Innovative circular ultralightweight cement mortar containing inorganic recycled building materials for the manufacturing of topologically optimized 3D printing architectural products (CUCEM3D project).

M. Frías-Rojas (1), I. Vegas-Ramiro (2), J. Moreno-Juez (2), S. Martínez-Ramírez (3), R. García (4), R. Vigil de la Villa (4), E. Goiti-Ugarte (2), I. Calderón (2), Lucía Fernandez (5), Eduardo Lahoz (1).

(1) Eduardo Torroja Institute (IETcc-CSIC), c/Serrano Galvache 4, 28033 Madrid, Spain
(2) Tecnalia, Area of Cement-Based Products, Building Technologies Division, Astondo Bidea, Edificio 700, Parque Tecnológico de Bizkaia, 48160 Derio, Spain
(3) Instituto de Estructura de la Materia (CSIC), C/Serrano 121, 28006 Madrid, Spain
(4) Department of Geology and Geochemistry, CSIC-UAM Associated Unit (Geomateriales), Autonomous University of Madrid, 28049 Madrid, Spain
(5) Escuela Superior de Ingenieros de Caminos, Canales y Puertos, Universidad Politécnica de Cataluña, 08034 Barcelona, Spain.

Abstract

The CUCEM3D project aims to set the scientific & technological basis for the synthesis and performance study of novel eco-hybrid cement-based mortar formulations containing inorganic recycled building materials (concrete, glass and gypsum) and circular lightweight aggregates (cost-effective and silica closed loop granular aerogels) for the manufacturing of topological optimized 3D printable architectural elements.

Keywords

Circular economy, Eco-hybrid cements, Silica aerogels, Circular 3D printing mortars.

1. Introduction

A recent report (1) revealed that the EU28 generates around 350 Mt of Construction and Demolition Waste (C&DW). Around 13% of materials are wasted on-site during the building phase and the existing building stock consumes 40% of Europe´s energy demand. Moving towards more industrialized building products, new trends are oriented to optimize both the design and the consumption in term of materials resources.

Despite the scientific and technical advances presented in the literature, it must be highlighted the importance of generating new knowledge on 3D printing products guaranteeing improved mechanical properties and rheology at early age, employing larger amounts of recycled C&DW contributing to facing the challenge of material efficiency within this sectorial activity and having improved thermal properties. Thus, due to the complexity of this type of products, the lack of knowledge and the potential benefit in new applications, CUCEM3D project seeks to design 3 new 3D printing products for new applications in the manufacture of 3D printing architectural products:

- <u>Eco-hybrid cements</u> making use of a mixture of CSA and bended eco-cement with at least 60% of C&DW (gypsum, concrete, glass or ceramics).
- <u>Novel silica closed loop granular aerogels</u> contributing to enhance the thermal performance of the new mortars. The incorporation of highly efficient cost-effective thermal insulation solutions will contribute to reducing energy consumption (20-30%) in existing buildings.
- <u>New resource efficient 3D printing mortars containing eco-cements, granular circular aerogels and fine recycled aggregates</u>.

2. Synthesis of novel eco-hybrid cements from C&DW.

The cement industry, due to the characteristics of the cement manufacturing process, is one of the major contributors to greenhouse gas emissions (2). In order to face this challenge, the cement industry is working on different techniques. One of them is related with the development and optimization of Calcium Sulfo-Aluminate (CSA) cements as a substitute (up to 100%) of Ordinary Portland Cement (OPC) (3). The other trend is related to the reduction of the amount of clinker in blended eco-cements (both OPC and CSA) using different industrial wastes and by-products as Supplementary Cementitious Materials (SCMs) such as C&DW (4) (5). However, both CSA and blended eco-cements have not seen yet a widespread use in concrete sector due to the special considerations that must be taken for its use.

In this context, CUCEM3D proposes the redesign of this type of mixed cement matrix (eco-hybrid cement) by performing modifications on each of the cements that comprise the mix making use, at the same time, of the different C&DW mineral additions, as follows:

i) the commercial OPC cement would be partially substituted (up to 15%) by a mixture of mineral wastes from the C&DW (concrete and glass) aiming to gain early age performances,

ii) the CSA cement would be produced at laboratory scale using at least 60% of C&DW as raw materials (concrete, glass and gypsum),

iii) the smart combination of CSA and blended cement incorporating high amount of C&DW would contribute to creating synergistic effects and minimize the environmental impact by reducing CO_2 emissions and the raw material consumption.

Figure 1: Recycled C&DW (<0,063mm) for the synthesis of novel eco-hybrid cements.

3. Synthesis of silica closed loop lightweight granular aerogels.

Silica aerogels with hydrophobic inner surfaces are especially interesting for thermal insulation since thermal conductivities (λ) up to 0.012 W/(m K) can be achieved (6) (being the lowest thermal conductivity for solids at ambient conditions). Due to the exceptional properties of these materials, they are the excellent candidates for different application fields demanding for enhanced thermal insulation, better acoustic barrier and lightness properties. Silica aerogels are already commercially available as granule or fiber-reinforced blanket; however, their high price, has avoided their broad access into the market.

The first stage of the aerogel synthesis, the precursor formation process accounts for up to 80% of total aerogel manufacturing cost at industrial scale (7). Therefore, new reaction approaches are envisaged within CUCEM3D project for the treatment of silica containing waste material toward the direct obtaining of silicic acid solutions, decreasing process cycle time, raw material intensity and costs.

These promising materials must overcome an economic barrier to be applied in the conservative building sector which is not used to assuming high material costs. Several attempts have been made so far to develop novel building products based on aerogel (8) but there are still relevant challenges to achieve more durable products and more compatible with other building conventional materials; mainly with cement-based materials and products.

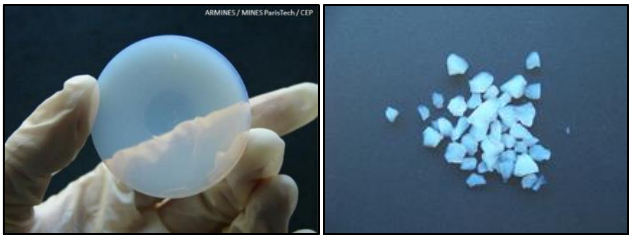

Figure 2: Cost-effective circular aerogels. Monolith and granular format.

3. Development of novel circular ultra-lightweight mortars for 3D printing at lab scale.

3D printing represents an advanced emerging technology that might potentially contribute to: i) reducing the incorporation of materials through the topological optimization of the building architectural and structural elements, to ii) optimizing the incorporation of secondary raw materials in mortar/concrete formulations and to iii) customizing products without incurring in extra costs (9).

Thermal insulating mortars (plasters or renders) constitute one of the possible solutions that can be used for new building or the retrofitting of old buildings under energy efficiency criteria (8). Within the CESAR project (10), has developed some formulations based on aerogel and cement-based matrices. These formulations still challenge points for this new generation of high performance insulating mortars and gaps for innovation: i) evaluation of aerogel particle size effect on the final properties of the insulating mortar, ii) better dispersion of aerogel granules in the cement matrix, iii) new formulations of aerogel-based cement matrices for new production technologies such as 3D printing.

CUCEM3D will therefore develop ultra-lightweight cement mortars for 3D printing including the eco-hybrid cements and the novel silica closed loop granular aerogels with the aim of obtaining enhanced mechanical and rheological properties at early age, enhanced thermal performances and maximize the resource efficiency through topological optimization and the use of C&DW.

Figure 3: Cement-based piece manufactured though 3D printing technology.

5. Conclusions

With the achievement of the objectives established in the project, the obtained results are expected to have a direct impact on the following technical, economic, environmental and social fields:

- Scientific-technical impact: Generation of new scientific and technological knowledge related to the following fields: valorization of concrete, glass and gypsum waste, new eco-cements, aerogels, topological optimization and 3D printing of cement based materials.
- Economic impact: Development of, at least, 3 new improved products/technologies with a potential European market considering a penetration rate of 5% by 2025: 1) eco-hybrid cement: 15 M€ per year; granular aerogels: 7.2 M€ per year and 3D concrete printing technology: 25 M€ in Europe.
- Environmental impact: Contribution to the valorization of 350 Mt of C&DW in Europe and 29 Mt in Spain by metabolizing valorized concrete, glass and gypsum waste into new high-grade circular applications; Potential reduction associated to avoided extraction of building raw materials of 5.0 ktons of CO_2-equiv. by 2030 in Europe linked to the new eco-cement formulations and aerogel thermal insulation.
- Social impact: Direct and indirect creation of more than 13 jobs related to both the achievement of tasks and the transfer of results. Extend the knowledge towards at least 100 students within the Autonomous University of Madrid.

Acknowledgements

The authors also thank the Spanish Ministry of Science, Innovation and Universities (MICIU) and the European Regional Development Fund (FEDER) for their funding to continue this line of research (RTI2018-097074-B-C21). The authors also thank the Spanish Association of Construction and Demolition Waste Recycling (RCDA), SIKA (Madrid, Spain) and Spanish Institute of Cement and their Applications (IECA).

References

1. Deloitte. Study on Resource Efficient Use of Mixed Wastes, Improving management of construction and demolition waste – Final Report. Prepared for the European Commission, DG ENV. 2017.

2. Bermúdez Alvite, J. 2005, Revista SOGAMA, pp. 1, 7-29.

3. Mineral Products Association. Novel cements: low energy, low carbon cements. 2013.

4. EU Horizon 2020. FISSAC project- Grant Agreement nº 642154. (www.fissacproject.eu).

5. EU Horizon 2020, VEEP project- Grant Agreement Nº 723582 (www.veep-project.eu).

6. Sol–gel science: The physics and chemistry of sol–gel. Brinker CJ, Scherer GW,. San Diego : Academic Press, 1990.

7. Based commercial price of alkoxy-silanes precursors (type methoxy (TMOS) or ethoxy (TEOS)). Market price between 2 – 2.5 €/Kg for supplies over 1 Ton.

8. Fixit 222, Aerogel high performance insulating plaster, in Fixit news, rendering 05/2013.

9. International Journal Production Economics. Weller C, Kleer R, Piller FT. 2015, pp. 164: 43-56.

10. Proyecto CESAR. Ministerio de Economía y Competitividad. Programa Nacional de Proyectos de Investigación Fundamental, BIA2015-65558-C3-2-R. 2016-2018.