# UTILISATION OF ACTIVATED GGBS FOR NON-REINFORCED CONCRETE APPLICATIONS

**Ludovic ANDRE[1,2], Laurent STEGER[1,2], Diane ACHARD[3], Laurent FROUIN[1], Martin CYR[2]**

[1] ECOCEM Materials Ltd., Paris, France
[2] LMDC, Université de Toulouse, INSA, UPS, France
[3] ECOCEM France SAS, Aix en Provence, France

*andre@insa-toulouse.fr, steger@insa-toulouse.fr, dachard@ecocem.fr, lau.frouin@gmail.com, cyr@insa-toulouse.fr*

## Introduction

Non-reinforced precast industry is a technical sector which uses low water-to-binder ratio, specific particular size distribution of aggregates, and needs high reactivity binders to ensure high production rates. The use of Supplementary Cementitious Materials is technically challenging in this industry but has benefits of reduced environmental impact and improved durability of the final products. A solution could be the partial replacement of Portland cement by ground granulated blast-furnace slag (GGBS) activated by several chemical compounds[1,2,3].

This paper aims to present the potential of GGBS to be used in non-reinforced concrete applications. The first part summarises the results of three industrial trials to produce blocks and curbs in precast plants with only limited amounts of GGBS and simple activation systems. The second part, realised at the laboratory scale with a specific and reproducible method developed to get close to dry concrete industrial process, aims to increase the GGBS content and to highlight the synergic effects of chemical activation and curing temperature.

## Materials and Methods

The Portland cement used in all experiments and industrial trials was CEM I 52.5 conforming to European Standard NF EN 197-1 and GGBS conforming to NF EN 15167-1. Their specific surface areas (Blaine) were 4000 and 4400 $cm^2/g$, respectively. A mixture of quartz sands (30% 0-2 mm and 70% 2-4 mm) was used in laboratory experiments. The chemical activation systems for GGBS used were based on different ways seen in literature: alkali (Na- and K-silicates, NaOH and KOH), alkali-sulfate ($Na_2SO_4$, with or without $Ca(OH)_2$), chloride (NaCl, $CaCl_2$), and chloride-sulfate ($CaCl_2$, $Na_2SO_4$, anhydrite, gypsum). The laboratory program was carried out on 4x4x16 cm mortar bars with a control density of 1.95 $T/m^3$, a realistic value in block industry. Binder content was 187 $kg/m^3$ (it was not possible to develop enough compaction energy to reduce it to 90-130 $kg/m^3$, more realistic value for the industry) with a W/B of 0.4. A dry-mixed method was applied, where pre-homogenised materials were

slowly wetted. The mortar was placed into the moulds in three layers of approximately the same thickness. The first two layers were pre-compacted to get a flat surface and a homogenised compaction. Finally, the last layer was compacted by hammering a mass of steal placed above the sample to reach a controlled height, for a controlled density. The blocks were placed in sealed bags at 20°C or 30°C, then demoulded and tested after 24 h.

# Results and Discussion

## Industrial trials

The first series of trials were conducted at industrial scale (Table 1) to evaluate whether or not GGBS could be used in precast industry for the manufacturing of non-reinforced concrete such as blocks and curbs. No modification of the processes was made, except the use of GGBS with or without accelerator. Only limited GGBS content (< 50%) were tested in precast plants. Compressive strength was measured at 14 days to assess the performance of the final products. Results are presented as strength activity index, defined as the ratio between the strength of the GGBS-based mixture over the reference mixture composed of Portland cement only.

**Table 1:** Details of the industrial tests

| Plant | Products | GGBS | Activator | Temperature |
|---|---|---|---|---|
| A | Blocks (390x190x190 mm) | 30, 40% | 2% of total binder mass (1% NaCl + 1% $Na_2SO_4$) | 2d at 30°C then stockpiled outside |
| B | Blocks (500x200x200 mm) | 50, 70, 80% | 2% $Na_2SO_4$ (of total binder); 0.3 and 1% (half NaCl, half $Na_2SO_4$) | 4d at 28°C then stockpiled outside |
| C1 | Blocks (500x200x200 mm) | 24, 32, 40, 48, 50% | 0.4% NaCl + 0.4% $Na_2SO_4$ (of GGBS content) | 3d at 10-15°C then stockpiled outside |
| C2 | Curbs (1000x150x250 mm) | 33, 40, 47% | 0.4% NaCl + 0.4% $Na_2SO_4$ (of GGBS content) | 1d at 10-15°C then stockpiled outside |

The trials at the industrial plants were well perceived by the producers, and it should be noted that for all trials, no friability issues were obtained on the final products at young age, so their handling was possible as for full Portland cement compositions. Figure 1 reports the strength activity indices at 14 days of all the formulations tested. It can be seen from this figure that:

- In plant A, the use of activator allowed for the increase of GGBS by 10% (30 to 40%), without affecting the strength of the blocks. The strength of the 40% mixture reached 7.2 MPa at 14 days (activity index of 0.87), a value above the minimum of 6 MPa needed by the producer.
- In plant B, the use of 50% of GGBS without activator led to equivalent results than the reference with only Portland cement. The high curing temperature maintained for 4 days may explain this good behaviour. However, the increase in GGBS content at 70 and 80% led to significant drops in the activity indices,

even with the presence of chemical activators. These results justified the development of other combinations of GGBS-activator-temperature to improve the behaviour of the binders (Laboratory Development).

- In plant C, only activated GGBS was used to produce blocks and curbs. On the one hand, the results for blocks were correct up to 48% of GGBS, with activity indices around 0.9 (plant C1). On the other hand, very high indices were obtained for curbs made with GGBS (plant C2), as these mixtures behave better than the cement alone.

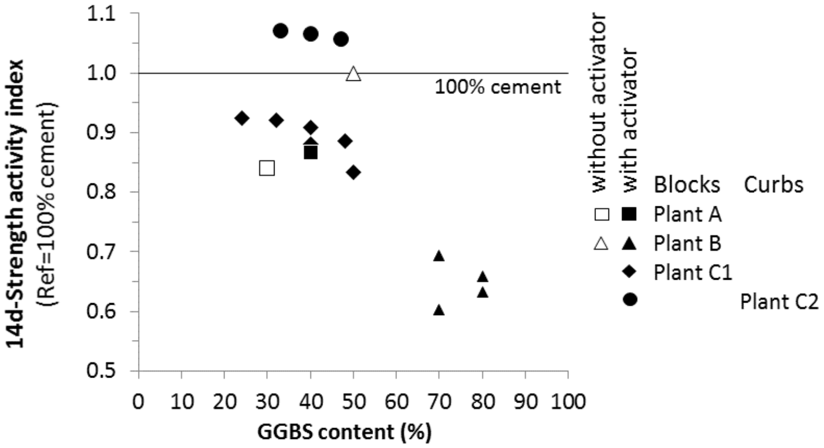


**Figure 1:** Industrial trials conducted on blocks and curbs in three different sites (Plants A, B and C)

## Laboratory development

Following the experiments made in industrial plants, tests were carried out at the laboratory scale to increase the GGBS content (> 65%), and to show that a synergic effect of the chemical activation and the temperature of curing could be positive, as already seen in the literature[2]. The compressive strength was measured at 1 day, to take account of the industrial production needs for the handling of the specimens without causing damages to the blocks/curbs.

Figure 2 presents the strength activity index (SAI) of the mixtures tested with different activating systems, and curing temperatures of 20°C and 30°C.

The reference for calculating the SAI was 100% Portland cement mixture cured at 20°C:

- Some activation systems (chlorides, chlorides + alkali-sulfate and alkali-sulfate alone at a lower extend), combined to a curing 10° higher than the reference, were very efficient and allowed the 70%-GGBS mixtures to reach (or almost reach) the performance of the reference made of 100% Portland cement. In this case, the synergic effect of chemical activators and temperature was clearly highlighted.

- Alkali-activation of high GGBS content mixture (88% GGBS, 7.4% sodium silicate) could also be efficient to increase the activity of GGBS, without the need of increasing the temperature of curing. However, the sodium silicate used was in a liquid form and precaution must be taken due to the high alkalinity of the activator. It should be noted that Na- and K-silicates were efficient in these tests, while NaOH and KOH led to the lowest results.

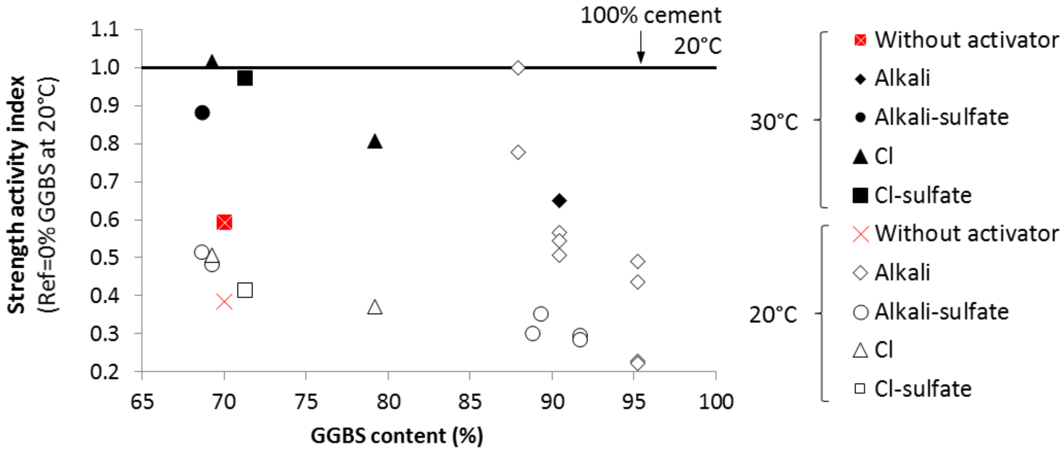


**Figure 2:** Strength activity index (SAI) at 1 day of blocks made in the laboratory and cured at 20°C and 30°C, with GGBS activated by chemical products. SAI calculated with the reference being the 100% Portland cement mixture cured at 20°C

## Conclusions

It was seen in industrial plants that it is already possible to replace up to 50% of OPC by GGBS in dry concrete applications, simply by assuring good thermal curing conditions. However, to increase GGBS content over 65%, a solution could be to take advantage of the synergy between chemical and thermal activations. Easy chemical activations to work with are chloride and alkali-sulfate, alone or associated. Finally, it is also possible to fully replace OPC by using alkali activated slag, but liquid sodium silicate must be handled with care in an industrial process due to its corrosive potential.

## References


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