Optimization of the powder content of mortar and concrete to achieve a reduction of CO_2 emissions

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The synergic utilization of Finely Gound Calcium Carbonate of high purity from Omya and the most innovative chemical admixtures from Master Builders Solutions allows optimization of the powder content of mortar and concrete, with a remarkable impact in terms of sustainability: reduced CO_2 emissions and significant water savings.

Concrete is the first man-made material produced in the world and is responsible nowadays for roughly 8% of global CO_2 emissions. With the growing population and increasing urbanization, the amount of concrete globally produced will further increase in the future, but this is not sustainable for the environment. Nowadays, the concrete industry cannot retrieve from taking actions to mitigate the environmental impact of its activity and move steps towards the achievement of the challenging goals of the Paris Climate Agreement.
As cement is the main responsible for the emissions of concrete, the key action that concrete producers can take is the reduction of the dosage of Ordinary Portland Cement (OPC) and the inclusion of alternative inorganic materials. But… what can cement be replaced with? Supplementary Cementitious Materials (SCM) like fly ashes, slag and pozzolans would be the preferred choice, as their pozzolanic activity would contribute to the strength development and durability enhancement of concrete. Unfortunately, fly ash and ground granulated blast furnace slag (GGBS) is slowly disappearing due to the conversion of power plants from coal combustion to greener technologies (wind, solar, etc.) or due to increased steel production from recycled sources. And natural pozzolans are available only in very limited geographical areas. Therefore, new standards are under preparation to allow new range of SCMs.
For these reasons, attention is turning towards some of the most common natural materials on earth: clay and limestone [1]. As a fact, mineral additions are the easiest, most cost-effective way to lower the environmental impact of cement-based materials like concrete. In recent years, the mineral industry and, in particular, the one of calcium carbonate has developed technical processes to offer mineral additions with higher added values for technical grout, mortar, and concrete formulations [2, 3, 4, 5, 6].
At the same time, the production of concrete with reduced content of cement cannot be implemented without the contribution of advanced chemical admixtures, that allow reducing the mixing water significantly while maintaining a good rheology and additionally contribute to the achievement of the compressive strengths.

This work explores the potential to develop mortars and concretes with reduced greenhouse gas emissions by reducing the dosage of Ordinary Portland Cement, lowering the water content, and including a properly designed amount of finely ground calcium carbonate (GCC).

The joined effort of Omya and Master Builders Solutions focuses on the development of reliable solutions based on the ECPC (Equivalent Concrete Performance Concept as defined in EN 206), with a specific combination of physical and chemical approaches: while significantly reducing the dosage of Ordinary Portland Cement, the optimization of the total powder content (cement + GCC) [8, 9, 10] is achieved by using ground calcium carbonate of different fineness, namely Betocarb HP and Betocarb F from Omya that synergically interacts with MasterCO_2re superplasticizer based on Intelligent Cluster System technology (ICS) from Master Builders Solutions, optimizing the binder dispersion and providing suitable workability retention. This combination has the potential to reduce the amount of water and carbon footprint involved in cement utilization. Thanks to its superior rheology, MasterCO_2re enables further water reduction compared to conventional polycarboxylate-based superplasticizers. To complement the effect of MasterCO_2re, the integration of a strength enhancer of the new generation, Master X-Seed STE, from Master Builders Solutions, guarantees an increase in long-term compressive strength. Its mechanism of action is based on the formation of hemicarboaluminate and monocarboaluminate, which are considered to be stronger crystals among the hydrated constituents of the cement [11]. The synergy between GCC and Master X-Seed provides higher efficiency in concrete mix optimisation.

The limestones quarried today are classified according to their mineralogy, hardness, and their chemical purity [12]. The French standard NF P 18-508 [7] has defined a premium category A for ground calcium carbonate with a restricted specification of 3g/kg for the clay content parameter, high calcium carbonate content with a minimum surface area. Both series of specifications are reported in Table 1.

Table 1. Overview of the main specifications in EN 197-1 and NF P 18-508

Product	Limestone	Ground Calcium Carbonate
Norm	EN 197-1	NF P 18-508, category A
Calcium carbonate content, %	>75	>95
$CaCO_3$ + $MgCO_3$, %		>95
Methylene blue value, g/kg (oz/lb)	<12 (0,19)	<3 (0,05)
Blaine surface area m^2/kg, (ft^2/lb)		>300 (1464)

For the present investigation fine Ground Calcium Carbonate, Betocarb F and Betocarb HP, are used for mortar and concrete mixes. Their chemical-physical characteristics are listed in table 2 and compared to traditional limestone filler.

Table 2. Properties of Ground Calcium Carbonate used in the experiment.

Product	Betocarb HP	Betocarb F	Limestone
Passing <63μm (0,025in), %	89	100	86
Blaine surface area, m^2/kg (ft^2/lb)	520 (2539)	1050 (5126)	330 (1611)
Calcium Carbonate, %	97.8	97.8	92.8
Methylene blue value, g/kg (oz/lb)	1.0 (0.016)	1.0 (0.016)	3.6 (0.058)

The approach to sustainable solutions explored in the present work has been tested in mortar and in concrete mixes, using different types of cements.

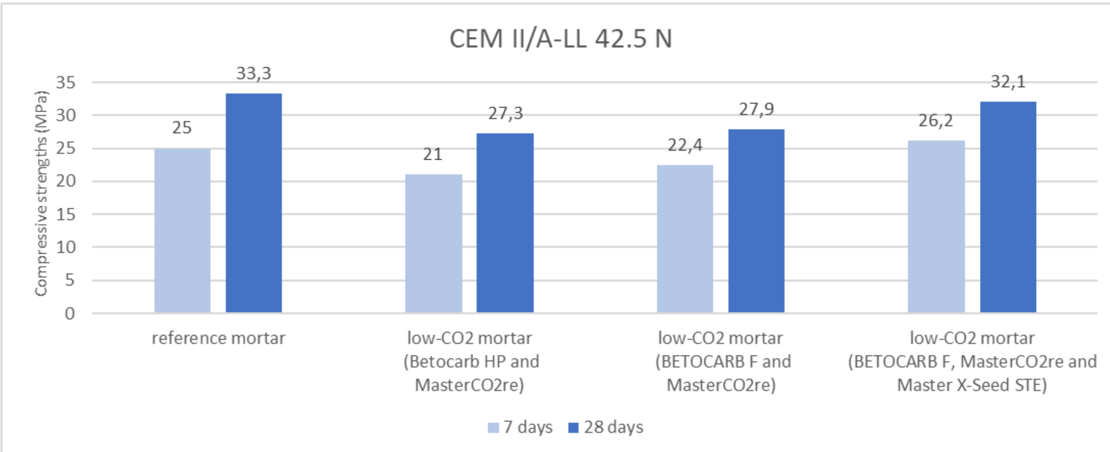
The composition of the mortar tests is reported in Table 3: a reduction of cement 31% has been applied, along with a remarkable reduction of water and the addition of Betocarb HP or Betocarb F granulated calcium carbonate to optimize the powder content. The same consistency has been achieved in all mortars by adjusting the dosage of MasterCO$_2$re. The compressive strengths values of the mortars are reported in the graphs 1 and 2.

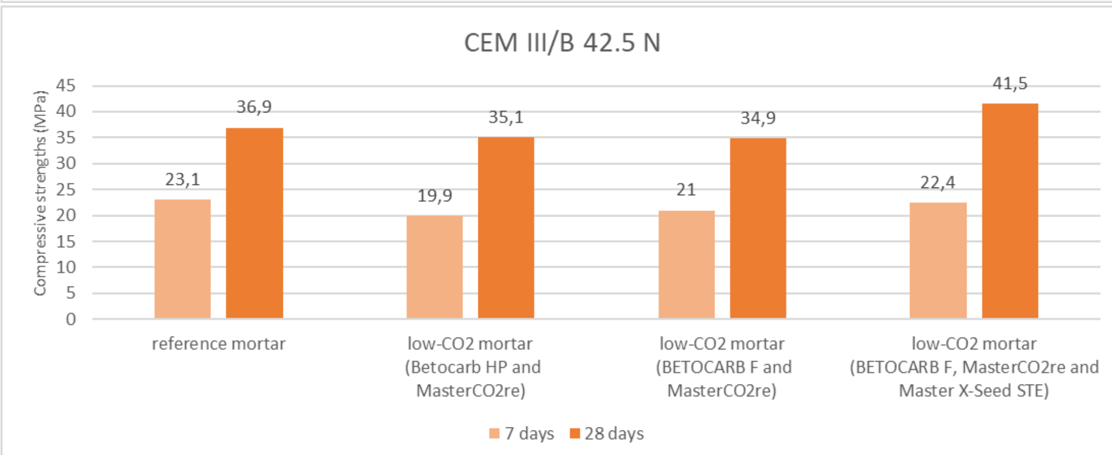
The results demonstrate the benefits of introducing GCCs to adjust the total powder content when both the cement and water content were reduced. The effect of the strength accelerator Master X-Seed STE on the 28 days compressive strength is remarkable and can more than offset the impact of the reduction of Ordinary Portland cement.

Table 3. Mortars compositions

Component	Reference Mortar		Reduced-CO_2 mortar	
	Weight (g)	Volume (l)	Weight (g)	Volume (l)
Cement	290	0.097	200	0.067
Sand 0/4	1827	0.677	1772	0.656
GCC	--	--	200	0.074
Water	191	0.191	160	0.160
MasterCO$_2$re	Adjusted to achieve consistency		Adjusted to achieve consistency	
Master X-Seed STE	--	--	1% bw of (cement+GCC)	

Graph 1 and 2. Mortar tests results



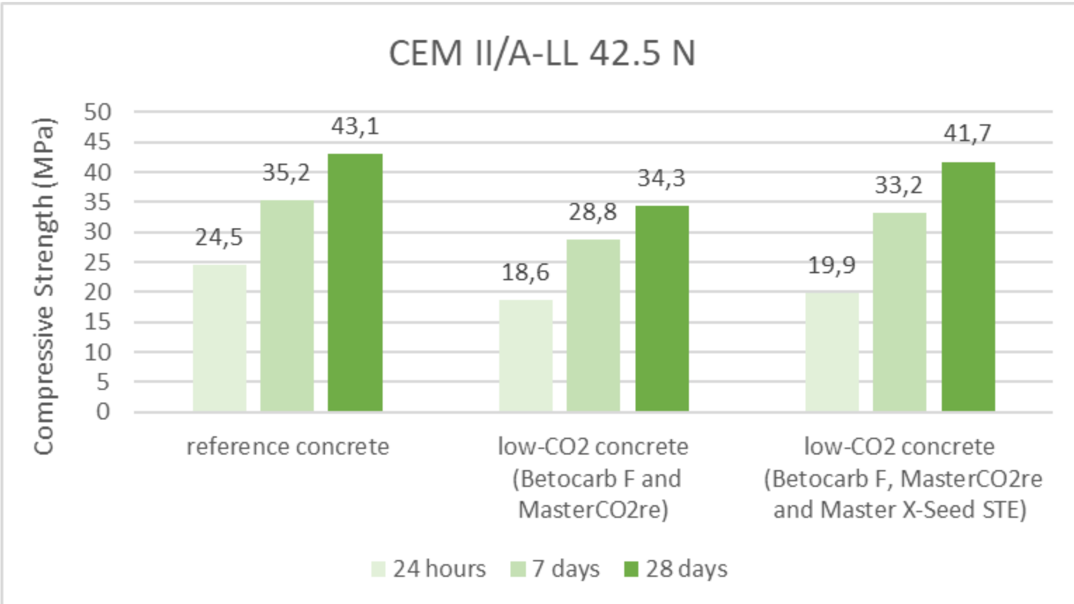


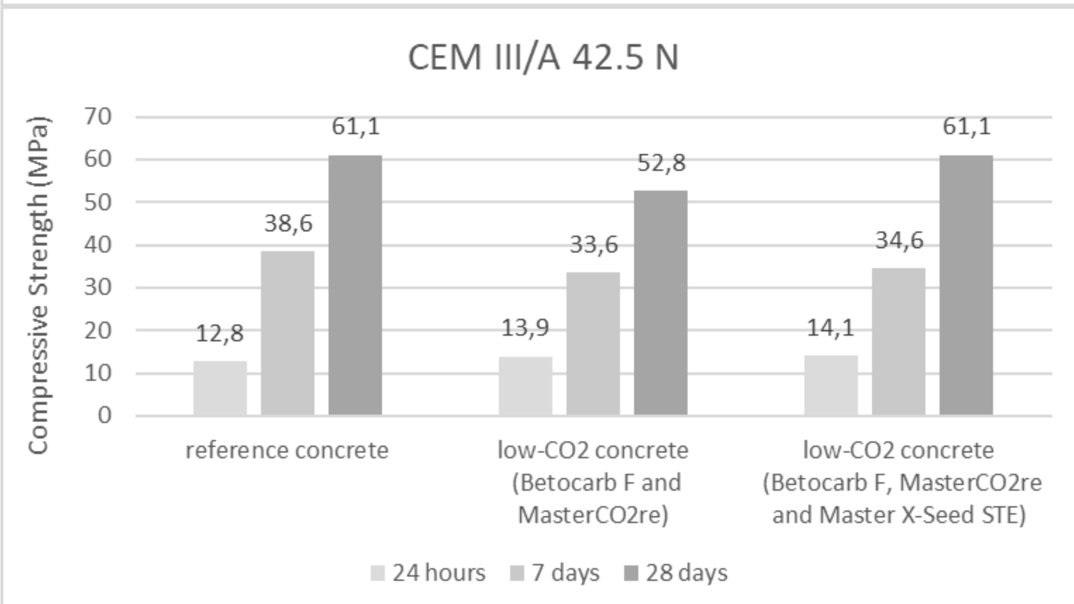
The same approach has been applied to concrete mixes with two cement types (CEM II/A and CEM III/A); the dosage of OPC has been remarkably reduced, along with the water content, as it is reported in the mix compositions in table 4 below. The powder content was optimized by the addition of Betocarb F, a fine GCC, and the reduction of water while maintaining a good rheology was allowed by the MasterCO2re superplasticizer; Master X-Seed STE plays a key role in the achievement of the desired 28 days strengths.
Graphs 3 and 4 present the compressive strengths results of concrete. With both cements, the low-CO_2 concrete achieved the desired strengths, despite the strongly reduced content of cement compared to the reference mix.

Table 4. Concrete compositions

Component (kg/m^3)	II/A-LL 42.5 N			III/A 42.5 N		
	Reference concrete	Low-CO_2 concrete (MasterCO_2re Betocarb F)	Low-CO_2 concrete (MasterCO_2re + Betocarb F + MasterX-Seed STE)	Reference concrete	Low-CO_2 concrete (MasterCO_2re + Betocarb F	Low-CO_2 concrete (MasterCO_2re + Betocarb F + Master X-Seed STE)
Aggregates	1942	1872	1872	1942	1856	1856
Cement (C)	290	215	215	290	200	200
Betocarb F	--	200	200	--	200	200
Water (W)	168	144	144	168	134	134
W/C	0,58	0,67	0,67	0,58	0,67	0,67
MasterCO_2re	0.38	0.87	0.87	0.38	0.84	0.84
Master X-Seed STE	--	--	4.1	--	--	4.0

Graph 3 and 4. Concrete Tests results





Conclusions

This paper has confirmed that the introduction of fine round calcium carbonate of high purity, Betocarb HP and Betocarb F from Omya, along with the reduction of mixing water enabled by innovative admixtures based on Intelligent Cluster System from Master Builders Solutions, allows the development of mortar and concrete mix designs with strong reduction of Ordinary Portland Cement and suitable rheology and workability retention. Adding the new generation strength enhancer Master X-Seed STE can complement the performance by increasing the ultimate compressive strengths.

This innovative approach, based on optimization of physical and chemical parameters, has proven to be a practical and innovative concept for the development of sustainable mortars and concretes with high stability and good aesthetic properties. It paves the way for a future and more sustainable construction; the advantages for the planet in terms of CO_2 emissions reduction and drinking water saving, are massive.

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