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Valorization of industrial wastes: SUS-CON building solutions

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Abstract

This work presents the promising results of the SUS-CON "*SUStainable, Innovative and Energy-Efficient CONcrete, based on the Integration of All-Waste Materials*" European project founded by 7FP (duration 2012-2015), dealing with the valorization of industrial wastes used as raw materials for sustainable building solutions. SUS-CON project aimed at developing new technology routes to integrate waste materials (e.g., ashes from thermal-power plants; slags from metallurgical plants; post-consuming plastics used as aggregates and binders) in the production cycle of concrete. The innovative concretes, developed on lab and industrial scale for ready-mixed and pre-cast applications, include up to 100% by weight of industrials wastes. The materials result lightweight with high thermal insulation performance, cost-effective and eco-sustainable with reduced environmental impact (low embodied energy and reduced CO_2 emissions). The developed building solutions might contribute to the reduction of industrial wastes disposal, with positive impacts also on the construction sector costs.

Keywords: SUS-CON Project; Industrial Wastes; Eco-Sostainable Concretes; Recycling

1. Introduction

Industrialization has become an important factor to the development of a country's economy, through the establishment of plants and factories. However, wastes or by-products discharged from them are severely disastrous to the environment and human health (Ho et al., 2012). Waste or by-products generated from industrial activities are increasing substantially and such materials for quantity, distribution and low changes to be

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used for high-value applications represent a serious environmental and socio-economic problem. Recycling of such wastes and using them in construction materials appears to be a viable solution not only to the pollution problem but also an economical option for the construction sector. Concrete is the most widely used construction material, therefore its demand and required raw materials, such as cement and aggregates, are very high in volume (Agrawal et al., 2014). Production of ordinary Portland cement (OPC), traditionally used as concrete binder, has a significant environmental impact being responsible for high energy consumption and CO_2 emissions. Moreover, aggregates represent major constutients of concrete and related mining activities have a significant environmental impact. The construction sector is currently required to become more sustainable, with special attention on the potential of post-consumer wastes and industrial by-products to reduce environmental impacts, energy consuption and costs, utilization of non-renewable raw materials and also prevent waste disposal (Baikenkar et al., 2014; Petrillo et al., 2016). A considerable attention is currently paid to alternative green cements, such as alkali activated materials (AAM) produced from fly ash and slag by-products produced from power stations and metallurgical plants, respectively. An alkali activated cement is a binder system derived by the reaction of an alkali metal source (activator) with an allumino-silicate powder (precursor). Blending such green binders with aggregates also from waste materials, such as post-consumer plastics, represents a further step towards more sustainable concretes development (Dave et al., 2015).

To assess the utilization of industrial wastes as construction material, SUS-CON "*SUStainable, Innovative and Energy-Efficient CONcrete, based on the Integration of All-Waste Materials*" project aimed at developing innovative technologies to integrate waste materials, recycled from different industrial activities, in the production cycle of concrete. Innovative cements-based on ash and slag were combined with lightweight aggregates from discarged plastic from recycling plants to produce sustainable concretes for both ready-mixed and precast applications (*see: www.sus-con.eu*). This paper reports on the promising results achieved by SUS-CON project, which objective was the technological transfer of production methodologies for innovative sustainable concretes. Based on lab scale optimization of concretes formulations, using lightweight aggregates and alkali activated cements, the validation of the developed technologies was carried out on industrial scale. Industrial manufacturers produced building blocks, insulation panels and floor screeds intended for installation on real scale buildings. The innovative building solutions developed within the Project results cost-effective, with reduced CO_2 footprint and embodied energy.

2. Materials

2.1 Binders

A range of allumino-silicate precursors, selected among industrial by-products, were investigated by XRF, XRD, FTIR, SEM to assess properties such as Si and Al content, amorphous content, particle size and shape. Materials showing potential for the activation were then selected for further investigations on the binder development: pulverized fly ash (PFA), ground granulated furnace slag (GGBS) and perlite tailings. Alkaline solutions, such as sodium silicate (also known as waterglass or liquid glass) and sodium hydroxide (NaOH solutions), were selected for the activations of the selected allumino-silicate precursors.

2.2 Aggregates

A range of post-consumer plastics, selected among industrial waste streams, were investigated to assess their suitability as lightweight aggregates for concretes. Rigid polyurethane foams, mixed plastic scraps rejected from plastic recycling process, exhaust rubber tyres and waste plastics from electrical and electronical equipment were processed to allow their size reduction. Mixed plastic scraps have been processed according to a technology patented by CETMA and referred as Remix. The materials were tested, according to relevant standards, in terms of physical (size distribution, density, water absorption) and chemical properties to assess their use as aggregates for non-structural concretes.

3. Methods

3.1 Concretes optimization on lab scale

The SUS-CON binders composition (alkali dosages, water content) and curing conditions were studied and their effects on mortars properties (consistency, setting time, compressive strenght) were assessed. Based on this investigation, the binders with satisfactory compressive strenght (> 20 MPa), consistency, initial setting time and density resulted: 100% PFA, PFA/GGBS 30%-70% blend both activated with sodium silicate/sodium hydroxide solutions and perlite tailings/μ-silica 90%-10% blend activated with sodium silicate/sodium hydroxide or sodium hydroxide solutions.
The compatibility of SUS-CON aggregates with traditional binders based on cement was evaluated. The use of recycled plastic aggregates resulted in lighweight concretes (density approximately 1100 kg/m^3), with low thermal conductivity (λ values 0.20-0.33 W/mK) and satisfactory compressive strenght (up to approximately 9 MPa). Based on this investigation, the best performing aggregates resulted: rigid polyurethane (PU), mixed plastic (also and rubber tyres.

The best performing aggregates and binder formulations were, therefore, combined for producing sustainable concretes made of 100% recycled materials. Different concrete formulations were developed for specific target applications such as building blocks, panels for facades and floor screeds. For each application workability, density and compressive strength were prescibed by industrial producers. Based on the application requirements and achieved results, eight successful mixes compliant with the presciptions for the selected applications were identified.

Fig. 1. Cross section of SUS-CON concrete samples made of recycled binders and plastic aggregates

3.2 Concretes production on industrial scale

Six satisfactory concrete formulations (three for blocks, two for panels and one for screeds) were identified for the production of building elements required for the demonstration phase. The concrete innovative solutions were validated through scaling up in real production plants. In total 50 panels and around 1000 blocks were succesfully produced, some for further characterization tests and others to be installed on real scale demo buildings. SUS-CON components were produced with equipment used for traditional concretes, with minimum equipment investments, and also using binders from different sources thus proving the adaptability and replicability of the developed technologies.

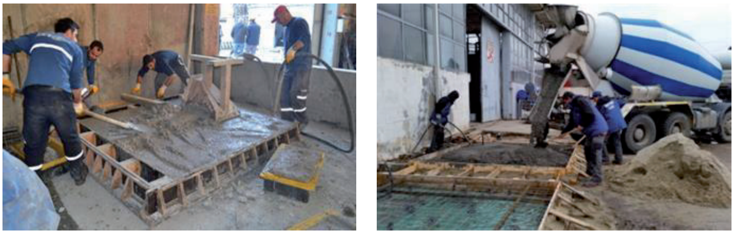

Fig. 2. SUS-CON concretes casting in real production plants

4. Results and discussion

4.1 Building blocks

Concrete formulations selected for industrial production of blocks are shown in Table 1, which also includes some technical performance. Blocks prototypes were also tested in terms of thermal transmittance; SUS-CON blocks resulted in half thermal transmitance if compared with commercial blocks, possibly due to the reduced density achieved by the use of lightweight aggregates.

Table 1. SUS-CON formulations for building blocks

SUS-CON blocks	Materials	Curing	Dry density [kg/m^3]	Compressive strength [MPa]	Thermal conductivity [W/mK]
Formulation 1	PU, PFA	Oven curing	942	5.6	0.16
Formulation 2	PU, PFA/GGBS	Room temp.	1184	15.1	0.21
Formulation 3	RX, PFA/GGBS	Room temp.	1475	18.2	0.27

4.2 Building panels

Concrete formulations selected for industrial production of panels are shown in Table 2, which also includes some technical performance. Panel prototypes were also tested in terms of fire resistance; fire resistance of SUS-CON panels resulted four times higher if compared with commercial paneles, possibly due to the use of alkali activated materials.

Table 2. SUS-CON formulations for building panels

SUS-CON panels	Materials	Curing	Dry density [kg/m³]	Compressive strength [MPa]	Thermal conductivity [W/mK]
Formulation 1	RX, PFA	Oven curing	1440	6.8	0.34
Formulation 2	PU, PFA/GGBS	Room temp.	1040	6.4	0.17

4.3 Floor screed

In the case of screeds only formulations requiring room temperature curing are acceptable, this is shown in Table 3 with relevant technical performance. As in the case of blocks and panels, also this concrete formulation has low thermal conductivity related to the low density obtained by the use of lightweight aggregates.

Table 3. SUS-CON formulation for floor screed

SUS-CON screed	Materials	Curing	Dry density [kg/m³]	Compressive strength [MPa]	Thermal conductivity [W/mK]
Formulation 1	PU, PFA/GGBS	Room temp.	1146	11.6	0.18

4.4 Real scale buildings

In order to fully demonstrate the applicabilty of SUS-CON building solutions on real scale, the produced blocks, panels and screeds were installed on demonstrators buildings located in three European sites representative of different climatic environments. SUS-CON demonstrators, when compared with reference demonstrators made with traditional concrete, resulted in improved thermal insulating performance.

Fig. 3. Demonstrators buildings made with SUS-CON concretes located, respectively, in Spain and Turkey

4.5 Environmental impacts, costs and safety

SUS-CON concretes were also analyzed in terms of LCA (Life Cycle Analysis), LCC (Life Cycle Costs) and HSE (Health, Safety and Environmental) aspects. The developed products, if compared with other commercial solutions, resulted in CO_2 emissions and embodied energy reduction up to 50% and up to 15% reduction in terms of costs depending on the composition. Finally, SUS-CON products and relevant production processes resulted non-hazardous.

5. Conclusion

The main outcomes of SUS-CON European project have been summarized in this paper. Innovative, sustainable and cost-effective concretes were developed combining different materials recycled from industrial wastes (post-consuming plastics, PFA from thermal-power plants, GGBS from metallurgical plants). SUS-CON concretes - specifically designed for building blocks, panels for facades and screeds - were validated in traditional production plants, therefore proving their potential for technological transfer on real scale. The approach developed within SUS-CON project promotes the utilization of widely spread industrial wastes for concretes that, on one side, allows the reduction of landfill problems and related environmental concerns and, on the other side, perceptibly economize the cost of construction materials.

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www.sus-con.eu Project web-site *"Sustainable, Innovative and Energy-Efficient Concrete, based on the integration of All-Waste Materials"*.