This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 723583

RE⁴ Project

REuse and REcycling of CDW materials and structures in energy efficient pREfabricated elements for building REfurbishment and construction

D5.1 Material development

Public summary of deliverable

Author(s)[1]:	CETMA, CBI, QUB, ACCIONA, ROS and NTUST
Date:	10/09/2018
Work package:	WP5 - Development of precast components and elements from CDW
Distribution[2]	This document is a public summary of the confidential deliverable D5.1 of RE[4] project.
Status[3]:	**Final**
Abstract:	D5.1 reports on the development of different building materials incorporating CDW. Formulations, testing and validation of concretes, based on Portland cement (OPC) and alkali activated binders (AAB), as well as lightweight insulating concretes and earthen materials are included.
File Name	RE4_D5.1_Material development_FINAL_V0.2_Public Summary

Version	Date	Description	Written By	Approved by
V2.0	10.09.2018	Public Summary of D5.1	CETMA	PC

[1] *Just mention the partner(s) responsible for the Deliverable*
[2] *PU: Public, RE: restricted to a group specified by the consortium, CO: Confidential, only for members of the consortium; Commission services always included.*
[3] *Draft, Revised, Final*

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Introduction

Deliverable 5.1 summarises the results obtained by the RE[4] team involved in *Task 5.1 – Development of materials incorporating CDW, Portland cement and alkali activated binders* (CETMA, RISE CBI, QUB, ROS, ACCIONA and NTUST) of *WP5 – Development of precast components and elements from CDW*. The work focused on the development of materials incorporating CWD: concretes based on different binders (ordinary Portland cement, alkali activated binder) for structural and non-structural applications, lightweight insulating concretes and earthen building materials.

Concretes based on CDW and Portland cement/OPC were formulated using a high level of CDW materials as aggregates (mineral fractions/MF). The mix design was optimized towards different applications according to industrial requirements (e.g. self-compacting concretes/SCC, vibrated concretes) for precast building solutions. The concrete mixes have been tested to assess consistency and hardened behaviour. Mechanical properties were evaluated and durability properties tested for specific mixes with satisfying fresh and hardened properties.

Concretes based on CDW and alkali activated binders/AAB (alumina-silicate precursors e.g. pulverised fuel ash/PFA or FA, ground granulated blast-furnace slag /GGBS or GGBFS) were formulated using a high level of CDW materials as aggregates (mineral fractions/MF). Fresh and hardened concrete properties have been tailored matching the industrial requirements and optimised mixes have been tested to assess consistency and hardened behaviour. Mechanical properties were evaluated and durability properties have been tested for specific mixes with satisfying fresh and hardened properties.

Lightweight (LW) insulating concretes based on CDW and OPC were formulated using high level of CDW lightweight materials as aggregates (heterogeneous rigid plastics/RP, mixed wood and plastic/WP). The goal was to maximise the use of lightweight CDW fractions, thus allowing a density reduction for the development of materials with improved insulating performance (e.g. layers for panels, substrates). The performance of lightweight concretes were assessed both in the fresh (e.g. consistency, air content, density) and hardened state (e.g. density, mechanical properties, thermal conductivity).

The **validation of the developed CDW-based concretes** (normal-weight, both OPC and AAB, and light-weight) was also performed**.** To the aim of this validation work, the best performing mixes resulting from the previous steps have been selected and a wider characterization performed. Selected concrete formulations have been tested on full-scale to assess, on one hand, their reproducibility and, on the other hand, their suitability for the production of building products intended for RE[4] demonstrators.

Earthen building materials fully based on recycled materials, such as clay and fine aggregates from CDW, were developed. The materials were tested to assess their performance in terms of workability and strength and their compliance with relevant standards.

Additional studies on **alkali activated building materials** (e.g. concretes, mortars) based on CDW and/or binders (PFA, GGBS) from different sources were also investigated.

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Materials

The following materials were used as aggregates for concretes development:

- mineral fractions (MF 0-2 mm, 2-8 mm, 8-16 mm), from S-EU (South Europe) and N-EU (North Europe) batches, suitable for use as received;
- rigid plastic LW fractions (RP 0-2 mm, 2-4 mm, 4-10 mm), provided in large scraps and suitable for use after a size reduction/sieving process;
- wood and plastic LW fractions (WP 0-2 mm), suitable for use as received.

As far as regards the binders, depending on the specific application, were used:

- OPC;
- PFA, GGBS from local sources as alumino-silicates precursors and commercial alkali activators.

Figure 1 - RE4 CDW used as aggregates for concretes development. Mineral fractions in three different sizes (0-2 mm, 2-8 mm and 8-16 mm), rigid plastic and wood and plastic fractions, respectively.

The following materials were used for earthen building materials development:

- mineral fractions (MF 0-2 mm), from S-EU and N-EU source, used as aggregates;
- fine fractions (clay), from S-EU and N-EU source, used for the preparation of the binder.

Figure 2 - Clayey soil used as binders for plasters/adhesives development.

Experimental activities

Several building materials, incorporating the CDW above mentioned, were developed in this study:

- concretes based on OPC/mineral aggregates and OPC/lightweight aggregates (self-compacting, vibrated);
- concretes based on AAB/mineral aggregates (vibrated);
- earthen building materials based on fine fractions (clay) and mineral aggregates.

Table 1 – Sorted CDW and related size fractions used for materials development.

Sorted CDW fraction	Size fractions (mm)	Intended use
Mineral fraction – sorted CDW	0/2, 2/8, 8/16	Self-compacting concretes, Vibrated NW concretes, Vibrated LW concretes
Lightweight fraction – sorted rigid plastic	Large scraps (size reduction/ sieving required)	Vibrated LW concretes
Lightweight fraction – sorted mixed wood and plastic	Fine fraction	Vibrated LW concretes
Mineral fraction – sorted CDW	Clay	Earthen building materials

Normal-weight (NW) concretes, based on both *ordinary Portland cement (OPC)* and *alkali activated binders (AAB)*, **light-weight (LW) concretes** as well as **earthen building materials** have been investigated, tested and validated on lab scale.

Results

Normal-weight concretes consist of normal-weight CDW aggregates (mineral fractions) combined with both conventional and recycled binders (OPC and AAB, respectively).

CDW/OPC self-compacting concretes, *CDW/OPC* and *CDW/AAB vibrated concretes* have been investigated and fully characterized. The approach followed consisted in the optimization of concrete formulations for target applications with specific requirements from industrial partners aiming, at the same time, at the maximization of CDW.

Self-compacting CDW/OPC concretes of class C40/50 have been optimised; consistency and compressive strength requirements, set by industrial partners, were achieved and excellent resistance to frost attack was observed.

Figure 3 – J-ring test on self-compacting CDW/OPC concrete.

Vibrated CDW/OPC concretes of class C25/30 have been optimised; consistency and compressive strength requirements, set by industrial partners, were achieved.

Figure 4 - Slump test on vibrated CDW/OPC concrete.

Vibrated CDW/AAB concretes of class C25/30 have been optimised; consistency and compressive strength requirements, set by industrial partners, were achieved and excellent resistance to carbonation was observed.

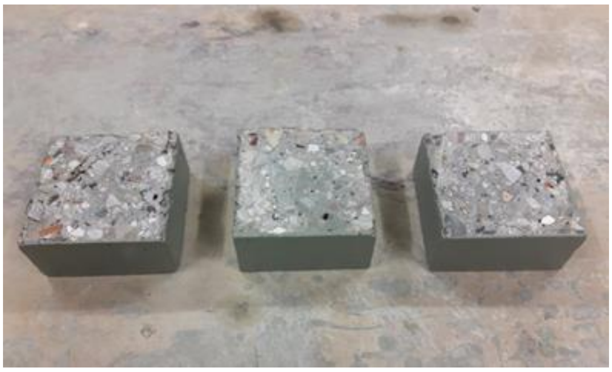

Figure 5 – Vibrated CDW/AAB concrete specimens.

Light-weight concretes consist of light-weight CDW aggregates (rigid plastic/RP, wood and plastic/WP) combined with conventional binders (OPC). Vibrated lightweight concretes with improved insulating performance have been developed. The approach followed consisted in the optimization of mix formulations suitable for building applications such as lightweight panel layers. The aim was the maximization of LW fractions targeting, at the same time, to meet specific requirements in terms of consistency, compressive strength and thermal insulating performance. Two different LW concretes have been developed and characterized, one for each aggregate typology; both of them for consistency, compressive strength, reduced density and, therefore, improved thermal conductivity have the potential to be used for insulating building panels.

Figure 6 - Light-weight OPC concrete incorporating RP aggregates.

Figure 7 - Light-weight OPC concrete incorporating WP aggregates.

The next step consisted in the **validation of the developed concretes** (both normal-weight and light-weight). To this aim the best performing concretes developed by each lab in the previous step (*CDW/OPC self-compacting C40/50*, *CDW/OPC vibrated C25/30*, *CDW/AAB vibrated C25/30* and *LW concretes*) were

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reproduced (using locally available raw materials) and validated by another lab. The main outcomes of this validation work are summarized in the following.

CDW/OPC self-compacting C40/50 consistency (at 15 and 30 mins) and compressive strength requirements (7dd and 28dd) set by industrial partners were achieved. Flexural strength at 28dd was in line with the results obtained for compressive strength (flexural strength of OPC concrete is approximately equal to 10% of its compressive strength). In addition, excellent resistance to frost attack was observed.

CDW/OPC vibrated C25/30 was reproduced using the same NE sorted CDW but a different cement (CEM II in place of CEM I). Density of the fresh concrete and 30 mins consistency were rather similar, whereas consistency at 15 mins differed substantially (class S3 for original mix versus S1). The difference in consistency could be attributed to differences in amount of extra water added in order to saturate the aggregates, differences in how this water was added or different water uptake by the cement. For the hardened concrete, the 28dd density and compressive strength as well as the compressive strength development were higher possibly due to the cement used. Flexural strength at 28dd was in line with the results obtained for compressive strength (flexural strength of OPC concrete roughly equal to 10% of its compressive strength).

CDW/AAB vibrated C25/30 was reproduced using locally available raw materials. Consistency (15 mins and 30 mins) and compressive strength requirements (3dd, 7dd and 28dd) set by industrial partners were achieved. Flexural strength at 28 dd was in line with the results obtained for compressive strength (flexural strength of OPC concrete is approximately equal to 10% of its compressive strength). In addition, excellent resistance to carbonation (28 dd and 56 dd) under natural environment exposure was observed. Finally its thermal conductivity was found to be 0.502 W/(m·K).

Two different typologies of LW concretes, based on RP and WP aggregates (RP/OPC and WP/OPC concretes) have been validated. The reproducibility of RP based concretes was demonstrated, this concrete meets the requirements for the preparation of layers of building panels. WP based concretes were not precisely reproducible (mainly due to the specific sand used – MF N-EU); this concrete needs a further improvement of the consistency in order to fully meet the requirements for the preparation of layers of building panels.

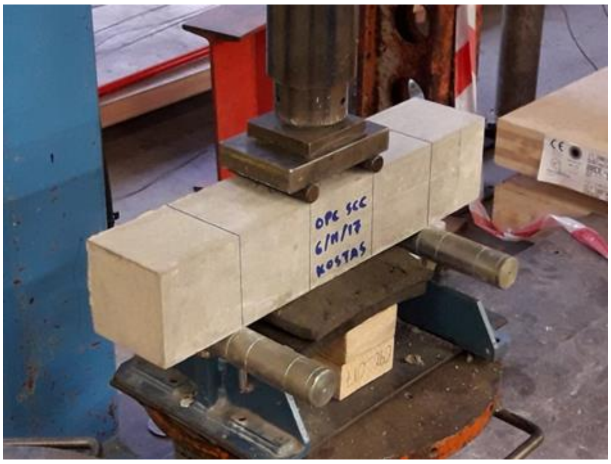

Figure 8 - **Four-point bending test of C50 OPC SCC beam.**

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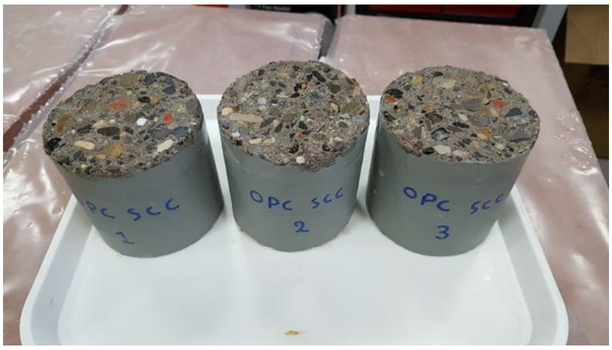

Figure 9 - **OPC SCC specimens after 28 freeze-thaw cycles.**

Earthen building materials consist of clay, used as binder, combined with fine aggregates from CDW. The investigations carried out proved that an earth building material can be produced from CDW aggregates, instead of natural aggregates, and can be used both as earth plaster and as earth mortar.

Figure 10 - **Tensile strength test specimen.**

Finally, additional studies on **alkali activated building materials** (e.g. concretes, mortars) based on CDW and/or binders (PFA, GGBS) from other three different sources were also carried out with satisfying results.

Figure 11 - **AAB mortars with RE^4 MF, RP and WP aggregates (from left to right).**

Materials developed in these lab tests (concretes, plasters, mortars) will be used as input for the development and production of building components/elements allocated to demonstration activities of RE^4 project.

Conclusions

Building materials incorporating CDW have been investigated, characterized and validated on lab scale.

CDW materials used in this study are:

- mineral fractions/MF;
- lightweight/LW fractions (rigid plastic/RP, mixed wood and plastic/WP)
- clay.

The main categories of *CDW-based building materials* developed in this study consist in:

- concretes;
- plasters/mortars.

Normal-weight concretes (*self-compacting*, *vibrated*), based on CDW MF combined with *ordinary Portland cement* (*OPC*) and *alkali activated binders* (*AAB*), were extensively investigated and performance assessed (e.g. fresh state, mechanical tests, durability). *Light-weight concretes* (*vibrated*), based on CDW LW fractions combined with OPC, were developed and performance assessed (e.g. fresh state, mechanical tests, insulating properties). *Plasters/mortars (earthen materials)*, based on clay and fine MF, were also investigated and properties evaluated (e.g. mechanical tests).

The *main goal* for each material investigated was the maximization of CDW incorporation, thus allowing the production of sustainable building materials, still in compliance with specific requirements assigned by industrial partners.

For each investigated material, the *main outcomes* resulting from the extended experimental campaign carried out are:

- *OPC/CDW concrete (self-compacting)*
Self-compacting CDW/OPC concretes of class C40/50 have been optimised on lab scale; consistency and compressive strength requirements, set by industrial partners, were achieved and excellent resistance to frost attack was observed.

- *OPC/CDW concrete (vibrated)*
Vibrated CDW/OPC concretes of class C25/30 have been optimised on la scale; consistency and compressive strength requirements, set by industrial partners, were achieved.

- *AAB/CDW concrete (vibrated)*
Vibrated CDW/AAB concretes of class C25/30 have been optimised on lab scale; consistency and compressive strength requirements, set by industrial partners, were achieved and excellent resistance to carbonation was observed.

- *Light-weight concretes (vibrated)*
Two different typologies of LW concretes, based respectively on RP and WP aggregates from CDW, have been developed and tested. In general, these materials meet the requirements of density, mechanical performance and insulating performance necessary for their use as layers for building panels.

- *Earthen materials*

In general it could be proved that the CDW material is suitable for the application as earth plaster and mortar. Additional investigations would be required to replace also the binder and to define reliable mixing ratios. The adjustment of the required mixing water can be achieved through industrial machinery that manufacturers normally use.

In conclusion, RE^4 CDW can be used for building materials (concretes, plasters, mortars) and are compliant with target requirements set for industrial production.

Building on the outcomes of this extended investigation, inputs for the production of prefabricated components/elements based on CDW and allocated to demonstration activities of RE^4 project can be obtained (*WP6 – Pilot level demonstration of CDW based prefabricated element*).

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