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Sustainable unfired bricks manufacturing from construction and demolition wastes

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HIGHLIGHTS

- CDWs can replace natural soils for the unfired brick manufacturing.
- Workability limited each CDW maximum replacement ratio.
- CDWs and binders could combined to optimize the brick technical properties.
- LCA allowed to quantify the environmental impact of each combination.

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ABSTRACT

The management of construction and demolition wastes is a huge challenge for most Governments. The greatest component of such wastes is concrete and masonry fragments or remains. Among the most common approaches to valorization of such wastes is to convert them to recycled aggregates, however this may be hampered by low quality of some recycled aggregates compared to natural aggregates. This paper presents the results of experimental investigation where concrete and ceramic remains were used to partially substitute clay soil in producing unfired bricks. The bricks were then tested for mechanical strength, water absorption freeze-thaw resistance. Additionally the environmental impact of the bricks was assessed based on Life Cycle Analysis (LCA). It was established that concrete waste could be used to substitute up to 50% of the clay whereas ceramic wastes could only substitute a maximum of 30% of the clay. Blended bricks made from clay and concrete waste mixes had a lower mechanical strength than those made from clay and ceramic waste. As regards water absorption, there was no marked difference between the two blends of brick however reduction in water resistance was slightly greater in bricks containing concrete waste that in those containing ceramic wastes. Also, tests showed that freeze-thaw resistance was greater in bricks blended with concrete wastes than in those incorporating ceramic wastes. Life Cycle analyses demonstrated that it is the binder content in the mix that largely determines the environmental impact of the blended bricks. Lastly, it was demonstrated that the most desirable technical and environmental credentials of brick material mixes resulted from using the binder combination: CL-90-S+GGBS 2/8.

1. Introduction

The construction sector is of strategic importance to the global economy. In the European Union alone, construction generates about 10% of Gross Domestic Product (GDP), provides 20 million jobs and has a direct impact on the quality of life of the population [7]. Infrastructure and building construction and demolition activities consume about 50% of raw materials and account for 33% of 900 million tonnes of waste generated in EU each year [7,3].

There is no particular composition of Construction and Demolition Wastes (CDW) as they vary depending on the kind of structure and or demolition process and the construction management systems employed. Generally CDWs typically include: (1) concrete from superstructure, (2) bricks, tiles and ceramics from floors, roofs and partition walls and, (3) in lesser quantities, other materials like glass, wood, plasterboard, asbestos, metals, plastics or hazardous materials. The majority of these wastes are usually disposed of in

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landfills without any form of recovery or re-use, hence generating important economic and environmental concerns. The EU has recognized the need for a sustainable management of waste and of use of natural resources. Consequently targets have been set to increase the re-use, recovery and recycling of non-hazardous CDW across Europe above 70% by 2020, from the current average rate of 47% [6,17].

There is a high potential for reuse and recycling of CDWs since most of their components can have a high resource value. As the different materials require specific ways for their valorization, the most effective management systems suggest the use of appropriate demolition techniques combined with recycling and re-use. This way glass, wood, asbestos, metals, plastics, hazardous materials, etc. can be separated, obtaining the majority of the inert waste fraction, comprising mainly concrete and masonry remains [21,23]. Such waste materials can be readily processed into Recycled Aggregates (RA) for use in place of Natural Aggregates (NA). Examples of use of RA include construction of bound /unbound pavement layers and the production of recycled concrete [24,16,25]. These applications are limited in practice because of the perceived lower quality and durability of RA when compared to NA. Therefore it is wide practice to exclude fine particles of RA and to limit the maximum ratio of the coarse RA fraction to the NA fraction [3,4,8,5,18,22]. For example, the European Standard EN 12620 allows, for concrete manufacturing, the use of RA with a grain size above 4 mm. The Spanish Standard EHE-08 recommends 20% as the maximum ratio of RA to total coarse aggregate in the mixes used for structural concrete.

Other potential ways for valorization of RA include partial substitution of natural clay soil by wastes, in the production of unfired bricks [11,14,13,26,10]. There are also some properties of RA that could further enhance sustainability of blended unfired bricks. For example, the finest RA fraction could be used to replace some natural materials or be used directly in the manufacture of other products, without any prior treatments. The minerals in RA may be chemically inert however the presence of any residual ceramic material can produce some pozzolanic properties [15,19]. As for the concrete element, particles could contain small quantities of residual cement that could still be reactive. Therefore this could potentially substitute for virgin binder in new construction or enable replacement of less sustainable binders like cement with more sustainable ones [3,22].

This research is primarily aimed at examining the suitability of using the fine fraction of CDW in the production of unfired bricks. Tests were conducted using fine materials resulting from crushed old concrete and clay bricks. Unfired brick samples were made with different dosages of five different binders. The test results were analyzed to determine: (a) the most effective binder and dosage in mix proportions that achieve target properties of the unfired bricks and (b) the environmental impact of each mix of combination.

2. Materials

The soil used in this study was a grey marl from the region of Pamplona, Northern Spain. Table 1 shows the chemical characterization of the soils and CDW fine fraction. Mineralogical compositions were estimated using X Ray Diffraction (XRD) analysis based on the chart proposed by Al-Rawas [2]. Using X Ray Fluorescence (XRF) analysis the soil compositions were expressed in terms of the most predominant or influential oxides.

According to the Spanish Standards UNE 103104 and UNE 103103, the material has typical plastic limit (PL) of 18% and a liquid limit (LL) of 26%. Therefore based on Casagrande Classification, this soil belongs to class CL, which is a low-plasticity clayey silt.

Table 1
Characterization of the marl soil, brick and concrete fine fractions.

FRX analysis			
Oxides	Concentration (%)		
	Marl soil	Bricks fine fraction	Concrete fine fraction
Na_2O	0.36	0.77	0.20
MgO	2.06	4.15	1.26
Al_2O_3	11.30	17.64	7.07
SiO_2	30.78	39.05	20.57
P_2O_5	0.12	0.18	0.13
SO_3	0.00	0.30	11.36
K_2O	1.96	3.56	0.92
CaO	36.64	17.10	42.23
TiO_2	0.53	0.64	0.36
Cr_2O_3	0.03	0.03	–
MnO	3.43	0.09	0.04
Fe_2O_3	0.01	5.98	2.47
Rb_2O	0.13	0.01	0.01
SrO	1.96	0.02	0.11
ZnO	–	0.013	0.02
ZrO_2	0.029	0.03	0.02
BaO	0.06	0.09	0.06
Cl	–	0.02	0.03
DRX mineralogy			
	Marl soil	Bricks fine fraction	Concrete fine fraction
	Calcite Illite Quartz Caolinite Attapulgite Ankerite	Quartz Calcite Muscovite Dolomite Chlorite Gypsum	Caolinite Calcite Quartz Gypsum Muscovite
Embodied CO_2 (kg CO_2/Tonne)	4	–	–
Embodied energy (MJ/Tonne)	100	–	–

From a mechanical point of view it is a low load-bearing capacity soil, which limits its possibilities of use as a construction material. To carry out this investigation, one tonne of the natural marl was extracted and, after homogenization of the sample, it was crushed to a maximum particle size of 1 mm.

The concrete fine fraction, which was supplied by a recycling plant in Vitoria, Northern Spain, was obtained by crushing old structural concrete. The recycling plant only valorizes the fraction 40–100 mm as RA, while any finer particles are disposed of in a landfill. For this investigation, a sample weighing 100 kg and with a maximum particle size of 4 mm was prepared by sieving the 0–40 mm fraction. The ceramic fine fraction was also obtained from the same recycling plant. In this case, to avoid contamination of the CDW by components such as plaster, mortar, etc., whole sized bricks were selected, crushed and sieved in laboratory to below 4 mm size.

In this investigation four additives were considered for use as binder components: (i) Portland Cement (PC), (ii) Calcareous Hydrated Lime (CL-90-S), (iii) Natural Hydrated Lime (NHL-5) and (iv) Ground Granulated Blast furnace Slag (GGBS). The PC used in this study was manufactured in accordance with the European Standard EN 197–1 and is marketed in Spain under the trade name CEM I 52.5 N. Table 1 shows the composition of all the additives, expressed in terms of their main oxides based on XRF analysis.

Table 2 also shows the embodied CO_2 and energy, as defined by Grist el al. [9]. Two different types of lime were used in this study: (1) A Natural Hydraulic Lime (NHL-5), obtained from burned non-pure limestone and manufactured in accordance with the European Standard EN 459–1. This Lime has hydraulic properties due to the presence of Aluminum and Silicon oxides as well as free Calcium. (2) A calcareous hydrated Lime (CL-90-S) obtained from