Activated Cement Paste: a novel supplementary cementitious material (SCM)

everox guide to unlocking 100% concrete circularity

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Abbreviations

Activated Cement Paste	ACP
Recycled Coarse Aggregates	RCA
Recycled Fine Aggregates	RFA
Fine Inert Filler	FIF
Concrete Demolition Waste	CDW
Supplementary Cementicious Materials	SCM

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Phasing out virgin materials in concrete.

Introduction

Concrete is the backbone of modern society. It takes many forms such as blocks, pre-cast elements, reinforced structures, and so on. The versatility of concrete coupled with its cheaper cost, ease of use, and wide-spread availability of raw materials make concrete the second-most consumed material, next only to water. Despite the intrinsic lower carbon footprint of concrete compared to other construction materials, the usage of huge volumes of concrete around the world is leading to higher CO_2 emissions. Cement, the key binder component in concrete, is the major contributor and responsible for approximately 8% of global anthropogenic CO_2 emissions. [1]

According to GCCA[2] since 1990, a 23% emissions reduction in CO_2 per ton of cement has been achieved through efficiency gains. Still, the global construction demand continues to grow, so the CO_2 reductions per ton doesn't directly translate to a decline in global CO_2 emissions from the cement industry. The current carbon footprint stands at 800-900kg CO_2 per ton of clinker (intermediate product of cement production). To make cement greener, there exist many possible pathways, with one of the most practical solutions being replacing cement with supplementary cementitious materials (SCMs).

Current European standards for cement composition (EN 197-1 to EN 197-6) include 38 common blended cement compositions, and this number will increase with many more upcoming cements to be standardized. The traditional SCMs are fly-ash and slag, both bi-products of heavy industry (coal firing and steel production) which are intrinsically linked with CO_2 emissions. With time, the traditional SCMs are decreasing in availability either due to shutting down of coal-fired power plants (fly ash) or transitioning of blast furnace industries (slag). Hence, newer SCMs with widespread availability and high reactivity are needed to replace the traditional SCMs. This need is ever more pressing, as decreasing SCM availability is leading to an increase in clinker in cement globally.

The increasing demand for new SCMs led to the expansion of European standards to include calcined clays (EN 197-5) and recycled concrete fines (EN 197-6). The advantage of recycled concrete fines (RCFs) is the global availability of construction and demolition waste (CDW), especially in regions with fast growth of the built environment [3]. The main challenge, however, is to produce "consistent and high quality" RCFs from CDW.

Fig. 1: Annual concrete waste market

Recycled Concrete Fines – opportunities and challenges

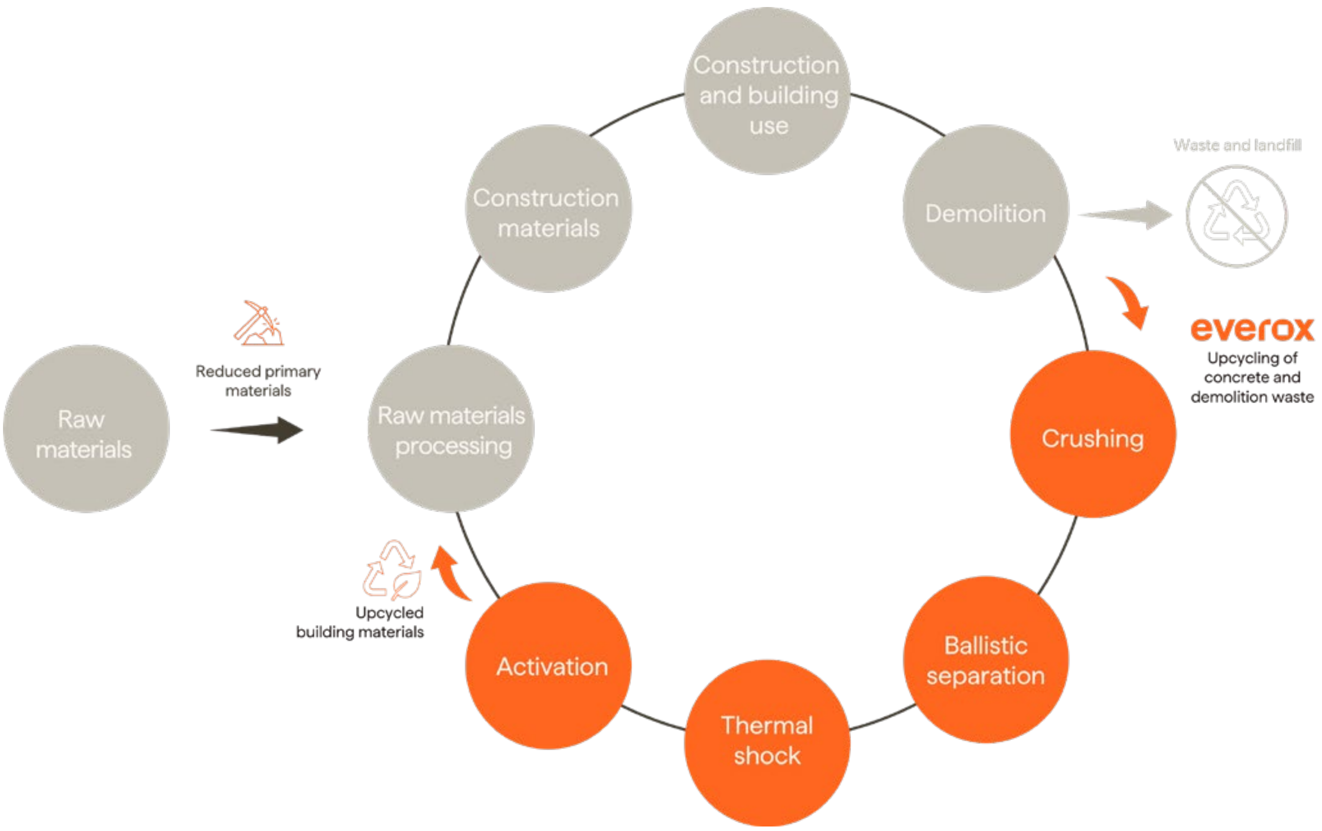
CDW typically includes concrete, bricks, mortar, tiles, metal, timber, plasterboard, asphalt, plastics, glass, rock and soil [4]. Every year, more than 3.5 billion tons of waste concrete is generated, which could potentially produce 1 billion tons per year of cementitious material. Europe alone generates about 350 million tons of CDW per year[5]. It is not practical and sustainable to landfill these enormous volumes of waste concrete. To tackle this problem, recycling of waste concrete is a viable option, where EoL concrete is crushed to produce new materials.

Common crushing techniques include a combination of jaw crushers and secondary impact crushers. A sieving step is included after crushing to obtain coarse and fine recycled aggregates. Although crushing and sieving EoL concrete is a viable solution to dispose of the EoL concrete, the final products are generally downcycled and used in low-grade applications, such as a base or sub-base material in road construction.

The main reason for this downcycling is due to the high porosity of recycled aggregates, mixed composition, presence of contaminants.

The key challenge to improve the quality of recycled aggregates lies in efficiently removing the adhered cement paste from recycled aggregates. This adhered cement paste is responsible for higher porosity and water absorption of recycled aggregates, which limits the usage of these aggregates. Recycled aggregates with higher liberation rates of adhered cement paste have two-fold advantages: 1) The water absorption of recycled aggregates reduces, leading to the possible usage of these aggregates in structural concrete, 2) the extracted cement paste can be activated and used as an SCM. However, crushing and sieving alone is not sufficient to liberate cement paste from the recycled aggregates.

Fig. 2: The everox concrete upcycling scheme



Patented upcycling technology and outcome products

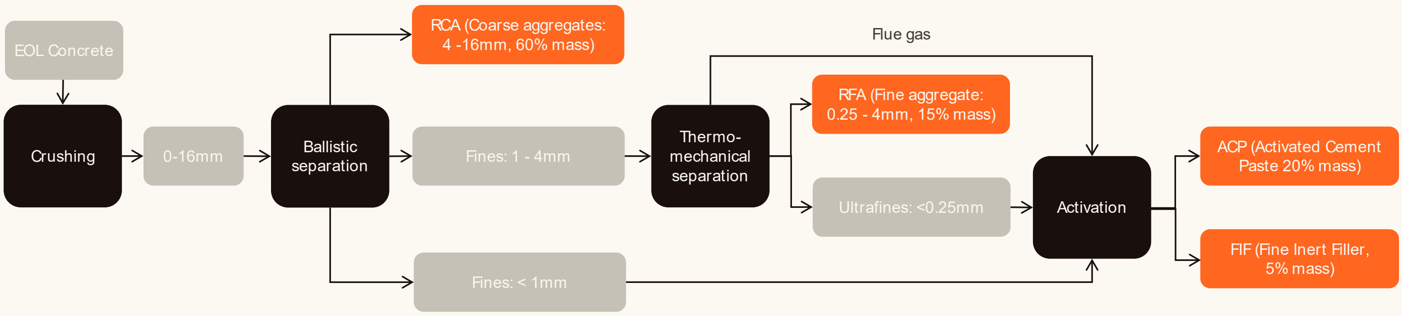
everox aims to unlock concrete-to-concrete circularity by upcycling 100% EoL concrete into aggregate, sand, and SCM. With a vision to phase out the use of virgin materials in new concrete, everox's aim is to generate a high yield of high reactive SCMs from waste concrete from its patented process, which involves a combination of crushing, ballistic separation, thermo-mechanical separation, and activation.

The first step of two-stage crushing with jaw and cone crushers, downsizes the EoL concrete to smaller 16mm fraction, with some cement paste liberation.

A measurement of surface cement paste on the aggregates determines the ratio of recirculation to second stage crushing to liberate cement paste. The second step involves the ballistic separation, which sorts input crushed concrete waste (0-16mm) into three product streams:

coarse aggregates (4-16mm), air knife fines (1-4mm), and rotor fines (<1mm). In the next step, the air knife fines (1-4mm) fraction is subjected to flash heating to thermo-mechanically extract the cement-rich thermo-fines (<0.25mm). The final step is to activate the rotor fines and thermo-fines and convert them into an SCM.

Fig. 3: everox upcycling process



Crushing

2 stage crushing with jaw and cone crusher, downsizing EOL to smaller 16mm and liberating cement paste.

Ballistic separation

Seperate coarse and fines. Dry process (no sludge), ability to handle moist input material (no dust), mobility flexibility.

Thermo-mechanical separation

Separate fines & ultrafines. Remove moisture, remove undesirable contaminants (e.g., wood and plastic).

Activation

Mechanical, thermal and carbonation treatment to activate the ultrafines and transform them into a SCM.

For a given amount of input waste concrete, the breakthrough everox process yields 60% clean recycled coarse aggregate (RCA) with water absorption < 4%. The dry and clean fine aggregate (RFA) fraction of 1-4mm accounts for 15% yield, with water absorption < 7%. Both these aggregate fractions are BRL 2506-1 certified.

The cementitious binder replacement comes in two forms: 1) activated cement paste (ACP), 2) fine inert filler (FIF). FIF accounts for 5% yield, with approximately 90% quartz content and size fraction<125 microns. The key novelty with everox upcycling process is the production of a reactive cement substitute – Activated Cement Paste (20% yield).

everox Activated Cement Paste as an upcycled SCM

The conventional concrete recycling techniques include crushing and sieving, which are not effective in liberating the adhered cement paste from aggregates. However, everox's process includes a recirculation of coarse fraction into the thermo-mechanical separation step that creates selective delamination at the cement paste-aggregate interface, leading to efficient liberation.

This process leads to a high yield (20%) of recycled cement paste. Before the carbonation step, this RCP is selectively milled to a fineness equivalent to cement (Dv,50 = 10 microns), and this product is called quartz-depleted RCP, which is moderately reactive.

Carbonation of quartz-depleted RCP leads to amorphization of hydrated phases leading to the formation of amorphous silica gel, which is very reactive.

The other phase formed through carbonation is calcium carbonate, which can act as an effective filler and accelerates the hydration reactions.

The carbonation process conditions are optimized such that some amounts of reactive calcium carbonate phases (vaterite and aragonite) are also formed.

Overall, this Activated Cement Paste (ACP) is a combination of reactive silica gel, both inert and reactive calcium carbonate phases, and some other mineral phases.

R3-reactivity test is the standard testing method to evaluate the pozzolanic reactivity of any SCM. As seen above in Figure 4, as of 2025, the industrial R3-reactivity of the Activated Cement Paste (ACP) is in the range of 150-200 J/g SCM. This reactivity is comparable to low to mid calcium oxide Fly ashes. In addition, the strength activity index (SAI) results at 28 days of cement blends with 25% and 50% replacements of ACP are standard compliant with more than 75% and 40% SAI respectively. In fact, when cement is replaced by 25% ACP, SAI is close to that of typical CEM I, showcasing the great potential of the SCM.

Fig. 4: R3-reactivity of SCMs, including everox ACP

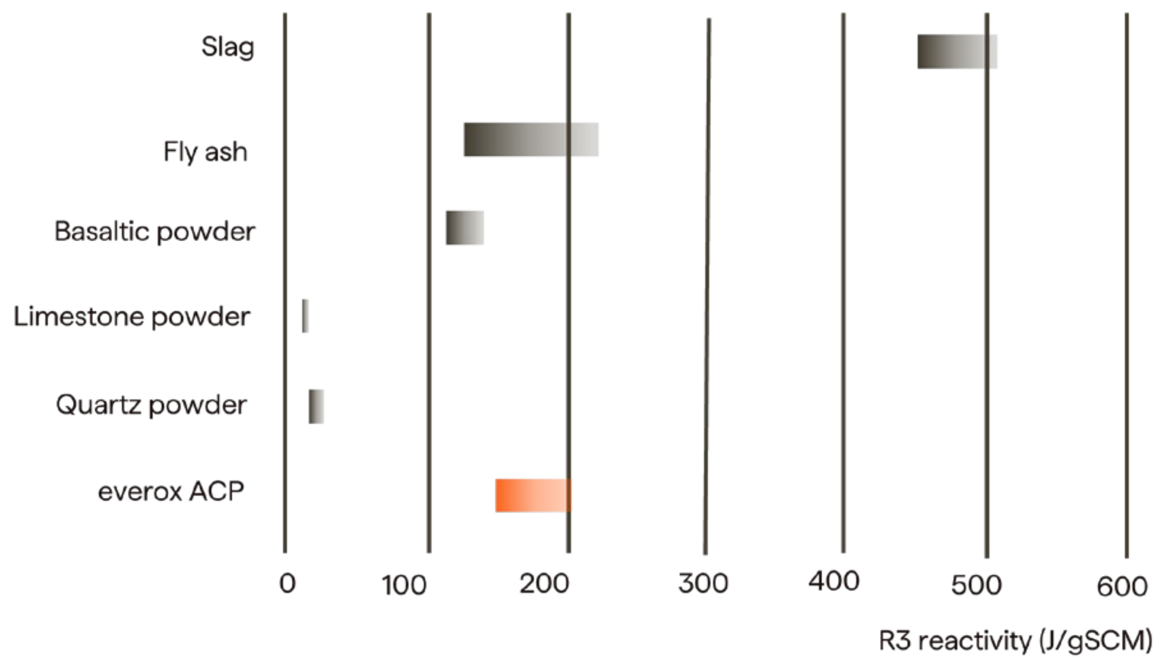
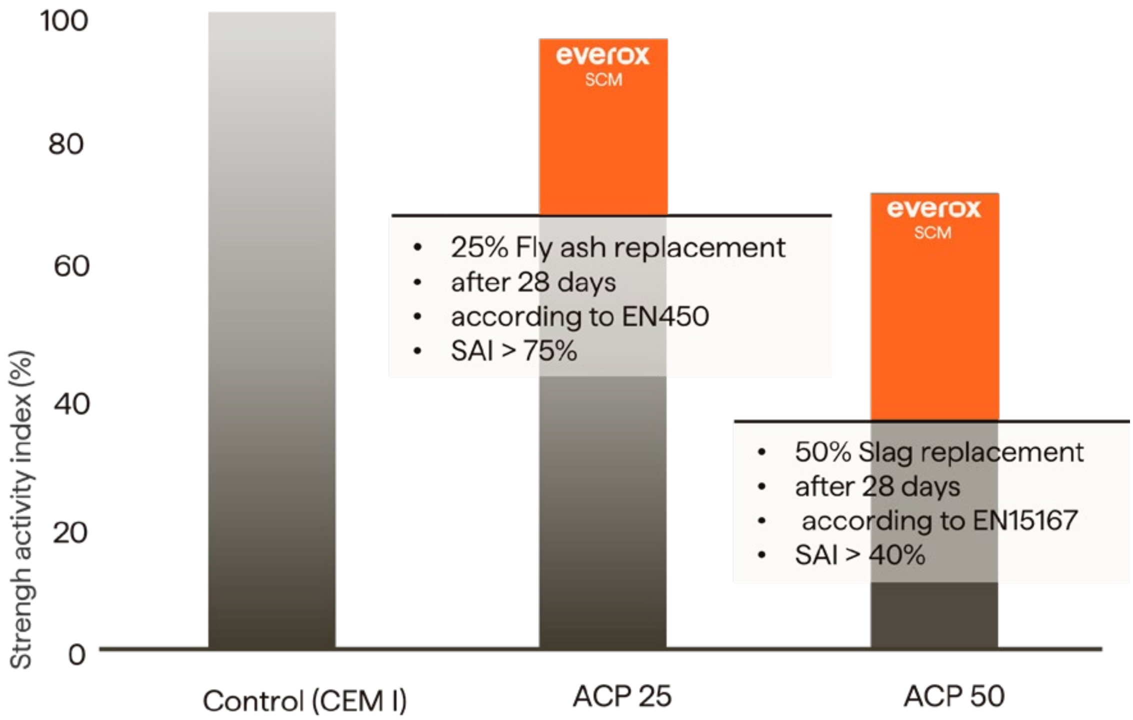


Fig. 5: Strength activity index (%)



Specifications

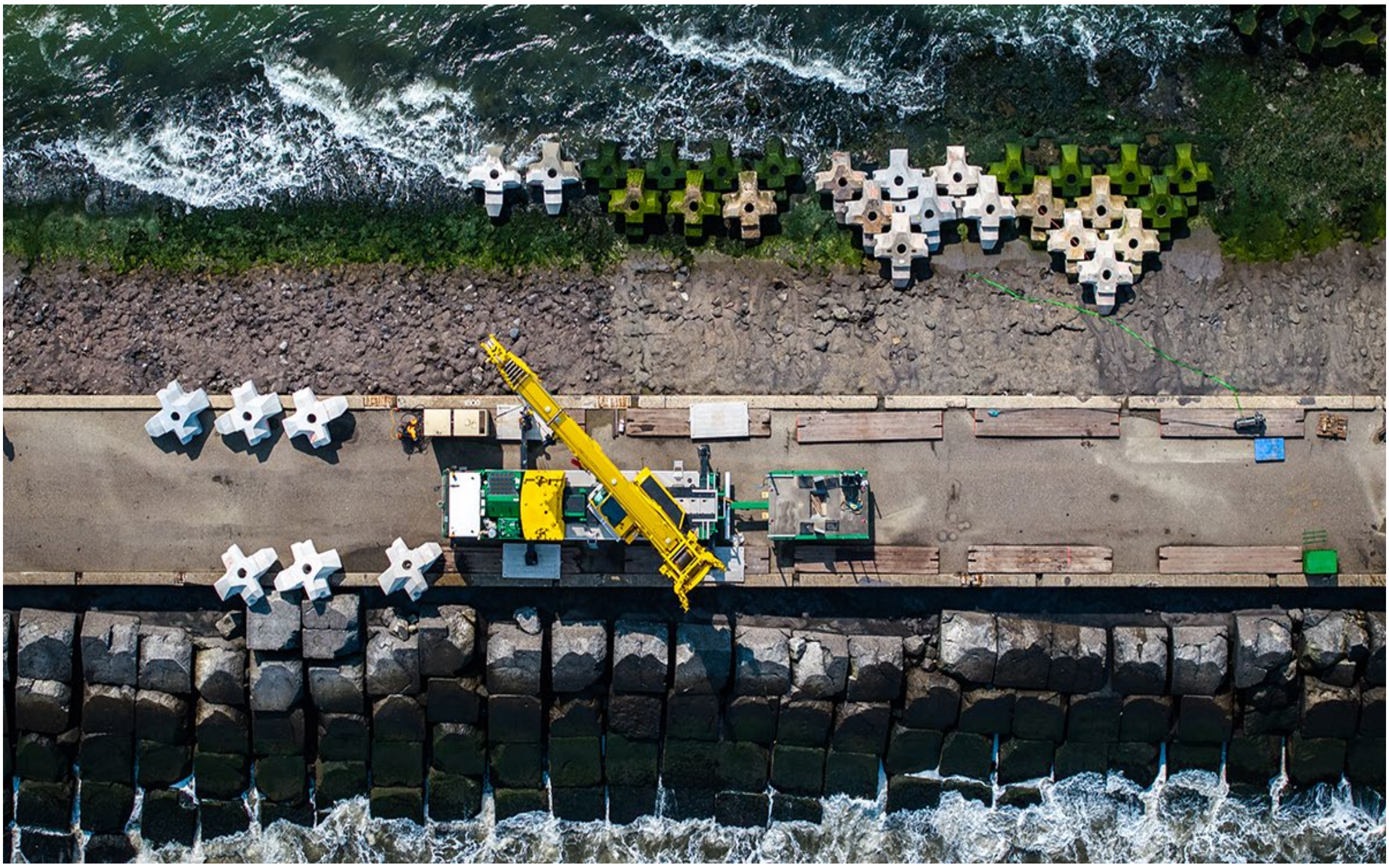
- Particle size: < 0.063 mm
- Medium particle size (D50): 10 µm
- Fineness: 5000 cm^2/g ± 15%
- Moisture: < 1.5%
- High cement paste content through quartz removal process
- Enhanced reactivity and durability via activation treatment
- Minimal chloride and sulphate content ensuring long-term durability

Compliance

- Relevant standards: EN 197-6: 2023 for RCP CEM II/X-F, CEM II/X-M and CEM VI
- KOMO certification according to updated BRL1804 (pending Q2 2026)
- KOMO certification according to updated BRL1802 (pending Q4 2026)

Applications

- Ready-mix concrete
- Cement blends
- Precast concrete elements
- Dry mortar blends
- Enables full concrete-to-concrete upcycling



Case Study at the living lab at the South Pier in Ijmuiden, Netherlands

The practical relevance of everox technology is demonstrated through the "Living Labs" project. everox concrete blocks were used to construct the Living Lab on the south pier of a port town IJmuiden (Netherlands), an initiative led by Rijkswaterstaat. The main objective of this project was to demonstrate that recycled materials can sustain the harshest of conditions and still deliver performance equivalent to conventional concrete. The everox blocks were continuously exposed to marine water (chloride ingress), tidal forces, and freeze-thaw cycles. The durability performance of these blocks is continuously monitored to demonstrate the long-term resilience of everox materials in real-world conditions.

The concrete mix design in this project included replacement of all coarse aggregates with everox RCA. Half of the fine aggregates were also replaced with everox RFA. Interestingly, 30 percent of cement was replaced with Activated Cement Paste. This mix design is not only promoting circular products, but has significantly lower CO2 footprint compared to conventional concrete mixes. Laboratory trials showed that the test mix designs with everox materials met the strength and exposure class requirements.

Chloride resistance (Rapid Chloride Migration), shrinkage and freeze-thaw tests were conducted and were used to optimize the concrete mix design.

everox concrete test blocks with an optimized mix design achieved a compressive strength of 52.3 MPa after 28 days (C40/50 strength class). This superior mechanical performance clearly shows the value of Activated Cement Paste as a potential cement replacement. It clearly indicates the wasted potential of EoL concrete going into landfills, which could be harnessed to liberate a large amount of RCP, process with everox technology, and convert it into a valuable SCM product. This reduces the usage of virgin materials and reduces the CO2 emissions of concrete drastically.

Conclusions

High-quality recycled concrete fines: A key to decarbonizing cement

Concrete is the past, present, and future of the global construction industry. With enormous volumes of concrete consumption around the world, the CO2 footprint of concrete needs to be lowered to achieve the Net Zero 2050 targets. The fastest way to achieve this is to replace cement (clinker) with supplementary cementitious materials (SCMs). Among all the SCM options, Recycled Concrete Fines (RCFs) are one of the most promising materials with their potential yet to be exploited on a large scale. The integration of RCFs into European cement standard EN 197-6 calls for the need to produce consistent and high-quality RCFs.

Revolutionizing SCMs with everox's Activated Cement Paste technology

The traditional methods of crushing and sieving to liberate adhered cement paste from the recycled aggregates are not efficient to produce a reactive SCM. This opportunity has been capitalized by everox through producing Activated Cement Paste with R3-reactivity of 150-200 J/g SCM (similar to Class F fly ashes). In addition, the strength activity indices of ACP-blended cements exceeded the values prescribed by the standard, indicating the strength-contributing potential of ACP. These results were achieved due to the processing of waste concrete via everox patented processes of crushing, ballistic separation, thermo-mechanical separation, and activation.

From lab to reality: structural validation of Activated Cement Paste

Among other reference projects, Activated Cement Paste was used to replace 30 percent of cement in the concrete mix design of the "Living Labs" project. This move has been a testament to the real-life structural performance of Activated Cement Paste, validating the positive trends observed at the laboratory tests. In fact, the Living Labs project includes exposing the concrete blocks to extreme environmental conditions, showcasing the durability potential of Activated Cement Paste.

From waste to performance: The three pillars of ACP success

The key to Activated Cement Paste's successful results can be attributed to the technological innovation at each step:

1) At the processing stage, the crushing and liberation steps to harvest a high yield of reactive component.

2) At the activation stage, the choice of activation steps and conditions to achieve higher intrinsic reactivity and mechanical strength of the output Activated Cement Paste.

3) At the application stage, the emphasis on the testing of the materials beyond laboratory in real-world conditions to demonstrate the potential of Activated Cement Paste.

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