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PREDICTIONS OF THE MECHANICAL PERFORMANCE OF CONCRETE MADE WITH TERNARY CEMENTS

Kim-Séang Lauch [(1)], Vinciane Dieryck [(1)], Benoit Parmentier [(1)]

(1) Belgian Building Research Institute, Limelette, Belgium

Abstract

To assess the suitability for use of composite cements for concrete, the mechanical performance of concrete made with ternary cements containing Portland cement (OPC), blast furnace slag (S) or fly ash (FA) and limestone filler (L) has been compared to predictive models from Eurocode 2. Eight blended cements of different proportions of OPC (from 45% to 65%), S and FA (from 10% to 30%) and L (from 5% to 35%) were selected alongside five reference cements (CEM I 52.5 R HES, CEM II/B-M (L-S) 32.5 R, CEM II/B-M (LL-S-V) 32.5 N, CEM II/B-V 32.5 R and CEM III/A 42.5 N LA). Two types of mixes were produced using constant water to cement (*w/c*) ratios of 0.45 and 0.55 and cement contents of 340 kg/m³ and 300 kg/m³ respectively. The results indicate that setting time and mechanical properties (compressive and indirect tensile strengths, modulus of elasticity as well as total shrinkage and creep) are mainly proportional to the clinker content and inversely proportional to the limestone filler content. Ternary cements containing slag seem overall to give a better concrete mechanical performance than those containing fly ash. The results show that the predictive models may not be suitable for most tested cements.

1. Introduction

As the production of Portland cement is responsible for significant amount of CO_2 emissions, replacing the clinker with by-products such as blast furnace slag (S) and fly ash (FA) is a compelling solution to reduce the environmental impact of concrete. The production of these supplementary cementitious materials (SCMs) tends to decrease in Belgium, while limestone filler (L) is abundantly available. Several studies investigated the synergetic action of these SCMs [1–5]. It has been found that a small dosage of limestone filler could have a beneficial effect on the early age properties of concrete, while fly ash and blast furnace slag contribute to the long-term mechanical properties as pozzolanic reaction rate is slower than hydration of Portland cement. These antagonist properties of limestone filler and fly ash or slag make these ternary mixes particularly interesting. The European standard EN 197-1 [6] includes requirements for cements for use in concrete. The aim of this study is to evaluate the performance of concrete made with newly developed ternary cements OPC-S-L and OPC-FA-L to assess their suitability for use for concrete. This approach is inspired by the methodology from Belgian standard NBN B 15-100 [18]. This paper focuses on the comparison of the mechanical performance of concrete made with ternary cements with the predictive models from Eurocode 2 (EC2) [19]. Fresh properties and setting time, compressive and indirect tensile strengths, modulus of elasticity, shrinkage and creep tests were carried out. Durability study is the subject of a companion paper by the same authors [7].

2. Experimental program

2.1 Materials

Composite cements were prepared by mixing CEM I 52.5 R HES (OPC), ground granulated blast-furnace slag (S), fly ash (FA) and limestone filler (L). As a set regulator, gypsum had been added with a concentration to obtain a total sulfate content of 3%. Chemical and mineralogical characterization showed that the studied SCMs meet all the requirements from standard EN 197-1, regarding the properties of the cement constituents [7]. Then the physical, chemical and mechanical properties of the ternary cements, with different proportions of Portland cement, blast-furnace slag or fly ash and limestone were determined. Two series, presented in Tab. 1, had been conducted. In series 1, ternary blended cements with slag (OPC-S-L) were studied, with reference cements CEM I 52.5 R HES, CEM II/B-M (L-S) 32.5 R and CEM III/A 42.5 N LA. In series 2, ternary cements with fly ash (OPC-FA-L) were investigated with reference cements CEM I 52.5 R HES, CEM II/B-M (LL-S-V) 32.5 N and CEM II/B-V 32.5 R. All the ternary cements, except CEM 3 [45OPC 30FA 25L], meet the requirements from the standard EN 197-1, regarding the compressive strength, initial setting time and soundness. The results show that ternary OPC-S-L cements reach higher compressive strength classes than OPC-FA-L cements.

2.2 Concrete mixes

Two types of concrete have been chosen, named T(0.45) and T(0.55) with *w/c* ratios of 0.45 and 0.55 respectively. The desired slump and the aimed compressive strength class are 120 ± 30 mm, C35/45 and 180 ± 30 mm, C25/30 respectively for the two types. The concrete mixes have been formulated so that the grading curve follows the limits specified in the standard EN 480-1 [8] (see Fig. 1), as specified by standard NBN B 15-100. There exists a slight difference between the two series: series 2 contains more fines below 0.5 mm. A polycarboxylic-ether superplasticiser has been used. The concrete mixes are more thoroughly described in the companion paper [7]. The concrete samples are conserved during 24h at a temperature of 20 ± 2°C. After removal, the specimens are placed in water at the same temperature for curing during a variable period depending on the test.

2.3 Testing methods

Fresh properties tests consisted in measuring the slump, density and air content according to standards EN 12350-2 [9], EN 12350-6 [10] and EN 12350-7 [11] respectively.
Setting time was carried out on concrete according to the Kelly-Bryant method described in a Belgian standard NBN B 15-204 [12]. This pull-out test was carried out on two moulds of 15 cm x 15 cm x 60 cm size, equipped with 10 steel rods of 10 mm diameter and 220 mm length. About 4 hours after casting, the rods were pulled out one after another at regular intervals and the pull-out forces or bonding strengths are recorded.

Table 1: Composition (% by mass), Blaine surface and strength class for cements, dosage of superplasticiser (% by mass cement) and fresh properties (slump, density and air content) for concretes of series 1 (OPC-S-L) and series 2 (OPC-FA-L).

	OPC (%)	S (%)	FA (%)	L (%)	Blaine surface (cm²/kg)	Strength class (mortar)	Superplasticiser PCE (%)		Slump (mm)		Density (kg/m³)		Air content (%)	
							T(0.45)	T(0.55)	T(0.45)	T(0.55)	T(0.45)	T(0.55)	T(0.45)	T(0.55)
Series 1 (OPC-S-L)														
CEM I 52.5 R HES (batch 1)	100	0	0	0	4780	52.5 R	0.80	0.25	140	175	2396	2398	3.0	1.9
CEM II/B-M (L-S) 32.5 R	74	12	0	14	3737	32.5 R	0.15	0.20	125	180	2372	2401	3.5	1.9
CEM III/A 42.5 N LA	59	41	0	0	4591	42.5 N	0.30	0.20	120	190	2378	2402	3.2	1.9
CEM 1 [65OPC 30S 5L]	65	30	-	5	4770	52.5 N	0.40	0.25	118	185	2417	2388	2.3	1.9
CEM 3 [45OPC 30S 25L]	45	30	-	25	4630	42.5 N	0.25	0.20	108	180	2394	2408	(*)	(*)
CEM 6 [50OPC 20S 30L]	50	20	-	30	4430	42.5 N	0.35	0.20	130	180	2409	2409	(*)	(*)
CEM 10 [55OPC 10S 35L]	55	10	-	35	4260	42.5 R	0.30	0.20	113	185	2384	2398	(*)	(*)
Series 2 (OPC-FA-L)														
CEM I 52.5 R HES (batch 2)	100	0	0	0	4930	52.5 R	2.00	1.30	160	170	2403	2396	2.3	1.8
CEM II/B-M (LL-S-V) 32.5 N	71	7	9	13	3360	32.5 N	1.00	0.60	90	160	2399	2385	2.2	1.6
CEM II/B-V 32.5 R	78	0	22	0	2960	32.5 R	0.85	0.60	95	165	2354	2357	3.3	1.5
CEM 1 [65OPC 30FA 5L]	65	-	30	5	4110	52.5 N	1.20	0.80	133	190	2369	2375	2.1	1.4
CEM 3 [45OPC 30FA 25L]	45	-	30	25	4120	-	0.70	0.60	135	160	2381	2372	1.7	1.5
CEM 6 [50OPC 20FA 30L]	50	-	20	30	4230	32.5 R	0.70	0.60	100	190	2392	2359	2.2	1.4
CEM 10 [55OPC 10FA 35L]	55	-	10	35	4440	32.5 R	1.00	0.70	110	190	2378	2373	2.0	1.5

(*) Not measured.

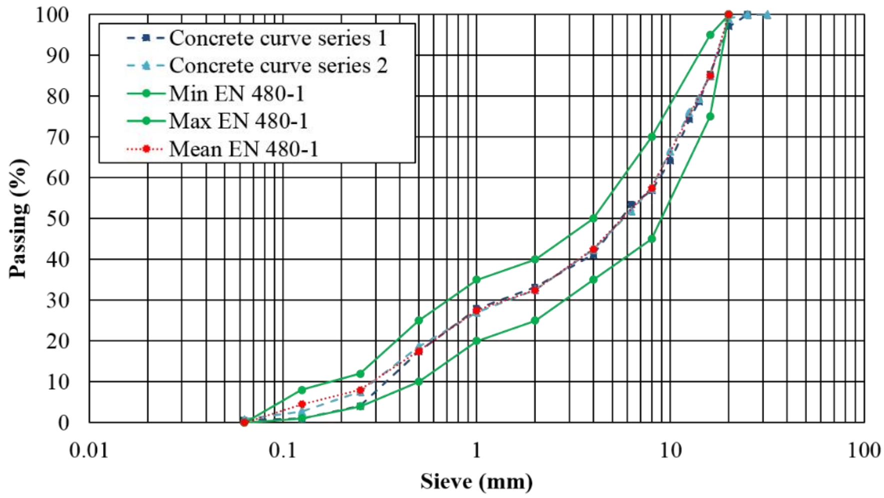

Figure 1: Grading curves for concretes (series 1 and 2) and the limits of standard EN 480-1.

Compressive strength was measured at 2, 7, 28 and 91 days, according to EN 12390-3 [13], on three cubes of 15 cm side. Indirect tensile strength was measured at 28 days according to EN 12390-6 [14], by splitting six core samples of 113 mm diameter and 113 mm length.
The (static compression) modulus of elasticity, total shrinkage and creep were measured according to Belgian standards NBN B 15-203 [15], NBN B 15-216 [16] and NBN B 15-228 [17] respectively. Each test used three prisms of 10 cm x 10 cm x 40 cm side. The samples were cured for 7 days under water at 20°C and then conditioned in a climatic chamber at 20°C and 60% relative humidity for 21 days. The shrinkage deformations $\varepsilon_{shrinkage}$ are measured from day 7 to day 91, and to the age of 7 months for the compositions where creep is also measured. The modulus of elasticity was measured at 28 days ($E_{cm,28}$) with a load applied at a third of the concrete compressive strength. The same load is applied to creep samples since day 28 for 6 months. The creep deformations ε_{creep} and the creep coefficient φ were then calculated by the following equations:

$$\varepsilon_{creep} = \varepsilon_{total} - \varepsilon_{shrinkage} - \varepsilon_{initial} \quad (1)$$

$$\varphi(t) = \frac{\varepsilon_{creep}}{\varepsilon_{initial}} \quad (2)$$

$$\varepsilon_{initial} = \frac{F_i \,/\, S}{E_{cm,28}} \quad (3)$$

Where F_i is the initial applied force and S the surface where the force is applied (100 mm x 100 mm in this case).

2.4 Evaluation approach

The evaluation approach of the performance of concrete is inspired by the methodology from Belgian standard NBN B 15-100 [18]. For the mechanical properties, upper and lower boundaries from predictive models from Eurocode 2 (EC2) [19] are specified in which the results should lie. The values in bold in the tables 2 and 3 are outside the limits. The influence of the composition on the concrete properties was analysed by correlation coefficients (R).

3. Results and discussion

3.1 Fresh properties

The dosages of superplasticiser (PCE) and the results of slumps, density and air content are presented in Tab. 1. In series 1, the dosage for the ternary cements OPC-S-L ranges from 0.2 – 0.4%, while in series 2, it ranges from 0.6 – 1.2% (by mass of cement). This difference could be explained by the difference in the grading curves of the concretes (see Fig. 1). Concretes from series 2 contain more fines, which could require a higher dosage of admixture. The air content is higher for a lower density and a higher dosage of PCE. In their compatibility study between polycarboxylate-based admixtures and blended-cement pastes, Alonso et al. [20] found that slag adsorbs less admixture and requires less PCE than fly ash to establish inter-particle repulsion. This could explain the better efficiency of PCE with slag (less dosage needed). The dosages of admixture are not excessive for concretes made with ternary cements. They stay in the recommended range from the manufacturer.

3.2 Setting time

The bonding strengths (single values) over time of series 1 and series 2 concretes are presented in Fig. 2 and Fig. 3. This method is also explained and compared to non-destructive (ultrasonic and electric) methods in the following papers [23, 24]. All ternary cements concretes, except CEM 3 [45OPC 30S 25L] show an evolution of the setting between the evolutions obtained by the reference concretes. In series 1, the evolution of setting of concretes made with OPC-S-L cements seems to be proportional to the limestone filler content, as CEM 1 [65OPC 30S 5L] concrete, with 5% of limestone filler, hardens quicker than CEM 10 [55OPC 10S 35L] concrete, with 35% of limestone filler. In series 2, it seems that the clinker content has more influence.

3.3 Compressive strength

The 28 days compressive strengths for series 1 and 2 concretes are presented in Tab. 2. The average compression strength $f_{cm,cube}$ was measured on three cubes of 15 cm side. The characteristic strength $f_{ck,cyl}$ is calculated from the following equation Eq. (4), according to the evaluation approach. This value is then compared to the aimed compressive strength (35 MPa for T(0.45) and 25 MPa for T(0.55) concretes).

$$f_{ck,cyl} = \frac{f_{cm,cube}}{1.2} - 8 \tag{4}$$

In series 1, CEM 1 and CEM 3 concretes reach the aimed values. In series 2, only CEM 1 concretes reach the aimed compressive strength classes. The difference between the two series for concretes with the same reference cement CEM I 52.5 R HES could be due to the difference in the grading curve. The results show that the compressive strength decreases with decreasing clinker content (correlation coefficient R = 0.9 in average) and increasing limestone filler content (R = -0.8). This could be explained by the dilution effect [2–5]. In series 1, CEM 10 [50OPC 10S 35L] concrete has the highest limestone filler content and presents the lowest strength. Concretes made with OPC-S-L cements present similar compressive strengths as the ones with reference concretes. In series 2, CEM 3 [45OPC 30FA 25L] concrete has the lowest clinker content and presents the lowest strength. Except for CEM 1 concrete, OPC-FA-L concretes present lower compressive strength than the reference concretes.

Table 2: 28 day compressive and indirect tensile strengths, modulus of elasticity and total shrinkage at 91 days for concretes of series 1 (OPC-S-L) and series 2 (OPC-FA-L). In bold: values that do not satisfy the criteria of the evaluation approach.

	Compressive strength (MPa)				Indirect tensile strength (MPa)		Modulus of elasticity (MPa)		Total shrinkage 91 days (µm/m)	
	$f_{cm,cube}$		$f_{ck,cyl}$							
	T(0.45)	T(0.55)	T(0.45)	T(0.55)	T(0.45)	T(0.55)	T(0.45)	T(0.55)	T(0.45)	T(0.55)
Series 1 (OPC-S-L)										
CEM I 52.5 R HES (batch 1)	72.6	57.0	52.5	39.5	5.40	(*)	40139	35485	438	468
CEM II/B-M (L-S) 32.5 R	45.7	37.2	**30.0**	**23.0**	(*)	(*)	35911	33852	350	343
CEM III/A 42.5 N LA	69.4	54.1	49.8	37.1	5.30	(*)	38837	35488	387	392
CEM 1 [65OPC 30S 5L]	68.0	50.7	48.7	34.3	(*)	(*)	38519	35378	369	417
CEM 3 [45OPC 30S 25L]	53.8	40.4	36.8	25.7	4.50	(*)	**38876**	35289	342	360
CEM 6 [50OPC 20S 30L]	49.9	36.5	**33.6**	**22.4**	(*)	(*)	**38095**	**35491**	344	357
CEM 10 [55OPC 10S 35L]	45.0	31.0	**29.5**	**17.8**	3.65	(*)	**37894**	**34553**	363	361
Series 2 (OPC-FA-L)										
CEM I 52.5 R HES (batch 2)	80.2	65.0	58.8	46.1	5.74	4.83	38123	**39729**	408	513
CEM II/B-M (LL-S-V) 32.5 N	47.9	34.8	**31.9**	**21.0**	**4.31**	**3.57**	36327	**34090**	426	425
CEM II/B-V 32.5 R	53.4	40.2	36.5	25.5	4.34	3.36	36998	33623	402	427
CEM 1 [65OPC 30FA 5L]	57.9	36.5	40.2	**22.4**	4.57	**3.65**	**35998**	34025	477	505
CEM 3 [45OPC 30FA 25L]	35.1	20.4	**21.2**	**9.0**	**3.40**	**2.79**	**33344**	**30279**	352	357
CEM 6 [50OPC 20FA 30L]	36.8	24.0	**22.7**	**12.0**	**3.46**	**2.81**	36037	**31454**	375	378
CEM 10 [55OPC 10FA 35L]	42.9	24.0	**27.8**	**12.0**	**3.84**	**3.08**	34605	**32195**	421	393

(*) Not measured.

De Weerdt [1] studied the synergetic effect between fly ash and limestone filler in ternary cements and found that the composition with 30% of fly ash and 5% of limestone filler was the optimum in terms of compressive strength. The evolutions of the strengths from 2 days old to 91 days old for T(0.45) concretes are shown in Fig. 4. At 2 days, OPC-S-L and OPC-FA-L cements have similar strengths. At 7 days and later ages, OPC-S-L cements present larger compressive strengths than OPC-FA-L cements (up to 35% higher for CEM 3 made with slag). This has already been observed previously because slag is not only pozzolanic but also hydraulic [3, 21]. This additional reactivity gives thus a less porous concrete than with fly ash.

3.4 Indirect tensile strength

The indirect tensile strengths at 28 days (mean of six individual values) are shown in Tab. 2. The results of ternary cements OPC-S-L and OPC-FA-L are in general lower than the ones of the reference concretes. As for the previous mechanical properties, the indirect tensile strength seems to be mainly influenced by the clinker (R = 0.9) and limestone filler (R = -0.8) contents. The evaluation approach defines two borders, based on $f_{cm,cube}$, which 5 of the 6 individual values have to be within:

$$f_{ct,sp,5\%} = 0.23\left(\frac{f_{cm,cube}}{1.2} - 8\right)^{2/3} \tag{5}$$

$$f_{ct,sp,95\%} = 0.43\left(\frac{f_{cm,cube}}{1.2} - 8\right)^{2/3} \tag{6}$$

Tab. 3 shows the six individual values as well as the corresponding borders for T(0.45) series 2 concretes. Regarding ternary OPC-FA-L cements, only CEM 1 satisfies the criteria. The values outside the borders (in bold) are all above the superior limit $f_{ct,sp,95\%}$. The few results for OPC-S-L cements shown in Tab. 2 satisfy the criteria. One can observe that indirect tensile strength at 28 days is higher than the predicted value for most cements. If this underestimation is confirmed in the long term, it might have an impact on the quantity of reinforcing bars, which is proportional to the tensile strength, to avoid brittle failure or even limit crack openings.

3.5 Modulus of elasticity

The results of modulus of elasticity are presented in Tab. 2. In series 1, the results of ternary OPC-S-L cements are similar to the reference cement CEM III/A 42.5 N LA. In series 2, the results of ternary OPC-FA-L cements are in general inferior to the reference cements. Again, the main factors influencing this property seem to be the clinker (R = 0.8) and limestone filler (R = -0.7) contents. Ternary cements OPC-S-L show higher values than OPC-FA-L cements (up to 14% for CEM 3 made with slag). The relation of modulus of elasticity with the compressive strength is presented in Fig. 5. The evaluation approach defines two borders:

$$E_{cm1} = 21\left(\frac{f_{cm,cube}/1.2 - 8}{10}\right)^{0.3} \tag{7}$$

$$E_{cm2} = 23\left(\frac{f_{cm,cube}/1.2 + 8}{10}\right)^{0.3} \tag{8}$$

The figure also shows the theoretical E-modulus from Eurocode 2 (see Eq. (9)), and borders of $E_{cm} \pm 30\%$ from the Model Code 2010 [22].

Table 3: 28 days indirect tensile strengths reached for type T(0.45) series 2 concretes (OPC-FA-L) and borders of the evaluation approach. In bold: values outside the borders.

	Indirect tensile strength at 28 days						Criteria (borders)	
	1	**2**	**3**	**4**	**5**	**6**	$f_{ct,sp,5\%}$	$f_{ct,sp,95\%}$
CEM I 52.5 R HES (batch 2)	5.09	6.25	5.75	5.4	5.78	6.14	3.48	6.50
CEM II/B-M (LL-S-V) 32.5 N	**4.76**	**4.36**	4.21	4.3	3.97	4.24	2.31	4.32
CEM II/B-V 32.5 R	4.25	4.37	4.19	4.34	4.21	4.68	2.53	4.73
CEM 1 [65OPC 30FA 5L]	4.84	4.73	4.08	4.34	**5.12**	4.3	2.70	5.05
CEM 3 [45OPC 30FA 25L]	**3.08**	**3.43**	**3.3**	**3.48**	**3.6**	**3.53**	1.49	2.79
CEM 6 [50OPC 20FA 30L]	**3.99**	3.32	3.32	3.41	**3.45**	3.26	1.84	3.44
CEM 10 [55OPC 10FA 35L]	3.77	3.81	3.66	3.75	**4.03**	**4.02**	2.11	3.94

A reduction factor of 10% of E_{cm} for limestone aggregates, cited in EC2, has not been applied.

$$E_{cm}\,(GPa) = 22\left(\frac{0.8\,f_{cm,cube}}{10}\right)^{0.3} \tag{9}$$

Fig. 5 shows that all ternary OPC-S-L and OPC-FA-L cements are above the predicted E_{cm} and that several are above the E_{cm2} border. These large moduli of elasticity could be explained by the high hardness of the limestone aggregates, as demonstrated by a fragmentation test (Los Angeles coefficient of 20). One can observe that the modulus of elasticity at 28 days is higher than the predicted value for most cements. For some applications like industrial floors where shrinkage is restrained, the developed stress could be more important because of a higher modulus of elasticity.

3.6 Total shrinkage

The shrinkage deformations of T(0.45) series 1 concretes are shown in Fig. 6. The deformations are less important for ternary OPC-S-L cements than for reference cement CEM I 52.5 R HES. It is the same for type T(0.55). For series 2, CEM 1 concrete shows a higher or similar deformation than reference CEM I 52.5 R HES, respectively for types T(0.45) or T(0.55). This reduced shrinkage with ternary OPC-S-L cements compared to Portland cement was also found by Courard and Michel [6]. According to them, due to less reactive materials, the mixtures containing slag probably do not attract water at the same rate, which may induce less chemical shrinkage. The influence of clinker and limestone filler contents is less significant for series 2 but it is for series 1 (R of 0.8 and -0.7 respectively). Concretes made with OPC-S-L cements present smaller deformations than OPC-FA-L cements (up to 29% for CEM 1), as shown by the total shrinkage at 91 days in Tab. 2. The evaluation approach defines two limits ± 49% of the shrinkage curve from Eurocode 2. This EC2 curve has been computed with a tool which takes into account the compressive strength class of cement and concrete, the average cross section radius, the relative humidity and number of curing days. Fig. 7 shows for example the results for CEM 1 [65OPC 30FA 5L] concrete. The experimental shrinkage is slightly lower than the predicted one but stays within the boundaries from the criterion.

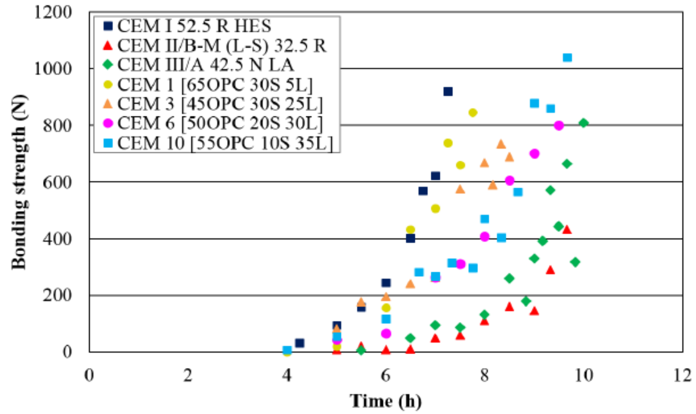

Figure 2: Bonding strength of series 1 concretes (OPC-S-L).

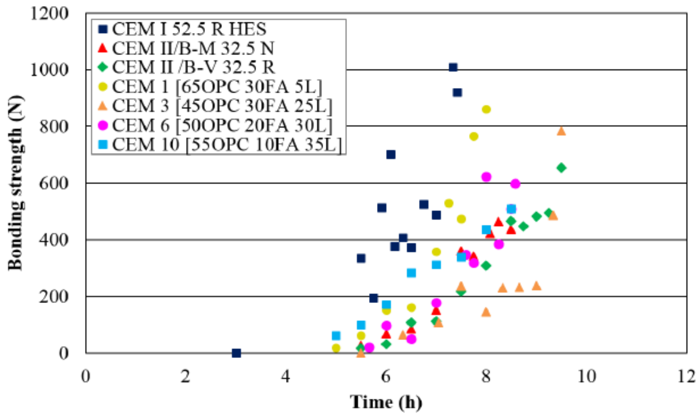

Figure 3: Bonding strength of series 2 concretes (OPC-FA-L).

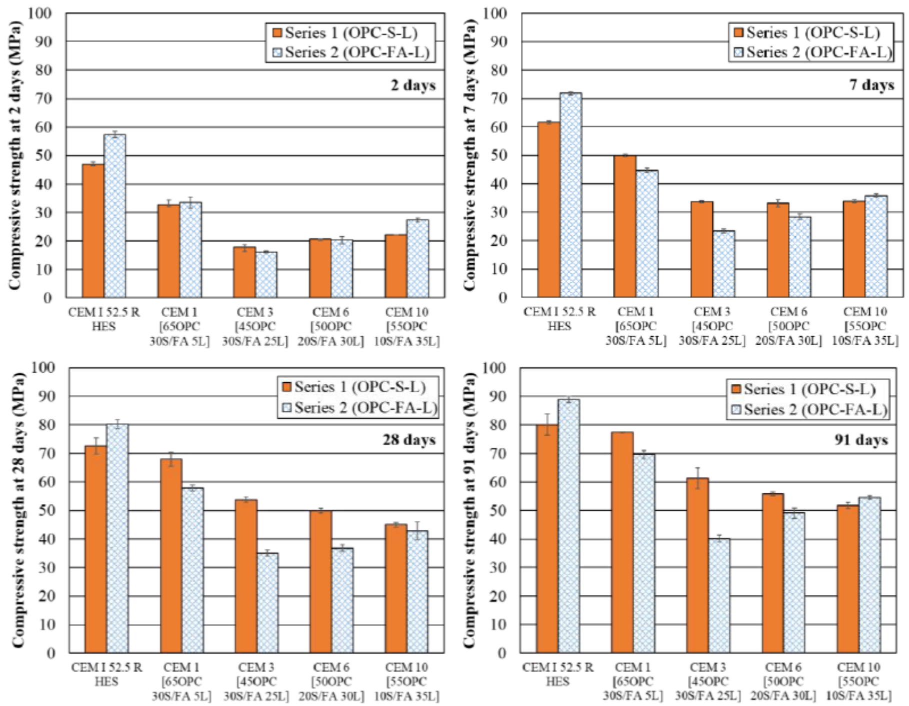

Figure 4: Comparison of compressive strength at 2, 7, 28 and 91 days for T(0.45) concretes of the series 1 (OPC-S-L) and series 2 (OPC-FA-L).

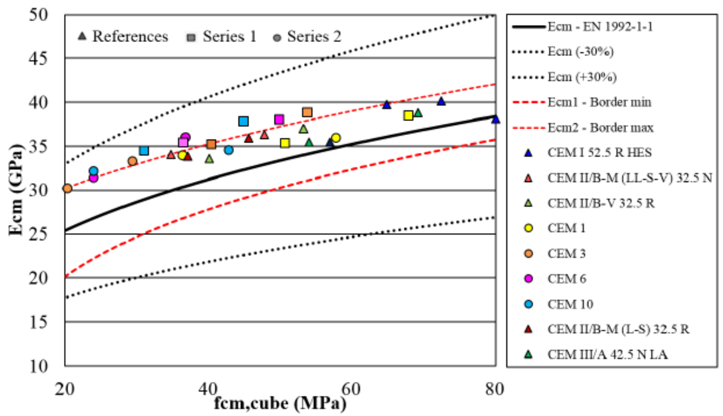

Figure 5: Modulus of elasticity – compressive strength relation for series 1 and 2 as well as theoretical values E_{cm} ± 30% and borders E_{cm1} and E_{cm2}.

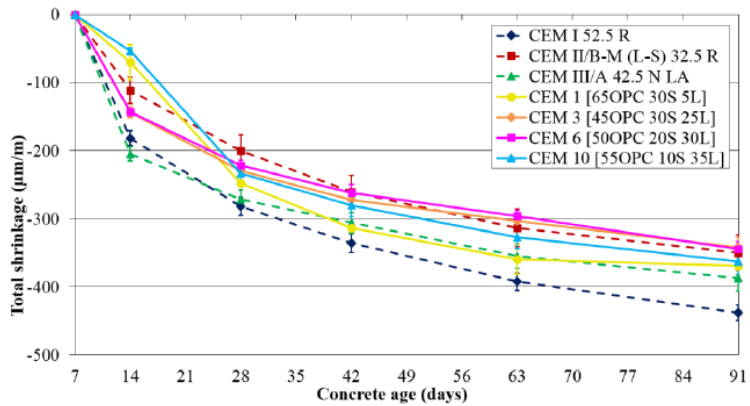

Figure 6: Total shrinkage for T(0.45) series 1 concretes.

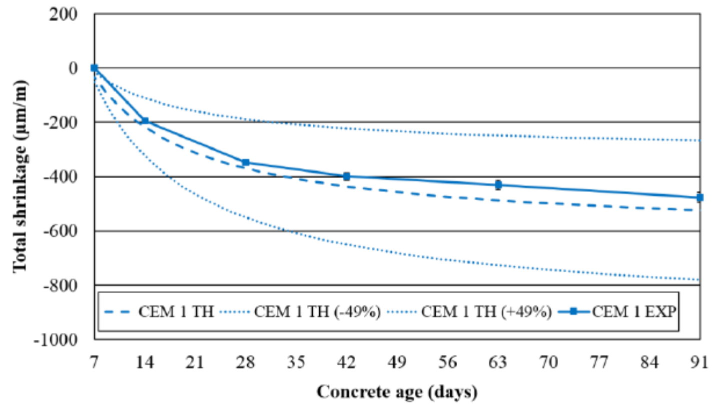

Figure 7: Experimental and EC2 total shrinkage for T(0.45) series 2 concrete CEM 1.

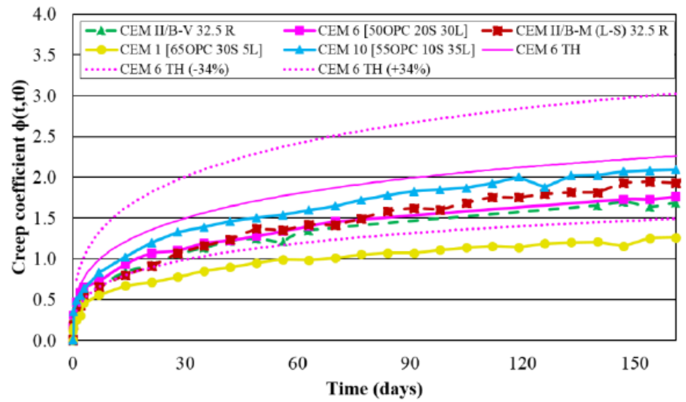

Figure 8: Experimental and EC2 creep for some T(0.45) concretes of series 1 and 2.

3.7 Creep

Creep tests were carried out on some concretes only. The results are shown in Fig. 8. For series 1, CEM 1 concrete shows the lowest creep while CEM 10 concrete shows a creep 65% higher. For series 2, CEM 6 concrete has a creep similar to the reference CEM II/B-V 32.5 R. The evaluation approach requires that experimental creep should lie within two limits ± 34% of the creep from Eurocode 2. This EC2 curve has been computed taking into account the compressive strength of concrete, the type of cement, the average cross section radius, the relative humidity and the age of concrete at the beginning of the test. Fig. 8 presents for example the EC2 curves for CEM 6 [50OPC 20FA 30L] concrete. For all ternary cements, experimental creep is lower than the predicted one but they stay in the ± 34% boundaries. It is difficult to draw trends but it seems that the presence of slag or fly ash is beneficial to reduce creep. One can observe that creep is lower than the predicted value for all cements. It might be positive for many applications as long term deflections under permanent load could be limited. But for applications where shrinkage is restrained, a low creep in compression might induce generally less relaxation in tension and hence generate higher tensile strains and more important cracking.

4. Conclusions

The effects of ternary cements made with blast furnace slag or fly ash (with a content up to 30%) and limestone filler (with a content up to 35%), on the fresh properties and mechanical performance of concretes were investigated. The following conclusions, for the tests conditions and materials of this study, can be drawn:

- Setting time and mechanical properties (compressive and indirect tensile strengths, modulus of elasticity, total shrinkage) are essentially influenced by clinker ($R > 0.8$) and limestone filler ($R < -0.7$) contents, as shown by correlation coefficients;
- Ternary OPC-S-L cements seem in general to contribute to a higher mechanical performance than ternary OPC-FA-L cements;
- Except for shrinkage and creep, most of the tested ternary cements did not satisfy the requirements of the evaluation approach.

This study shows that despite the fact that ternary cements with high amount of limestone and slag or fly ash meet the requirements of European standard EN 197-1 in terms of initial setting time, soundness and compressive strength, these cements could not be used in concrete in all applications. Predictive models of the mechanical performance may not be suitable for most of the tested composite cements. There are some cases for which these poor predictions could have an impact in terms of underutilization of the performance of the material depending on the applications. A more thorough statistical research should be made but this first study shows that the predictive models from Eurocode 2 are not valid for most of the tested ternary cements. Finally, it could be interesting to perform ring tests in order to study the cracking susceptibility due to restrained shrinkage.

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