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**Abstract**

Portland cement (PC), whose main phase is alite (Ca<sub>3</sub>SiO<sub>5</sub>, C<sub>3</sub>S), is one of the most manufactured products in the world. However, cement industry is one of the major contributors for greenhouse gases (GHG) emissions. In the fabrication of PC, 0.96 tons CO<sub>2</sub> per ton PC are emitted into the atmosphere. Belite cements (BC), whose main component is the belite phase (Ca<sub>2</sub>SiO<sub>4</sub>, C<sub>2</sub>S), can decrease the CO<sub>2</sub> footprint of cements. The main disadvantage of these BCs is its low mechanical strengths at early ages although they have very good mechanical values at late ages and also very good durability performances. Thus, it is necessary to study how to increase the mechanical properties at early ages, for instance, by activation.

To do this, an *in-situ* synchrotron X-ray powder diffraction study has been performed up to 48 hours of hydration using a PC and two different BCs (one activated during the clinkering stage and one non-activated). These cements have been hydrated without and with three different admixtures, two of them C-S-H seeding (XS100 and XS130) (also contains alkanolamine) and the other one being a single alkanolamine (trisopropanolamine, TIPA). Data have been collected at the BL04-MSPD beamline at ALBA synchrotron (Barcelona, Spain). The results were analysed by the Rietveld methodology to determine the phase content evolutions with time and with the activators. Figs. 1-3 shows, as an example, the hydration evolution of the activated cements without and with the XS130 admixture.

In this study, we have obtained two main conclusions. The first observation is that C-S-H seeding accelerates the hydration of the three cements at early ages, mainly by enhancing calcium sulphate and calcium aluminates dissolutions. It has also been observed that admixtures do not significantly accelerate the hydration of crystalline C<sub>3</sub>S and C<sub>2</sub>S. The second is a synergy between C-S-H seeding and alkanolamines when compare to single alkanolamine dosage. The work to be discussed in this communication has been submitted for possible publication.

**Keywords**

Rietveld analysis; synchrotron radiation; CO<sub>2</sub> footprint; accelerators; C-S-H gel

**Materials**

**Table 1.** Elemental composition (wt%) for the anhydrous cements from XRF.

	CaO	SiO <sub>2</sub>	SO <sub>3</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	MgO	K <sub>2</sub> O	Na <sub>2</sub> O	Other	Lol
PC-42.5	62.9	19.7	3.4	5.0	3.4	1.5	1.1	0.3	0.3	2.7
BC-Buz	59.3	21.4	4.8	4.3	2.8	2.7	0.9	0.2	0.9	2.9
BC-n.a.	60.1	24.4	2.8	2.9	4.8	1.2	0.5	0.1	1.3	2.0

**Table 2.** RQPA (wt%) for the anhydrous cements from SXRPD.

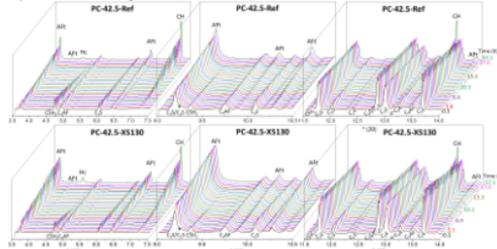
	C <sub>3</sub> S	C <sub>2</sub> S	C <sub>4</sub> AF	C <sub>3</sub> A	C <sub>4</sub> A <sub>3</sub> S	MgO	CC	C <sub>2</sub> H <sub>2</sub>	C <sub>2</sub> H <sub>0.5</sub>	C <sub>2</sub> S	ACn
PC-42.5	50.0	7.5	9.6	6.8	-	3.6	1.0	2.0	-	19.5	-
BC-Buz	23.0	46.9	10.4	3.4	1.9	1.8	3.4	-	-	2.1	7.1
BC-n.a.	29.2	47.4	14.4	-	-	-	2.8	-	-	6.2	-

**Table 3.** Textural parameters for the anhydrous cements.

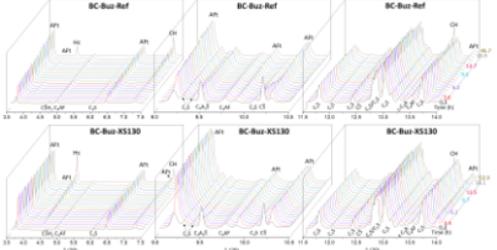
	D <sub>v10</sub> (µm)	D <sub>v50</sub> (µm)	D <sub>v90</sub> (µm)	BET (m <sup>2</sup> /g)	Blaine (m <sup>2</sup> /Kg)	Density (g/cm <sup>3</sup> )
PC-42.5	3.6	18.1	50.3	1.2	370	3.13
BC-Buz	1.5	12.8	55.2	1.4	502	3.17
BC-n.a.	2.6	8.0	32.7	1.2	429	3.23

**Results from synchrotron (ALBA, Spain)**

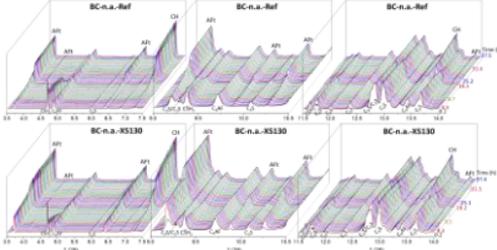
**Figure 1.** SXRPD raw patterns (λ=0.62005 Å) for the PC-42.5-Ref and PC-42.5-XS130.



**Figure 2.** SXRPD raw patterns (λ=0.62005 Å) for the BC-Buz-Ref and BC-Buz-XS130.



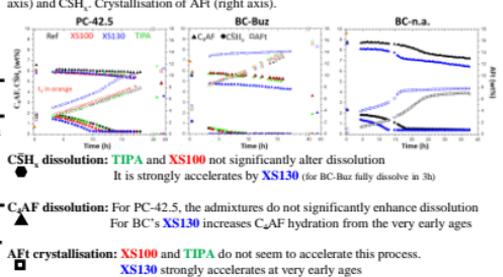
**Figure 3.** SXRPD raw patterns (λ=0.62005 Å) for the BC-n.a.-Ref and BC-n.a.-XS130.



**Discussion**

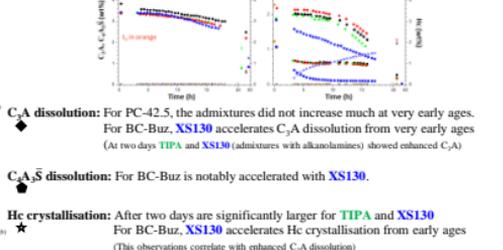
C<sub>3</sub>S: Ca<sub>3</sub>SiO<sub>5</sub>; C<sub>2</sub>S: Ca<sub>2</sub>SiO<sub>4</sub>; C<sub>4</sub>AF: Ca<sub>4</sub>Al<sub>2</sub>Fe<sub>2</sub>O<sub>10</sub>; C<sub>3</sub>A: Ca<sub>3</sub>Al<sub>2</sub>O<sub>6</sub>  
 C<sub>2</sub>H<sub>2</sub>: CaSO<sub>4</sub>·xH<sub>2</sub>O; C<sub>2</sub>A<sub>3</sub>S: Ca<sub>3</sub>Al<sub>2</sub>O<sub>7</sub>(SO<sub>4</sub>)<sub>2</sub>; CH: Ca(OH)<sub>2</sub>  
 AFr: Ca<sub>2</sub>Al<sub>2</sub>(SO<sub>4</sub>)<sub>3</sub>(OH)<sub>12</sub>·26H<sub>2</sub>O; He: Ca<sub>2</sub>Al<sub>2</sub>(CO<sub>3</sub>)<sub>3</sub>(OH)<sub>12</sub>·5.5H<sub>2</sub>O

**Figure 4.** Phase content evolutions with time from *in situ* SXRPD. Dissolution of C<sub>4</sub>AF (left axis) and C<sub>2</sub>H<sub>2</sub>. Crystallisation of AFr (right axis).



**C<sub>4</sub>AF dissolution:** For PC-42.5, the admixtures do not significantly enhance dissolution. For BC's XS130 increases C<sub>4</sub>AF hydration from the very early ages.

**Figure 5.** Phase content evolutions with time from *in situ* SXRPD. Dissolution of C<sub>3</sub>A and C<sub>4</sub>A<sub>3</sub>S (left axis). Crystallisation of Hemicarbonate, He (right axis).

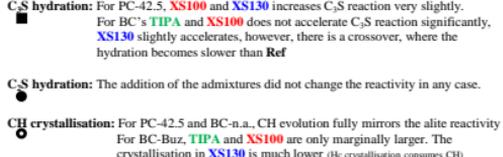


**C<sub>3</sub>A dissolution:** For PC-42.5, the admixtures did not increase much at very early ages. For BC-Buz, XS130 accelerates C<sub>3</sub>A dissolution from very early ages (At two days TIPA and XS130 (admixtures with alkanolamines) showed enhanced C<sub>3</sub>A).

**C<sub>4</sub>A<sub>3</sub>S dissolution:** For BC-Buz is notably accelerated with XS130.

**He crystallisation:** After two days are significantly larger for TIPA and XS130. For BC-Buz, XS130 accelerates He crystallisation from early ages (This observations correlate with enhanced C<sub>3</sub>A dissolution).

**Figure 6.** Phase content evolutions with time from *in situ* SXRPD. Dissolution of C<sub>2</sub>S (left axis). Crystallisation of CH (right axis).



**C<sub>2</sub>S hydration:** For PC-42.5, XS100 and XS130 increases C<sub>2</sub>S reaction very slightly. For BC's TIPA and XS100 does not accelerate C<sub>2</sub>S reaction significantly. XS130 slightly accelerates, however, there is a crossover, where the hydration becomes slower than Ref.

**C-S-H hydration:** The addition of the admixtures did not change the reactivity in any case.

**CH crystallisation:** For PC-42.5 and BC-n.a., CH evolution fully mirrors the alite reactivity. For BC-Buz, TIPA and XS100 are only marginally larger. The crystallisation in XS130 is much lower (He crystallisation consumes CH).

**Conclusions**

Two main conclusions can be drawn:  
 C-S-H seeding accelerates the PC and BC's hydration, mainly by boosting calcium sulphate(s) and calcium aluminate(s) availabilities. In the studied experimental conditions, C<sub>3</sub>S and C<sub>2</sub>S reactivities are not significantly enhanced.  
 Synergy between alkanolamines and C-S-H seeding is proved as the dissolutions of calcium sulphate(s) and calcium aluminate(s) are further enhanced when compared to single admixture dosage.

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