Final technical e-publication 2021

# HOW TO SHAPE A CIRCULAR FUTURE FOR THE CONSTRUCTION SECTOR

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# VEEP PROJECT :

# Final technical e-publication - 2021

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# HOW TO SHAPE A CIRCULAR FUTURE FOR THE CONSTRUCTION SECTOR

Around 461 million tons of Construction and Demolition Waste (hereafter CDW), excluding excavation materials, are yearly generated in the European Union and concrete is the most used material.

Over the last years, novel technology has been developed aiming to guarantee high quality recycled concrete aggregates for use in new concrete manufacturing, thereby closing the concrete loop.

The most advanced concrete recycling technologies currently produce upgraded coarse (>4mm) recycled concrete aggregates by removing cement paste and fines from the surface of the aggregates.

However, the fine (0-4 mm) fraction, accounting for roughly 40% of the recycled concrete, still faces technical barriers to be incorporated into new concrete and consequently, it is often down-cycled.

At the other extreme, there are minor (e.g. glass) and emerging (e.g. mineral wool) C&DW materials, currently accounting for 0.7% of the total generation, but revealing growing rates till 2030, as consequence of the European regulations on building energy efficiency and building retrofitting.

In global terms, those emerging CDW streams have not yet found technological and business solutions along with their whole circular supply chain, being mostly landfilled.

*In this context, the main objective of VEEP has been to develop and demonstrate a series of technological solutions for the massive retrofitting of our built environment, aiming at cost-effectively reducing building energy consumption.*

*Moreover, VEEP developed the following innovative construction materials:*

- *A greener and more resistant Silica Aerogel, which is one of the best material for the insulation application*
- *A new and green concrete (normal weight and lightweight)*
- *Two novel multilayer Precast Concrete Elements (PCEs) through the smart combination of VEEP concrete, aerogel composites and innovative plastic formworks*

VEEP Project Consortium focused on the production of aggregates and micro-fibers and on the consolidation of materials and manufacturing development.

In particular, an Advanced Drying Recovery (ADR), a mechanical system of sorting and classifying wet CDW particles according to their particle size, has been assembled in Hoorn (the Netherlands) to fulfil the mobility requirements. VEEP ADR new design allows to fit the truck reducing the assembling/disassembling from 7 days to just 1 day.

**The ADR system has a capacity of treatment of 50t/h. The ADR can treat aggregates of any composition with a size 0-16 mm.**

A novel Heating **Air Classification system (HAS) has been also developed to treat the aggregates with a size 0-4mm**. Such technology is designed to further expose the fine fraction aggregates into a hot gas so as to remove the associated moisture of aggregates and also destroy undesirable CDW contaminants. **A HAS pilot plant (3ton/hour) has been developed at the Delft University (TUD).**

In relation to the **concrete aggregates treatment technologies patent application has been filed by TUD and granted** (30.09.2019/PCT/NL2019/050653, IPN: WO 2020/071906 A1).

The HAS technology has been shown to improve the quality properties of the ultrafine recycled particles in an important way for its application as an additive in new green cements.

The ADR and HAS integration technologies represent a step forward in the market of treating CDW as it makes it possible to reduce the end of life concrete to aggregates, sand and ultra-fines which are suitable to use in the production of new concrete.

Within VEEP project two types of ultrafine recycled concrete particles (either siliceous or limestone end of life concrete waste) were treated in the pilot HAS technology for their conversion into Supplementary Cementitious Material (SCM). The physic-chemical effect of the ultrafine recycled concrete particles and their potential use as SCM in new cement-based products was assessed by employing substitutions of up to 10% of the conventional binder.

*Figure 1. Laboratory equipment for the manufacture of standard mortars and cement control @Tecnalia laboratory*

HAS technology is designed to remove both water content and impurities , while enriching the materials with CaO, $SiO_2$, $Al_2O_3$, $Fe_2O_3$ components, and with amorphous content containing hydrated phases of cement pastes (C–S–H). These improvements provide the product with physic-chemical properties that mean it can be employed as SCM in new cement-based products for the reduction of up to 5% of the cement content.

A combination of the seed effect, the filler effect and cementing activity, regenerated through the dehydration process of the initial C–S–H following HAS heat treatment, can improve the hydration (Figure 2) and the mechanical properties both at early and advanced ages (Figure 3), when employed in partial replacement of up to 5% of commercial CEMII Portland cement[1].

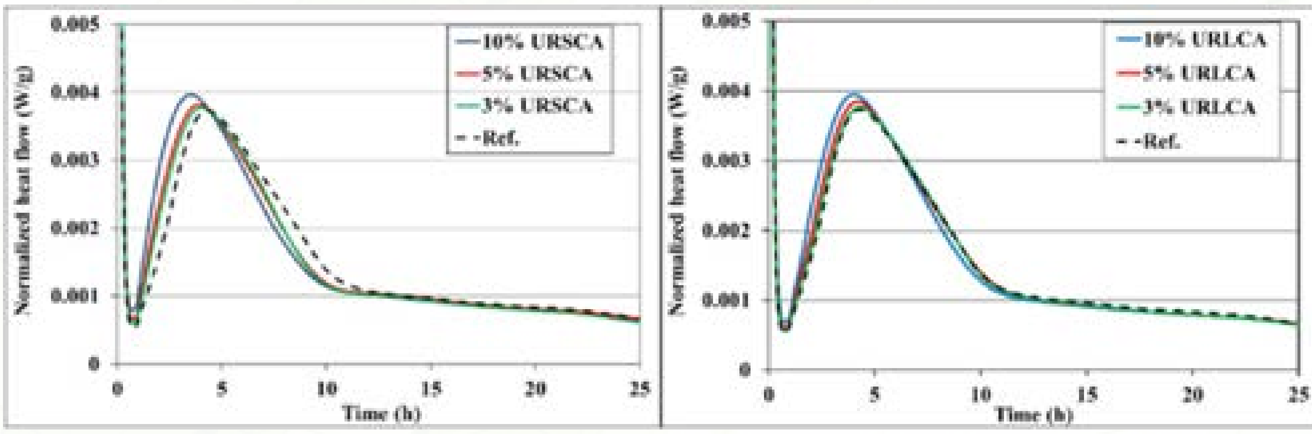


*Figure 2. Normalized heat flow of cement pastes*

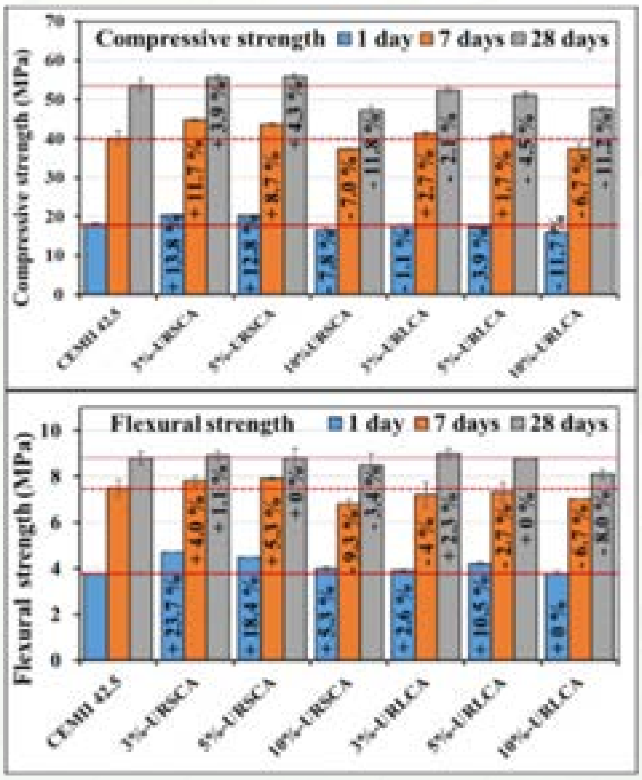


*Figure 3. Compressive and flexural strength of mortar pastes blended with ultrafine recycled concrete additions*

The results suggested that the overall environmental impact could be reduced by up to 5% when employing the ultrafine recycled concrete particles as SCM in circular cement-based products, reducing greenhouse gas emissions by as much as 41 kg $CO_2$ eq./ton of cement.

The integration of ADR and HAS Technology (that would help to commercialize recycled demolition aggregates at a competitive price) has also been analyzed and tested by project partners TUD and Strukton.

[1] *J. Moreno-Juez, Iñigo J. Vegas, Abraham T. Gebremariam, V. García-Cortés, F. Di Maio, Treatment of end-of-life concrete in an innovative heating-air classification system for circular cement-based products, Journal of Cleaner Production, Volume 263, 2020, 121515*

Concerning the materials development, a new green concrete and a new concrete aerogel have been developed. In relation to the aerogel production one of the main goal was to optimize the aerogel synthesis with the silica solutions produced from silica-rich CDW recycled materials. Experimental activities conducted among several waste sources to confirm that siliceous concrete waste fractions are the most promising materials for the preparation of cost-effective aerogel composites. The level of impurity and other residues plays a crucial role in the final economy of the process. Keey Aerogel designed, installed and validated a production site integrating the transformation of silica-rich waste.

*Figure 4. VEEP green aerogel*

Sustainable concrete were optimized by incorporating recycled concrete aggregates and ultrafine recycled particles retrieved from the processing through the ADR+HAS technology of construction and demolition and demolition wastes (CDW). Both recycled coarse aggregates (RCA) and recycled fine aggregates (RFA) were employed to fully replace the natural coarse and fine aggregates in the concrete mix design.

Based on the results achieved in this project[2], it was concluded that it is possible to fully replace natural coarse and fine aggregates with recycled coarse and fine aggregates without compromising the mechanical properties of the concrete. The use of the novel technology (ADR + HAS) allows to improve the performance of recycled aggregates and, therefore, the behaviour of recycled concrete with a total substitution of both coarse and fine aggregates (Figure 5).

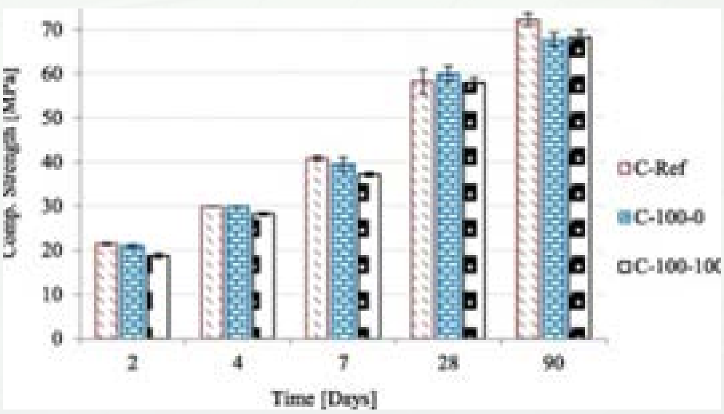


*Figure 5. Compressive strength of recycled concrete and reference concrete*

[2] *Abraham T. Gebremariam, Ali Vahidi, Francesco Di Maio, J. Moreno-Juez, I. Vegas-Ramiro, Artur Łagosz, Radosław Mróz, Peter Rem, Comprehensive study on the most sustainable concrete design made of recycled concrete, glass and mineral wool from C&D wastes, Construction and Building Materials, Volume 273, 2021, 121697*

The project revealed the possibility of designing the most green and sustainable concrete that contains more than 75% (by weight) recycled components retrieved from CDW. Furthermore, it demonstrates the viability of the full use of recycled concrete aggregates valued through the novel technology ADR + HAS in new eco-designed concretes that strongly improve consumer confidence and raise awareness to promote the use of recycled aggregates in high value-added applications.

Finally the PCEs have been eco-designed to reduce environmental impact and provide competing U value [0,17 W/($m^2$ K) ] and panels manufactured with recycled VEEP Concrete and VEEP Green Aerogel. The development of novel plastic formworks was also undertaken: the **innovative designed and manufactured formworks allow a time reduction of 4 minutes per square meter and bi-directional panel casting flexibility, contributing to the achievement of the target +15% daily panels (PCEs) production.**

*Figure 6. VEEP innovative formworks' prototype*

*Figure 7.  VEEP Panel 1 (PCE1) for Structural Application*

After the prototyping phase, the PCEs design was revised to match with some needed adjustments in mock-ups design. In accordance with the design optimization regulatory framework, determining the correct thickness of the minimum external concrete layer and technical specifications of the selected anchors, a review of the PCE1 and PCE2 sections was carried out.

Then a production plan was prepared to allow an agile production. All raw materials were collected and the mix design was tested in the end-users' production plants ready for the panels production.


*Figure 8. VEEP PCEs concrete main production phases*

The VEEP panels are produced following the eco-design approach, by means of innovative flexible plastic formwork, employment of innovative recycled materials, and optimized production process.

These factors influenced the production under manifold perspectives:

- The panel production is faster (innovative formwork technologies);
- Fewer operations are performed to produce one panel compared to standard manufacturing process;
- The footprint required by the production is reduced (less panel weight and recycled materials);
- Thermal efficiency is improved, thanks to the super insulation material (i.e. aerogel);
- Smooth hedges can be obtained all over the panel, thanks to the improved formworks water- tightness.

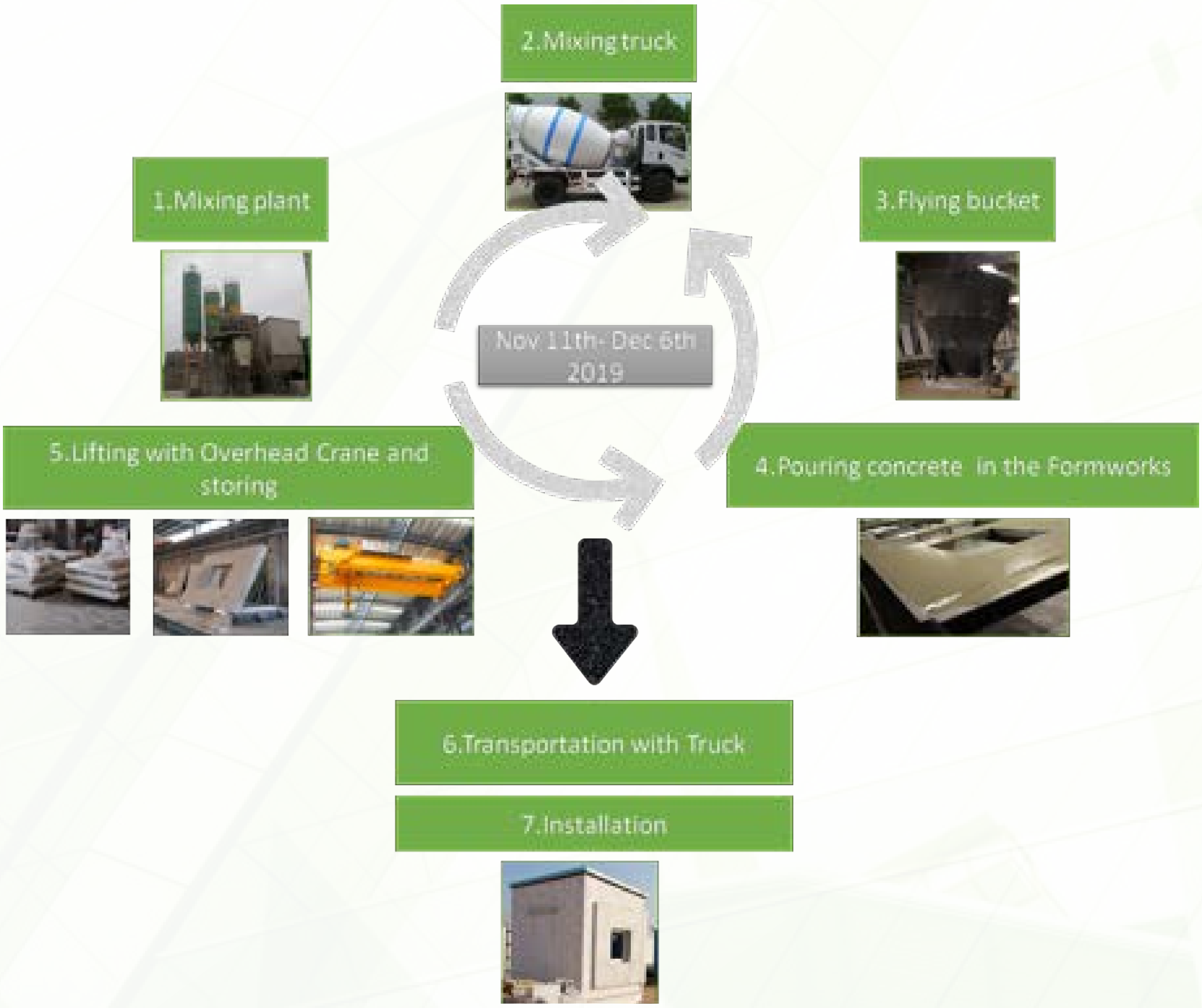


*Figure 9. VEEP PCEs advanced manufacturing cycle*

*Figure 10. Innovative Formworks, assembled for PCE1, 3,6mX2,4m, height 26cm, with steel caps, window and door frames*

*Figure 11. VEEP Panel 2 (PCE2) for Refurbishment Application*

Both panels have been assembled through VEEP innovative plastic formwork. Several tests (dry density, fresh consistency-slump, compressive strength, modulus of elasticity in compression, tensile strength, flexural strength, thermal conductivity, capillary water absorption, water penetration under pressure, SEM and elemental analysis, porosimetry, carbonation resistance, freeze-thaw, acoustic, fire resistance and fire reaction) have been successfully carry out.

**The fire resistance test** was performed in the TECNALIA´s Fire Safety Lab. according to EN 1364-1, EN 1364-2, EN 1364-3 and EN 1364-4 in a hot box, for testing pieces with dimensions of 1m x 1m. This test provides an estimated fire resistance classification but not the fire classification.


*Figure 12. Fire resistance test (PCE1)*


*Figure 13. Fire resistance test (PCE2)*

According to the standard EN 1364-1, EN 1364-2, EN 1364-3 y EN 1364, the minimum fire resistance time is 60 minutes for this kind of products.

In the case of the PCE1, after 240 minutes the test is stopped since the sample stands perfectly the test and the temperature at the outer layer stabilizes from 220 minutes. The sample is not deteriorated, it maintains its initial appearance on the unexposed face. The estimated classification to fire resistance of the PCE1 was EI 240.

In the case of the PCE2, the fire classification is given for an excess of the average and maximum temperature recorded in the outer layer, obtaining an estimated classification to fire resistance EI 90.

**In terms of fire reaction both faces composed of recycled concrete and aerogel were tested to assess the reaction to fire obtaining a very high performance to the fire reaction with a class B-s1,d0 (very limited contribution to fire, no smoke production and no flaming droplets production).**

*Figure 14. Fire reaction test (concrete surface)*

*Figure 15. Fire reaction test (aerogel surface)*

**In terms of Acoustic test** the test is performed on both the panels in the horizontal transmission rooms, composed of a source and a receiving room. The receiving room is composed of a double concrete box of twenty and ten centimeters of thickness each one, acoustically disconnected and the source room, forty centimeters thick, is composed of a double box of metal frame and gypsum board, acoustically disconnected. The mobility of the source room allows the mounting of the test specimen outside, as well its subsequent installation between the test rooms. These rooms comply with the requirements of EN ISO 101405:2010.

*Figure 16. Acoustic test (PCE1)*

*Figure 17. Acoustic test (PCE2)*

The rating obtained according to EN ISO 7171:2013 was Rw (C;Ctr): 58 (2; 6) dB for PCE1 and Rw (C;Ctr): 48 (1; 3) dB for PCE2.

The concretes manufactured for the prototypes and the prototypes were characterized concluding that both the concretes and the panels comply with the requirements of the different building standards and with the requirements imposed by the project for the final application in new façade and refurbishment.

The cost of both panels is expected to not exceed 90 € per squared-meter once industrialization processes will occur and both panels comply with the requirement of the different building standards.

Finally three mock-ups have been built in 2 different climatic scenarios in order to evaluate the performance of VEEP panels: at the ACCIONA´s Ecopark in Madrid (Spain) and at the Strukton´s facilities in Hoorn (Netherlands). VEEP mock-ups were built by project partner Strukton starting from December 2019 until February 2020.

In particular, there are 3 project mock-ups: "reference building", "new building", "retrofitting building".

The mock-ups were built with the novel panels, which were designed and developed within VEEP project. Moreover, different type of sensors have been installed to monitoring the efficiency of new panels and to quantify energy, acoustic and durability performance of each PCE solution. This will strongly improve the monitoring assessment as the data will be compared to experimental data collected on the reference building located in same climatic conditions.

*Figure 18. VEEP Mock-up in Spain*

*Figure 19. VEEP mock-up in Spain*

*Figure 20. VEEP mock-ups in the Netherlands*

*Figure 21. VEEP mock-ups in the Netherlands*