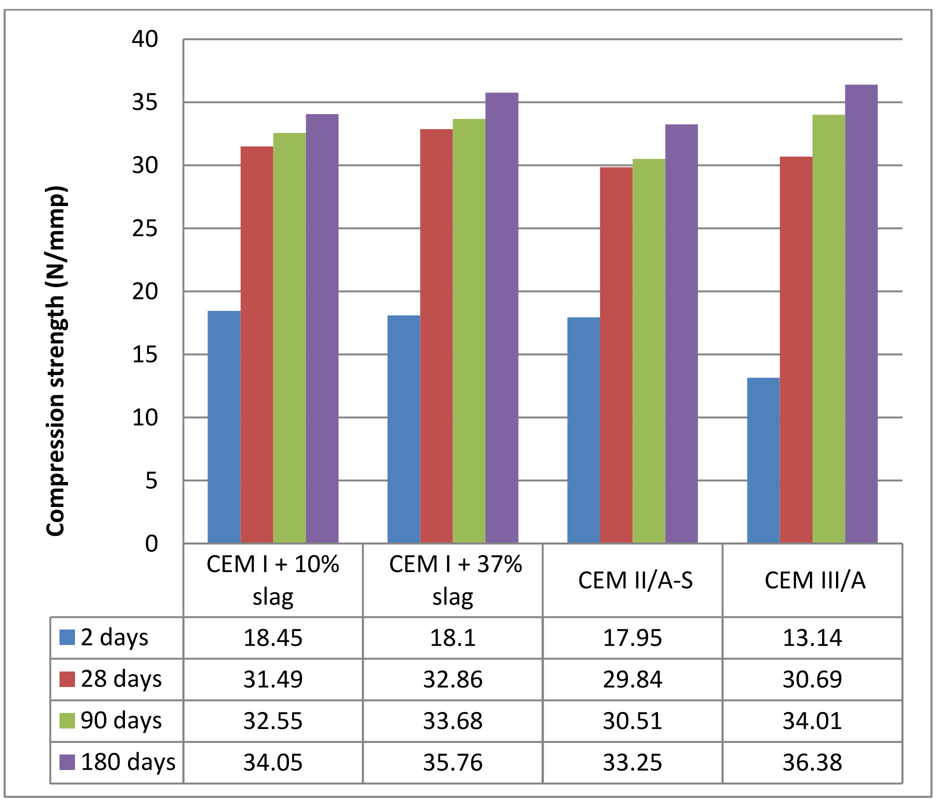


Figure 36. - The variation of compressive strength over time - for C20/25a concretes with ratio a/c = 0.50 depending on cement type

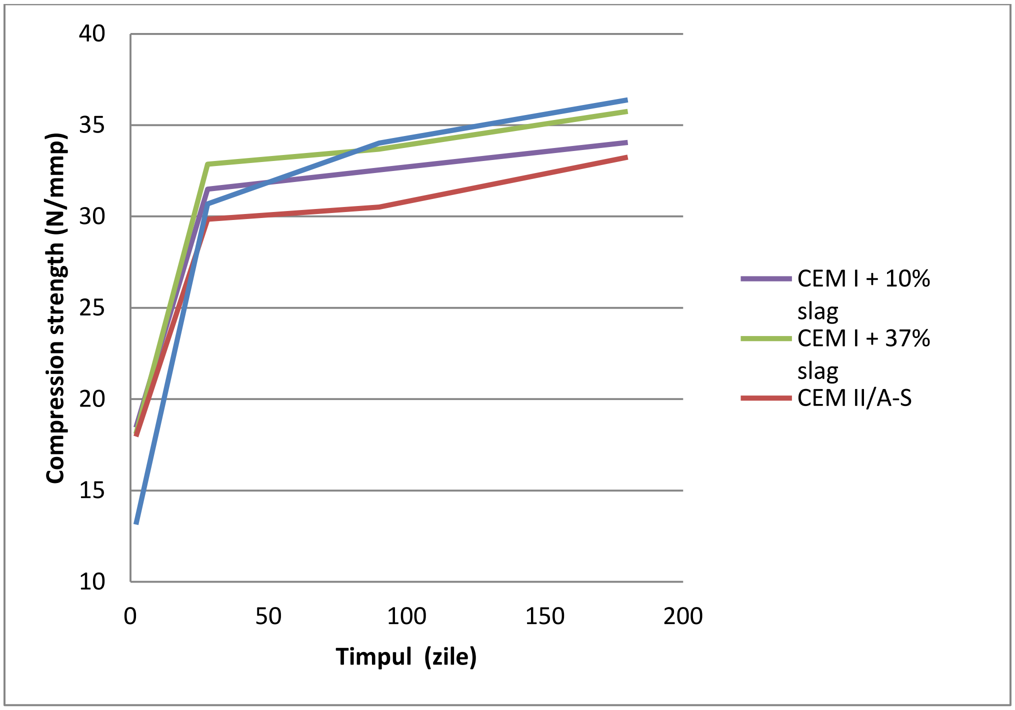


Figure 36'. - The variation of compressive strength over time - for C20/25a concretes with ratio a/c = 0.50 depending on cement type

2.2.3. Carbonation of concrete

The specimens used to determine the carbonation depth were maintained for 7 days in water and then under standardized laboratory conditions (65% humidity and 20°C temperature) until the test date. The evolution of carbonation was surveyed on specimens kept in the laboratory and examined at different times, 90 and 180 days.

Immediately after splitting, the concrete section was moistened with a 1% phenolphthalein alcohol solution. After applying the indicator solution, the carbonate area retains the initial color of the concrete and the non-carbonated area is red-violet (phenolphthalein changes color to pH <9.2). The depth of the carbonate layer of the concrete was determined according to SR CR 12793 [11].

Table 36 presents the results for carbonate depth values for the compressive strength class C16/20.

Table 36. - The values obtained for carbonate depth of concrete C16/20 in laboratory conditions

Cement type	Cement dosage (kg/m^3)	Slag dosage (kg/m^3)	Laboratory conditions 90 days / 7 days in water				Laboratory conditions 180 days / 7 days in water			
			average individual value	medium value	maximum individual value	medium value	average individual value	medium value	maximum individual value	medium value
CEM I+10% slag	248	25	1.10	1.20	3.17	3.12	3.45	3.13	4.66	5.01
			1.60		2.97		2.85		5.41	
			0.90		3.23		3.08		4.95	
CEM I+37% slag	219	81	1.90	1.43	4.69	3.98	3.45	3.39	6.91	6.48
			1.18		3.73		3.54		6.43	
			1.21		3.51		3.18		6.10	

CEM II/A-S	260	0	0.80	0.89	3.04	3.73	1.27	2.02	6.23	5.85
			1.10		4.18		2.62		5.51	
			0.78		3.96		2.18		5.81	
CEM III/A	260	0	5.10	5.36	6.99	8.15	5.95	6.13	10.69	9.73
			5.64		7.88		6.10		9.55	
			5.35		9.58		6.35		8.94	

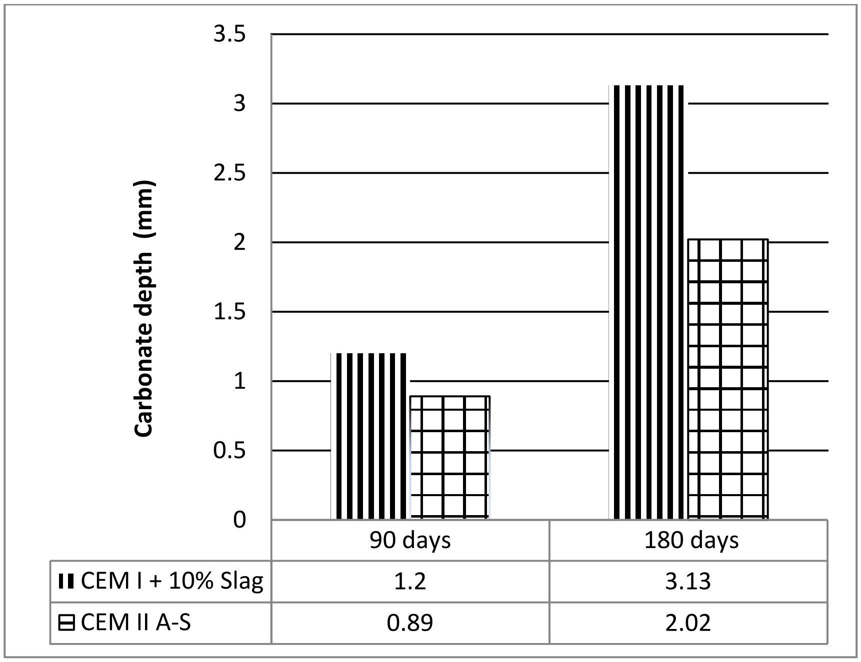


Fig. 37. - The carbonation depths of the C16/20 concrete with CEM I and 10% slag and concrete with CEM II/A-S

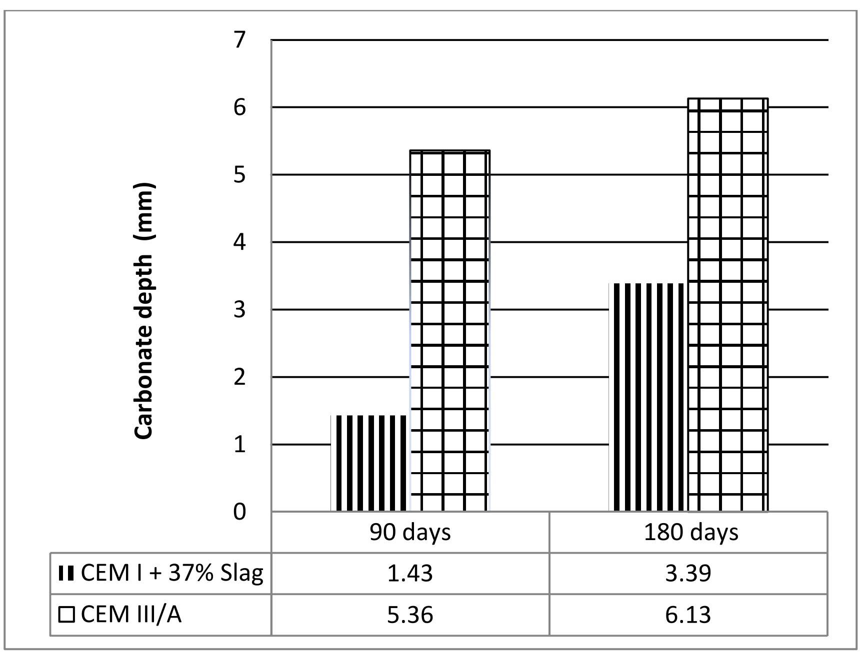


Fig. 38. - The carbonation depths of the C16/20 concrete with CEM I and 37% slag and concrete with CEM III/A.

2.2.4. Frost-thaw resistance

Repeated freezing / thawing behavior of concrete was studied by the "cube test" non-destructive method according to CEN/TS 12390-9 [12]. Tables 37 and 38 show the amount of scaling concrete for the prepared concrete at A/C = 0.5.

Table 37. - The amount of scaling concrete after 56 frost-thaw de-icing salt cycles, cubes of 100 mm

Number of cycles	7 cycles	14 cycles	28 cycles	56 cycles	Total scaling concrete amount after 56 cycles , g	Reducing the mass of the concrete specimen after 56 cycles	
Cement type	Scaling concrete amount, g	Scaling concrete amount, g	Scaling concrete amount, g	Scaling concrete amount, g		**P, %**	**Average P, %**
CEM II/A-S	0.12	0.22	0.42	1.34	2.10	0.10	
	0.14	0.18	0.74	2.36	3.42	0.16	
	0.10	0.19	0.80	1.23	2.32	0.11	
Residue	0.27	0.24	1.47	6.84	8.82	0.13	**0.12**
total	**0.63**	**0.83**	**3.43**	**11.77**	**16.66**	**0.49**	
CEM III/A	0.10	1.21	5.10	46.44	52.85	2.45	
	0.17	2.21	10.79	80.68	93.85	4.34	
	0.15	1.18	4.14	51.90	57.37	2.67	
Residue	0.47	6.27	34.77	215.46	256.97	3.97	**3.36**
total	**0.89**	**10.87**	**54.80**	**394.48**	**461.04**	**13.43**	
CEM I+10% slag	0.18	0.22	0.38	2.12	2.90	0.13	
	0.17	0.27	0.57	3.47	4.48	0.20	
	0.14	0.32	0.50	3.08	4.04	0.18	
Residue	0.30	0.39	1.32	7.71	9.72	0.15	**0.17**
total	**0.79**	**1.20**	**2.77**	**16.38**	**21.14**	**0.67**	
CEM I+37% slag	0.14	1.10	7.24	65.10	73.58	3.35	
	0.17	2.45	17.12	103.36	123.10	5.60	
	0.16	2.14	8.20	56.12	66.62	3.03	
Residue	0.33	6.24	53.04	283.74	343.35	5.21	**4.30**
total	**0.80**	**11.93**	**85.60**	**508.32**	**606.65**	**17.19**	

Table 38. - The amount of scaling concrete after 100 frost-thaw de-icing salt cycles, cubes of 100 mm

Number of cycles	100 cycles	Total scaling concrete amount after 100 cycles, g	Reducing the mass of the concrete specimen after 100 cycles	
Cement type	Scaling concrete amount, g		**P, %**	**Average P, %**
CEM II/A-S	3.56	5.66	0.26	
	8.89	12.31	0.56	
	2.67	4.99	0.23	
Residue	30.72	39.54	0.60	**0.41**
total	**45.84**	**62.50**	**1.65**	
CEM III/A	10.30	63.15	2.93	
	7.06	100.91	4.67	
	4.50	61.87	2.88	
Residue	9.66	266.63	4.12	**3.65**
total	**31.52**	**492.56**	**14.59**	

CEM I+10% slag	2.42	5.32	0.24	
	11.92	16.40	0.74	
	4.36	8.40	0.38	
Residue	43.23	52.95	0.80	**0.54**
total	**61.93**	**83.07**	**2.17**	
CEM I+37% slag	12.28	85.86	3.91	
	15.79	138.89	6.32	
	9.36	75.98	3.45	
Residue	38.58	381.93	5.79	**4.87**
total	**76.01**	**682.66**	**19.47**	

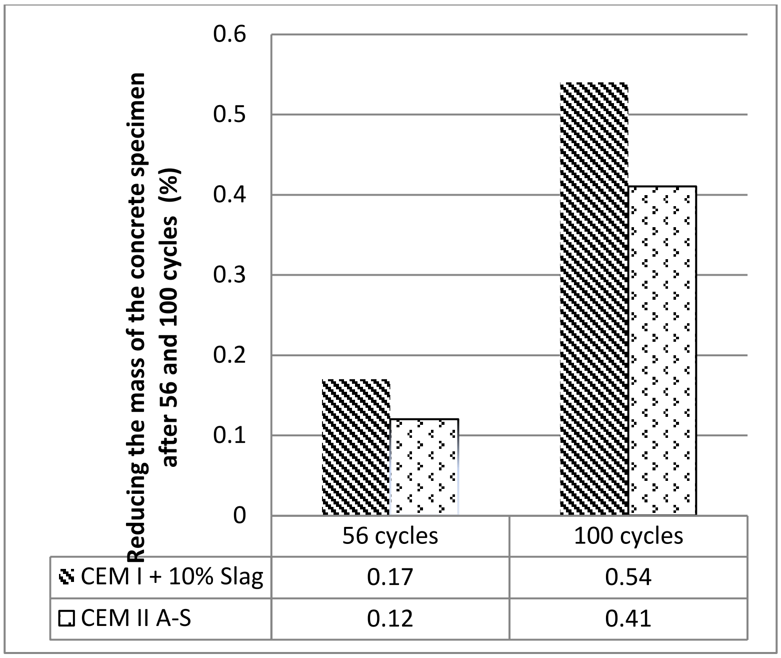


Fig. 39. - Reducing the mass of the C20/25a concrete specimen after 56 and 100 frost-thaw de-icing salt cycles - concrete with CEM I and 10% slag and concrete with CEM II/A-S

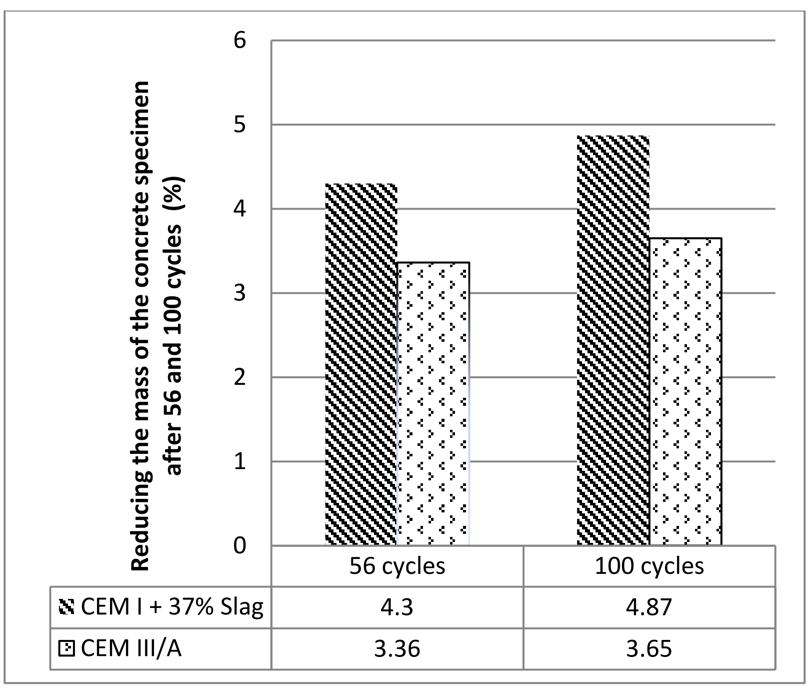


Fig. 40. - Reducing the mass of the C20/25a concrete specimen after 56 and 100 frost-thaw de-icing salt cycles, concrete with CEM I and 37% slag and concrete with CEM III/A

2.3. Applying performance methods

2.3.1. Carbonation of concrete

2.3.1.1. "European"method

Analyzing the aspects of carbonation resistance related to the equivalent durability procedure of the European norm CEN/TC104/SC1-N 703 [2], a comparison was made between concrete with cement CEM I + 10% slag considered as candidate concrete and concrete with cement CEM II/A-S being the reference concrete (table 41) and between concrete with cement CEM I + 37% slag considered as candidate concrete and concrete with cement CEM III/A being the reference concrete (table 42).

The measured value of the carbonate depth of the candidate concrete must be less than or equal to the reference concrete

$$\pm \frac{1}{\sqrt{2}}\sqrt{((2.33\sigma_R)^2 - (2.33\sigma_r)^2\left(\frac{n-1}{n}\right))} \qquad (11)$$

taking into account the mean values at 90 and 180 days for n≥3. where:
σ_r - the mean standard deviation for candidate concrete was considered;
σ_R - the average standard deviation for reference concrete was considered.

2.3.1.2. Dutch method

Analyzing the aspects of carbonation resistance related to the equivalent concrete performance concept of the Dutch normative VC12 WG4 [3], a comparison was made between concrete with cement CEM I+10% slag as candidate concrete and concrete with cement CEM II/A-S being as a reference concrete (table 41) and between concrete with cement CEM I + 37% slag considered as candidate concrete and concrete with cement CEM III/A being the reference concrete (table 42).

For each aspect of durability, the assessment was based on the evaluation parameter Tj:

$$T_j = \sqrt{\frac{[\, m_r - \frac{m_t}{1+0.01 d_j}]}{s/\sqrt{n}}} \qquad (12)$$

where: $$s = \sqrt{\{\, s_r^2 + \frac{s_t^2}{(\,1+0.01\, d_j)^2}\,\}} \qquad (13)$$

where:

m_r is the average test result of the n samples of the reference concrete;
m_t - the average test result of the n samples of the test concrete;
s_r - the standard deviation of the averages per sample of the reference concrete;

s_t - the standard deviation of the averages per sample of the test concrete;
n - the number of samples;

dj - the limit value of the durability aspect j, as shown in Table 39.

Table 39. - Limit values for " dj "

Durability aspect j	Difference d [%] that leads to rejection with a probability of 90%
Carbonation	+30
Chloride ingress cloruri	+30
Frost-thaw de-icing salt resistance	+30
Seawater resistance	+40
Sulphate resistance	+40

For approval T_j should be larger than the limit values shown in table 40.

Table 40. - Limit values for " Tj "

Number of samples (n)	Limit value T_j
3	1.533
4	1.440
5	1.397
6	1.372
7	1.356
8	1.345
9	1.337
10	1.330
11	1.325
12	1.321

For efficacy, Tj > 1.533 when n = 3 and dj = 30.

2.3.1.3. Synthesis of the obtained results

Table 41 and 42 shows the results obtained by applying the two performance methods.

Table 41. - Carbonation performance analysis for concrete C16/20 prepared with CEM I+10% slag taking as reference the concrete prepared with CEM II/A-S

<table>
<tr><td>Normative</td><td colspan="2">Carbonation of concrete</td></tr>
<tr><td rowspan="4">European document CEN/TC104/SC1-N 703 [7]</td><td colspan="2">Candidate concrete value ≤ reference concrete value
$\pm \frac{1}{\sqrt{2}}\sqrt{((2.33\sigma_R)^2 - (2.33\sigma_r)^2\left(\frac{n-1}{n}\right))}$ unde n ≥ 3</td></tr>
<tr><td>Laboratory conditions 90 days</td><td>m_r = 1.20 (candidate concrete);
m_R = 0.89 (reference concrete);
σ_r = 0.36; σ_R = 0.18</td></tr>
<tr><td>Criterion</td><td>0
$1.20 \le 0.89 + \frac{1}{\sqrt{2}}\sqrt{((2.33x0.18)^2 - (2.33x0.36)^2\left(\frac{3-1}{3}\right))}$</td></tr>
<tr><td>Laboratory</td><td>m_r = 3.13 (candidate concrete);</td></tr>
</table>

	conditions 180 days	m_R = 2.02 (reference concrete); σ_r = 0.30; σ_R = 0.69
	Criterion	0 $3.13 \le 2.02 + \frac{1}{\sqrt{2}}\sqrt{((2.33x0.69)^2 - (2.33x0.30)^2\left(\frac{3-1}{3}\right))}$=3.07
Dutch normative VC12 WG4 [8]	Tj = $\frac{\left[mr - \frac{mt}{1+0.01xdj}\right]}{s/\sqrt{n}}$, unde s = $\sqrt{sr^2 + \frac{st^2}{(1+0.01dj)^2}}$	
	Laboratory conditions 90 days	m_r = 1.20 (candidate concrete); m_R = 0.89 (reference concrete); s_t = 0.36; s_r = 0.18; s=0.33; T_j <0
	Criterion	0 $T_j = \frac{[mr - \frac{mt}{1+0.01xdj}]}{s/\sqrt{n}} = \frac{[0.89 - \frac{1.20}{1+0.01x30}]}{0.33/\sqrt{3}} < 0$
	Laboratory conditions 180 days	m_r = 3.13 (candidate concrete); m_R = 2.02 (reference concrete); s_t = 0.30; s_r = 0.69; s=0.73; T_j <0
	Criterion	0 $T_j = \frac{[mr - \frac{mt}{1+0.01xdj}]}{s/\sqrt{n}} = \frac{[0.89 - \frac{1.20}{1+0.01x30}]}{0.33/\sqrt{3}} < 0$

Legend: X is the achieved criterion;
0 - unachieved criterion.

Table 42. - Carbonation performance analysis for concrete C16/20 prepared with CEM I+37% slag taking as reference the concrete prepared with CEM III/A

Normative	Carbonation of concrete	
European document CEN/TC104/SC1-N 703 [7]	Candidate concrete value ≤ reference concrete value $\pm \frac{1}{\sqrt{2}}\sqrt{((2.33\sigma_R)^2 - (2.33\sigma_r)^2\left(\frac{n-1}{n}\right))}$ unde n ≥ 3	
	Laboratory conditions 90 days	m_r = 1.43 (candidate concrete); m_R = 5.36 (reference concrete); σ_r = 1.41; σ_R = 0.27
	Criterion	0 $1.43 \le 5.36 - \frac{1}{\sqrt{2}}\sqrt{((2.33x0.27)^2 - (2.33x0.41)^2\left(\frac{3-1}{3}\right))}$
	Laboratory conditions 180 days	m_r = 3.39 (candidate concrete); m_R = 6.13 (reference concrete); σ_r = 0.19; σ_R = 0.20
	Criterion	X $3.39 \le 6.13 - \frac{1}{\sqrt{2}}\sqrt{((2.33x0.20)^2 - (2.33x0.19)^2\left(\frac{3-1}{3}\right))}$=5.91
Dutch normative VC12 WG4 [8]	Tj = $\frac{\left[mr - \frac{mt}{1+0.01xdj}\right]}{s/\sqrt{n}}$, unde s = $\sqrt{sr^2 + \frac{st^2}{(1+0.01dj)^2}}$	
	Laboratory conditions	m_r = 1.43 (candidate concrete); m_R = 5.36 (reference concrete);

	90 days	s_t = 0.41; s_r = 0.27; s=0.41;
	Criterion	X $T_j = \frac{[mr - \frac{mt}{1+0.01xdj}]}{s/\sqrt{n}} = \frac{[5.36 - \frac{1.43}{1+0.01x30}]}{0.41/\sqrt{3}}$ = 17.83 > 1.533
	Laboratory conditions 180 days	m_r = 3.39 (candidate concrete); m_R = 6.13 (reference concrete); s_t = 0.19; s_r = 0.20; s=0.25;
	Criterion	X $T_j = \frac{[mr - \frac{mt}{1+0.01xdj}]}{s/\sqrt{n}} = \frac{[6.13 - \frac{3.39}{1+0.01x30}]}{0.25/\sqrt{3}}$=24.58>1.533

Legend: X is the achieved criterion;
0 - unachieved criterion.

2.3.2. Frost-thaw resistance

2.3.2.1. "European" method

Analyzing the aspects of frost-thaw de-icing salt resistance to the equivalent durability procedure of the European norm CEN/TC104/SC1-N 703 [7], a comparison was made between concrete with cement CEM I+10% slag as candidate concrete and concrete with cement CEM II/A-S being the reference concrete (Table 43) and between concrete with cement CEM I + 37% slag considered as candidate concrete and concrete with cement CEM III/A being the reference concrete (Table 44).

2.3.2.2. Dutch method

Considering the values obtained for reducing the mass of concrete samples after 56 frost-thaw de-icing salt cycles (Table 37) and 100 frost-thaw de-icing salt cycles (Table 38), the same comparison was made between the concrete with CEM I+10% slag considered as candidate concrete and concrete with CEM II/A-S being reference concrete according to the Dutch norm VC12 WG4 [8] (Table 43) and between the concrete with CEM I+37% slag considered as candidate concrete and concrete with CEM III/A being reference concrete according to the Dutch norm VC12 WG4 [8] (Table 44).

2.3.2.3. Synthesis of the obtained results

Table 43 and 44 shows the results obtained by applying the two performance methods.

Table 43. - The performance analysis for concrete C20/25a prepared with CEM I+10% slag taking as reference concrete prepared with CEM II/A-S, after 56 and 100 freeze-thaw with de-icing salt cycles

Normative	Frost-thaw de-icing salt resistance of concrete	
European document CEN/TC104/SC1-N 703 [7]	Candidate concrete value ≤ reference concrete value $\pm \frac{1}{\sqrt{2}}\sqrt{((2.33\sigma_R)^2 - (2.33\sigma_r)^2\left(\frac{n-1}{n}\right))}$ unde n ≥ 3	
	56 cycles	m_r = 7.05 (candidate concrete); m_R = 5.55 (reference concrete); σ_r = 0.81; σ_R = 0.71
	Criterion	0

		$7.05 \leq 5.55+\frac{1}{\sqrt{2}}\sqrt{((2.33x0.71)^2-(2.33x0.81)^2\left(\frac{3-1}{3}\right))}= 5.94$
	100 cycles	m_r = 27.69 (candidate concrete); m_R = 20.83 (reference concrete); σ_r = 5.72; σ_R = 4.05
	Criterion	0 $27.69 \leq 20.83 + \frac{1}{\sqrt{2}}\sqrt{((2.33x4.05)^2-(2.33x5.72)^2\left(\frac{3-1}{3}\right))}$
Dutch normative VC12 WG4 [8]	$Tj = \frac{\left[mr-\frac{mt}{1+0.01xdj}\right]}{s/\sqrt{n}}$, unde $s = \sqrt{sr^2+\frac{st^2}{(1+0.01dj)^2}}$	
	56 cycles	m_r = 7.05 (candidate concrete); m_R = 5.55 (reference concrete); s_t = 0.81; s_r = 0.71; s=0.94
	Criterion	0 $T_j = \frac{\left[mr-\frac{mt}{1+0.01xdj}\right]}{s/\sqrt{n}} = \frac{\left[5.55-\frac{7.05}{1+0.01x30}\right]}{0.94/\sqrt{3}}$ = 0.23 < 1.533
	100 cycles	m_r = 27.69 (candidate concrete); m_R = 20.83 (reference concrete); s_t = 5.72; s_r = 4.05; s=5.98
	Criterion	0 $T_j = \frac{\left[mr-\frac{mt}{1+0.01xdj}\right]}{s/\sqrt{n}} = \frac{\left[20.83-\frac{27.69}{1+0.01x30}\right]}{5.98/\sqrt{3}}$ < 0.

Legend: X is the achieved criterion;
0 - unachieved criterion.

Table 44. - The performance analysis for concrete C20/25a prepared with CEM I+37% slag taking as reference concrete prepared with CEM III/A, after 56 and 100 freeze-thaw with de-icing salt cycles

Normative	Frost-thaw de-icing salt resistance of concrete	
European document CEN/TC104/SC1-N 703 [7]	Candidate concrete value ≤ reference concrete value $\pm\frac{1}{\sqrt{2}}\sqrt{((2.33\sigma_R)^2-(2.33\sigma_r)^2\left(\frac{n-1}{n}\right))}$ unde n ≥ 3	
	56 cycles	m_r = 202.22 (candidate concrete); m_R = 153.71 (reference concrete); σ_r = 30.80; σ_R = 22.45
	Criterion	0 $202.22 \leq 153.71 + \frac{1}{\sqrt{2}}\sqrt{((2.33x22.45)^2-(2.33x30.8)^2\left(\frac{3-1}{3}\right))}$
	100 cycles	m_r = 227.55 (candidate concrete); m_R = 164.18 (reference concrete); σ_r = 33.83; σ_R = 22.18
	Criterion	0 $227.55 \leq 164.18 +\frac{1}{\sqrt{2}}\sqrt{((2.33x22.18)^2-(2.33x33.83)^2\left(\frac{3-1}{3}\right))}$
Dutch normative VC12 WG4 [8]	$Tj = \frac{\left[mr-\frac{mt}{1+0.01xdj}\right]}{s/\sqrt{n}}$, unde $s = \sqrt{sr^2+\frac{st^2}{(1+0.01dj)^2}}$	

	56 cycles	m_r = 202.22 (candidate concrete); m_R = 153.71 (reference concrete); s_t = 30.80; s_r = 22.45; s=32.64
	Criterion	0 $T_j = \frac{[\,mr - \frac{mt}{1+0.01xdj}]}{s/\sqrt{n}} = \frac{[\,153.71 - \frac{202.22}{1+0.01x30}]}{32.639/\sqrt{3}} < 0$
	100 cycles	m_r = 227.55 (candidate concrete); m_R = 164.18 (reference concrete); s_t = 33.83; s_r = 22.18; s=34.19;
	Criterion	0 $T_j = \frac{[\,mr - \frac{mt}{1+0.01xdj}]}{s/\sqrt{n}} = \frac{[\,164.18 - \frac{227.55}{1+0.01x30}]}{34.19/\sqrt{3}} < 0$

Legend: X is the achieved criterion;
0 - unachieved criterion.

2.4. Conclusions

1. Various methods for assessing the durability of concrete, descriptive and performance methods have been applied in the article. Methods have been applied to the case of a concrete with the same slag content but also in the cement and concrete composition respectively.

2. The activity index method allows the calculation of an A/C equivalent ratio when using mineral additions in concrete. By applying the method, it was possible to determine the *k*-value concept and based on it, concrete compositions with additions were made.

3. In terms of compressive strength, it was similar for the two compositions, these being in the same compressive strength class. Applying performance methods to determine carbonation resistance using composition with cement CEM II/A-S and CEM III/A as reference cements, highlights that concrete with the same amount of slag but in concrete does not achieve similar performance. The same conclusions resulted from applying the frost-thaw resistance of concrete.

4. In conclusion, it can be stated that prescriptive methods of "deem to satisfy" in general, but also customized to the A/C equivalent ratio concept in the case of use of the mineral additions, should be completed with applying performance methods in order to ensure the same lifetime of concrete constructions.

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