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Carbon Neutral Concrete – Challenges and Solutions for Sustainable Future

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Abstract. *As the climatic impact is becoming a more important topic for most of the nations which signed the COP 26 accords; many concrete and cement companies have announced their carbon reduction ambitions. Although the CO_2 reduction pace varies from one country / company to the other, many of them have clearly stated their commitment towards concrete carbon neutrality in 2050. As a result, we can observe the accelerated emergence of a multitude of new technologies targeting the reduction of carbon content in concrete.*

The presentation proposed will go over the consequences for the concrete industry of this construction industry's endeavor climatic impact reduction. It will explain some of the main challenges paving the cement and concrete industry's journey towards carbon neutrality. It will deep dive in the principles and impacts of the most recent and advanced regulations in terms of low carbon construction such as, for example, RE2020 in France. It will also illustrate some of the realistic solutions currently implemented to reduce the carbon footprint of concrete and cement and adapt to this new market environment, including the use of the latest loT technology which allows the concrete producer to improve their material management, operational efficiency as well as the commercial leverage.

In a world where raw materials scarcity becomes increasingly stringent, it will also explore the solutions for the concrete industry to promote circular economy. Finally, it will describe the most probable paths towards carbon neutral concrete and how they will inevitably include environmental footprint reduction beyond climatic impact.

Keywords: *Carbon Neutrality; CO_2 Reduction; Low-Carbon Binder; IoT Technology; Sustainability.*

1 Introduction

This introduction provides an overview of the dissertation's topic, which focuses on the challenges, innovations, and opportunities associated with the cement and concrete industry's transition to sustainable practices. It highlights the environmental concerns that have led to changes in the industry and discusses the strategies being employed to reduce its environmental impact, including the use of alternative binders, supplementary cementitious materials, and low carbon cement technologies. The introduction also emphasizes the challenges the industry faces, such as meeting the demands for high-strength and durable concrete, vertical construction, and modular construction, and highlights the importance of innovations in production and application to reduce the industry's overall environmental footprint. Finally, it discusses the impact of the French RE 2020 regulation on the industry and the importance of eco-design, recycled materials, and wastewater treatment in achieving sustainable practices. Overall, this introduction effectively sets the stage for the dissertation's exploration of the cement and concrete industry's journey towards sustainability.

2 Construction Changes Towards Sustainability is accelerating

The construction industry aims to reduce greenhouse gas emissions and limit global warming, as set out in the COP26 summit. To achieve these goals, the industry must focus on reducing the GWP of construction materials and processes. Market drivers and innovative materials are accelerating this transition, with demand for materials that support taller structures, alternative methods, and improved energy efficiency. Examples like engineered wood products (CLT, GLT …) offer structural performance, design flexibility, and ease of installation, while precast construction methods are becoming increasingly favourable in achieving significant reductions in CO_2 emissions.

The cement and concrete industry are transforming towards sustainability driven by net zero targets, innovative materials, and supportive regulations like the French RE 2020. This multi-faceted approach includes optimizing concrete production, reducing emissions from cement and binder production, and improving efficiency in design and construction. The French RE 2020 incentivizes the adoption of low-carbon concrete and construction techniques, creating a comprehensive framework for addressing the environmental impact of buildings throughout their life cycle. By prioritizing sustainability efforts, the construction industry can significantly reduce its environmental impact and contribute to a more sustainable future.

Saint-Gobain (Chryso-GCP) is committed to leading the way in sustainable construction, as the industry is responsible for a significant portion of global CO_2 emissions, waste, and resource consumption. Innovation is at the core of the company's strategy, with a focus on improving production processes and developing solutions that are virtuous throughout their lifecycle. Emerging technologies, such as those explored in a recent white paper on affordable, sustainable housing, are also a key area of focus. Saint-Gobain has a Catalog of Innovations and has partnered with material science laboratories to extend the life of materials and reduce their carbon footprint.

3 Cement additives and Concrete Admixtures: A Critical Role

Cement additives and concrete admixtures are vital for the sustainable transformation of the cement and concrete industry. They enable the production of blended cement, new binders, and low environmental impact concrete, significantly reducing the industry's carbon footprint. Proper selection of polymers, inhibitors, and hydration catalysts is essential for achieving desired performance and sustainability outcomes. Dedicated services, including mix-design expertise and CO_2 content calculation, are necessary for successful implementation.

Blended cement and new binders production enable innovative cement compositions with new mineral blends and supplementary cementitious materials (SCMs), promoting sustainable and energy-efficient cement manufacturing. Production enablers for low environmental impact concrete develop new binders and concrete with improved performance while minimizing environmental harm. Collaborative approaches combined with these innovations result in high-performing and environmentally responsible construction materials.

Ultra-Low Carbon Concrete (ULCC) is gaining popularity as the construction industry aims to reduce its environmental impact. Cement additives and concrete admixtures play a crucial role in driving the cement and concrete industry towards greater sustainability.

Table 1: Examples of Ultra-Low Carbon Concrete

Concrete Type	Reference CO_2 (kg/m^3)	ULCC CO_2 (kg/m^3)	CO_2 Reduction (%)
C35/40 - S4 - XF1 (3500 psi - 8' slump)	250	100	60
C25/30 - S4 - XF1 (3500 psi - 8' slump)	240	120	50

Innovative binders in concrete formulations can significantly reduce environmental impact, as shown in Table 1. Ultra-Low Carbon Concrete with 100% activated GGBS achieves a 60% CO_2 emissions reduction, while flashed clay binder reduces emissions by 50%. These examples demonstrate that ULCC can overcome rheology and workability challenges, making it a vital component of sustainable construction. CHRYSO's EnviroMix® offers admixtures and services to optimize concrete formulation and reduce CO_2 emissions.

CHRYSO® EnviroMix has extensive experience in multiple climates and offers a cutting-edge solution for low carbon concrete development. It employs polymers, inhibitors, and hydration catalysts to disperse clinker, control shrinkage, and achieve desired rheological properties. Performance targets include no retardation, flash setting, or extreme thixotropy, early strength acceleration, and workability retention. CHRYSO's R&D expertise has led to the development of specific polymers, catalysts, durability approaches, and CO_2 content calculation.

CHRYSO® EnviroMix Impact is a dedicated service that calculates the greenhouse gas impact of customers' current concrete mix and the targeted mix design using CHRYSO® EnviroMix Technology. This tool provides a comprehensive life cycle analysis, including impacts on GHG emissions, air pollutants, ecosystem services, resource extraction, and water pollution and consumption.

CHRYSO® offers tailored solutions for cement producers, concrete producers, and contractors, including process optimization, low and ultra-low carbon concrete admix solutions, and strength and demoulding prediction. The CHRYSO® EnviroMix Impact tool is undergoing certification for an Environmental Product Declaration (EPD). Collaborating with partners and customers, CHRYSO® aims to build a sustainable, low carbon future for the construction industry. By combining strengths and efforts, innovative solutions can meet the evolving needs and ambitions of the global construction market.

GCP Applied Technologies offers a wide range of sustainable construction products that reduce CO_2 emissions and costs while maintaining high performance. GCP at products cover various stages of the construction lifecycle, including cement and concrete production, delivery, placement, curing, and the concrete life cycle.

GCP's cement additives (OPTEVA®, TAVERO®, and CLARENA®) decrease clinker usage and energy consumption in cement production. Water reducers (ADVA®, MIRA®, DARACEM®, and ZYLA®) reduce the need for cement and water in concrete mixes. Control-flow admixtures (CONCERA®) improve concrete rheology, and accelerators, retarders, hydration stabilizers, viscosity modifiers, corrosion inhibitors, alkali-silica mitigators, shrinkage reducers, air entraining agents, and fiber reinforcements enhance concrete durability and performance. Supplementary cementitious materials (HRMK® 100 Metakaolin and Force®

10,000D Silica Fume) improve concrete performance. GCP's VERIFI® system monitors concrete consistency in transit, reducing rejected loads and enhancing operational productivity.

GCP's cement and concrete additives have demonstrated carbon emission savings of 14%, with the potential for even greater reductions. These products offer CO_2 and cost reductions while maintaining high performance and quality, making them ideal for sustainable construction.

Industrial case study 1 – Pozzolan Cement

Industrial Case Study 1 demonstrates the successful use of CO2ST® Reducer technology to produce a pozzolan cement with lower clinker content and reduced CO_2 emissions while maintaining the same performance as existing Type I cement. Results from the field trial revealed a 6 MPa increase in strength at 28 days compared to the current quality improver additive, which could potentially result in an 8% reduction in clinker content.

Table 2: First Industrial Trial with CEM I 42.5R (6 MPa -> potential 8% less clinker)

Parameter	Dose (g/t)	Blaine (cm^2/g)	R45 (wt%)	LOI (%)	$CaCO_3$ (%)	2d Strength (MPa)	7d Strength (MPa)	28d Strength (MPa)
Reference Quality Improver	500	3480	3.8	2.5	4.1	29.5	42.7	53.5
CO2ST® Reducer	1000	3505	4.1	2.8	4.8	30.2	45.6	59.4

Clinker Reduction:

The CEM II/A-P cement, with 4% limestone, 8% pozzolan, 5% gypsum, and 83% clinker, has an 8% lower clinker content than the CEM I cement. The CO2ST® Reducer at a dosage of 900-1000 ppm successfully achieved the target performance.

Table 3: Long-term industrial trial with CEM II/A-P 42.5R (8% less clinker)

Parameter	Production (Mton/y)	Additive	Dosage (g/ton)	R2 Strength (MPa)	R28 Strength (MPa)
CEM I 42.5 R	1.15	Reference	500-600	27-29	55-56
CEM II/A-P 42.5 R	0.5	CO2ST Reducers	900-1000	28	56

Carbon Reduction and Cost Savings (Potential reduction: 9% CO_2 and 1.7 m€/year):

Using CO2ST® Reducer technology resulted in an 8% clinker replacement, reducing CO_2 emissions by 60 kg/ton of cement, equivalent to a yearly reduction of around 30,000 tons of CO_2 or 9%. At an ETS CO_2 price of €50/ton, this translates to potential savings of up to 1.7 million euros per year.

Industrial case study 2 – Geopolymers:

This case study aims to achieve a more eco-friendly and more cost-effective product by reducing cement usage while maintaining strength. Using geopolymer mix designs and limited

to customer materials, the goal is to achieve comparable strengths to OPC with less cement. The CO2ST® Reducer mix design effectively reduces cement content, CO_2 emissions, and cost while maintaining strength and performance. The new mix design reduces CO_2 emissions by 58 CO_2/m^3 and saves $1.78 per cubic meter. The compressive strength of the CO2ST® Reducer mix improves significantly at all ages compared to the reference mix, demonstrating the potential for sustainable, high-performance concrete solutions.

Table 4: Customer Lab Trial

Mix Design	Cement	Fly ash	Slag	CO_2/m^3	$/m^3
Reference mix design	100%	0%	0%	-	-
CO2ST® Reducer mix design	15%	15%	70%	58	1.78

Enhancing Lower Quality Aggregates:

Lower quality aggregates can create problems in concrete production, such as reduced workability, lower strengths, challenging rheologies, and high variability. Admixtures like CLARENA® can selectively absorb clay particles and mitigate the detrimental effects of clay on concrete properties. This leads to improved workability, strength, and rheology of the concrete, ultimately reducing costs and embodied CO_2 emissions. Admixtures designed to enhance lower quality aggregates create more sustainable and cost-effective concrete solutions.

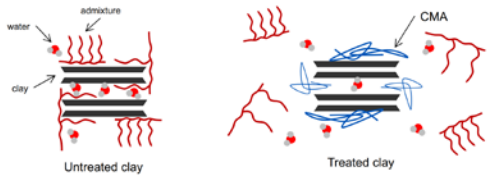

Figure 1: Working Mechanism of Clay Mitigating Admixture (CMA)

Industrial case study 3: Clay Mitigating Admixtures and CO2ST® Reducer

This case study demonstrates the effectiveness of CO2ST® Reducer, a clay mitigating admixture, in enabling the use of lower quality aggregates while maintaining workability retention. The technical target is to maintain current workability levels with high-clay content aggregates, reducing admixture dose and low-quality aggregates. The lab trials show it's possible for the use of lower quality aggregates without compromising workability. This ultimately leads to more sustainable and cost-effective concrete manufacturing practices.

- Admixture reduction (L/m^3): 0.5
- Aggregate value ($/m^3$): 4

Improving Placeability and Finishing with Next Generation Rheology Modifiers

Next-gen rheology modifiers, such as CONCERA®, improve the placeability and finishing of concrete, resulting in cost and environmental benefits. These admixtures increase workability without additional cement, leading to cost savings and reduced environmental impact. They also improve the rheological properties, enhancing durability and reducing maintenance costs, and improve placement efficiency, increasing construction productivity. The use of CONCERA® promotes sustainable and cost-effective concrete manufacturing, reducing the environmental impact of the construction industry.

4 VERIFI®: A Flagship IoT Solution for Transit Concrete Management

VERIFI® is an IoT-enabled system developed by GCP that monitors, measures, and manages concrete products in transit to ensure they are delivered in-spec every time, providing improved materials management, operational efficiency, and commercial leverage. The system has been adopted by the industry at an increasing rate, with 6000 trucks equipped in 2020. The system can be installed on new or existing trucks and includes components such as a computer processor, admixture tank, and hydraulic pressure sensors. The VERIFI® system developed by GCP revolutionizes the industry by bringing significant value to the ready mix concrete industry in four key areas: operational productivity, materials management, commercial leverage, and sustainability. The system increases concrete production output, shortens cycle times, improves asset utilization, and extends asset life. It optimizes admixture and cement use, reduces waste and material consumption, and minimizes returned concrete. The improved quality of concrete produced with VERIFI® allows for higher market prices and fosters transparency and trust with customers. The system also enhances sustainability by reducing raw material and fuel consumption and lowering waste generation. The VERIFI® In-Transit system generates savings across numerous areas and enables business model transformation through the integration of data, intelligence, material science, and construction knowledge. VERIFI® also allows for reduced overdesign, resulting in lower material costs.

5 Conclusion

The construction industry is undergoing a major transformation towards sustainability to reduce its significant environmental impact. Saint-Gobain, along with its affiliated brands Chryso and GCP, is at the forefront of the drive towards sustainable construction, with innovative products and solutions that reduce CO_2 emissions, improve efficiency, and promote sustainable practices. Innovative solutions like next-generation concrete additives, IoT-enabled systems, and sustainable materials are contributing to more sustainable and cost-effective concrete production processes. The industry's move towards sustainability requires a multi-faceted approach, including improving efficiency in design and construction, optimizing concrete production, and reducing emissions from cement and binder production. Regulatory frameworks like the French RE 2020 are also incentivizing the industry to adopt innovative, low-carbon materials and construction techniques to meet stringent sustainability requirements. The development of sustainable infrastructure with minimal environmental impact is crucial for achieving ambitious net-zero targets set at the COP26 summit to limit global warming and reduce greenhouse gas emissions. VERIFI® is a revolutionary IoT-enabled system that has been

widely adopted in the ready mix concrete industry, offering significant value in terms of materials management, operational efficiency, commercial leverage, and sustainability. With its ability to increase concrete production output, improve asset utilization, and reduce waste generation, the VERIFI® system enables business model transformation and generates savings in multiple areas, making it a valuable investment for producers.

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