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Recycling of construction and demolition waste generated by building infrastructure for the production of glassy materials

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ABSTRACT

The use of waste materials generated by construction and demolition industry to yield valuable glassy materials, i.e. enamel for glazed ceramic tiles and cellular glasses is presented in this study. Both types of materials are produced by one-step treatment at moderate temperatures after simple waste chemical composition adjust. The enamels are manufactured directly from the initial waste powder by melting, while the expanded materials result from mixing of the vitreous material obtained after waste vitrification with an adequate foaming agent and posterior thermal treatment. Through the manuscript the feasibility of one step production of second generation profit materials is discussed in order to help achieving sustainable development and environmental protection.

1. Introduction

In the last century the construction industry, either building or assembling, reached very high activity indexes. Although a sign of wellness, and considered as one of the key industries for economical worldwide growth, this industry is accompanied with an extraordinary waste generation. Thereby, construction and demolition waste (CDW) is considered as the heaviest and bulkiest waste in the European Union (EU), representing about 25–30% of all generated waste. The CDW issued principally from activities such as construction or demolition of buildings and civil infrastructure, road planning and maintenance varies in composition and contains different materials, like concrete, bricks, gypsum, wood, glass, metals, plastics, solvents, asbestos or excavated soil, many of which can be recycled [1].

Referring to the Age of sustainable development, the waste generation problems must be addressed, especially in the construction industry, where valuable raw materials can result. In this sense, CDWs are considered as priority treatment for European Union. In addition, CDWs present high potential for recycling and reuse, since some of its components possess high resource value. For example, aggregates derived from CDW are frequently reused in roads, drainage or other construction projects [2,3]. Nowadays the technology for separation and recovery of CDW is well established, being readily accessible and in general inexpensive. However and despite its potential, the percentage of recycling and material recovery of CDW varies greatly (from 10% to 90%) across the EU [1].

In this context, it is worth to mention the European zero waste program, which estimates that the waste management could reduce the material's input needs by 17–24% in 2030, representing an overall saving potential of €630 billion/year for the European industry. The later will lead to the satisfaction of 10% to 40% of the raw materials demand, while contributing to achieve also the EU target to reduce greenhouse gas emissions by 40% [4].

Waste reduction, reuse and recycling are very important elements in the waste management resulting in natural resources conservation, valuable landfill space reduction, raw materials and energy needs diminishing, air and water pollution control and, not at last place, new jobs creation potential [5]. There are, however, some constraints on reusing waste materials; they must fulfill some engineering requirements in terms of physical and compositional properties and they should not contain excessive amounts of harmful components which might cause problems in use [6].

The properties of CDWs vary considerably depending on its origin and composition. It is convenient to distinguish between materials originated from construction and demolition of buildings and those from pavement. The former offers composition in which a wide variety of wastes are included, presenting sometimes even dangerous components, which can contaminate other recyclable items and are time and money spending. The vitrification is reported as the safest approach for non flammable hazardous waste treatment [7]. It is a process able to convert directly the waste materials without separation into homogeneous stable glasses for subsequent application [8–10]. However, vitrification is

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reported as high-energy consuming treatment, producing glasses with low transparency. The use of this treatment appears more expensive than waste deposition in landfills or waste immobilization into cementitious matrix. Thus, a possible cost reduction of this technology involves conversion of the produced glassy materials into directly marketable products such as cellular glasses and enamels for glazed ceramic tiles production [11].

The cellular glasses are light rigid materials, with low thermal conductivity, good mechanical properties and acoustic insulation capacity [12]. Being fire and waterproof materials, the cellular glasses are increasingly considered in civil engineering as insulating or lightweight filling materials [13–15].

Cellular glasses are formed in two steps: i) viscous flow sintering of fine glass powders and ii) subsequent foaming of the pyroplastic mass with specific additives under heating at 850–1000 °C [14]. The foaming process occurs upon releasing different gases (CO, CO_2, SO_x) generated from the thermal decomposition of the additives (typically carbonates [16] or sulfates). However, the gas release may represent an environmental problem. An alternative to the above-mentioned foaming process is cellular glass production by means of redox reactions between additives and glass components. However if carbon-containing species (C, SiC) are used as additives greenhouse effect gases will be produced, meanwhile the use of iron(III) oxide or aluminum nitride [14,17], producing oxygen or nitrogen during redox reaction, are examples for environmentally friendly process.

The enamel is a glassy substance chemically formulated to adhere on the surface of preformed tile and subsequently fused into the body when fired. It is essentially composed by silica (glass forming element), alumina (for stability) and additives (to help melting). Various minerals, oxides and chemical compounds could be also employed for color.

The CDWs due to their composition are good candidates for being recycled as raw materials for the production of the above-mentioned materials. In this context, the present work is devoted to the feasibility of glassy materials directly obtained from construction waste as marketable products with a special emphasis made on material's final state and their possible future quick utilization without any further treatments.

2. Materials and methods

Three groups of CDWs are used as raw materials, i.e. bricks, glazed tiles and concrete wastes. Additionally, some commercial products are employed either to adjust chemical compositions (MgO, SiO_2 and NaOH) or as foaming agents (AlN and $CaCN_2$).

The chemical composition of the samples is determined by X-Ray microfluorescence spectrometry (XRMF) in an EDAX Eagle III spectrophotometer using Rh source of radiation.

X-ray diffraction (XRD) analysis is performed on X'Pert Pro PANalytical diffractometer using Cu-Kα radiation ($\lambda = 15{,}404$ Å), working at 40 mA and 45 kV and equipped with position sensitive detector. The diffractograms are recorded over 2θ-range 5–80° using 0,05° step size and 80 s step time.

Thermogravimetric analysis is carried out on Seiko Exstar 6000 thermobalance, up to 1200 °C in air, using a heating rate of 10 °C min^{-1}.

The material's density is measured by the He pycnometry method on Pentapycnometer 5200e Quantachrome Instrument.

The tribological properties are tested on Microtest® pin-on-disk apparatus, providing continuous measurement of the material's friction coefficient.

The mechanical strength analysis is carried out on Microstest EM1/FR under compression strength.

Table 1
Chemical composition of the used CDW (oxides wt%).

Waste	% weight							
	SiO_2	CaO	Al_2O_3	Fe_2O_3	K_2O	Na_2O	MgO	Others oxides
Brick	69,7	5,9	14,2	4,7	3,7	1,6	–	0,13 (V, Mn)
Glazed tile	68,7	7,9	15,4	4,9	3,0	–	–	0,01 (Mn)
Concrete	20,4	67,0	1,5	2,7	0,7	–	7,4	0,4 (Ti)

3. Results and discussion

All waste materials are milled prior any characterization or use. The chemical compositions obtained by XRMF are shown in Table 1. For bricks and glazed tiles silicon is the main element according to the preponderance of silica and silicate phases, observed in the diffractograms (Figs. 1, brick, and 2, glazed tile). Similarly, the concrete sample is rich in silicon and calcium, in agreement with the presence of silica, silicates and especially calcium carbonates as main crystalline phases (Fig. 3).

In the case of the brick sample, seven characteristic phases are identified by XRD (Fig. 1): iron (III) oxide, Fe_2O_3 (JCPDS#01-073-0603); silica, SiO_2 (JCPDS#01-078-1253), two feldspars $NaAlSi_3O_8$ (JCPDS#00-009-0466) and $(Na,K)(Si_3Al)O_8$ (JCPDS#00-009-0478), illite (JCPDS#00-026-0911), calcium carbonate, $CaCO_3$ (JCPDS#01-086-2334) and sodium iron oxide, Na_5FeO_4 (JCPDS#00-036-0874).

For the glazed tile sample, the aluminosilicate occurrence is confirmed by the presence of $(Ca, Na)(AlSi)_2Si_2O_8$ (JCPDS#00-020-0528); together with crystalline calcium magnesium silicate, $Ca_2MgSi_2O_7$ (JCPDS#01-076-0841); iron (III) oxide Fe_2O_3 (JCPDS#01-073-0603) and silica, SiO_2 (JCPDS#01-078-1253) (Fig. 2). Manganese traces determined by elemental analysis were not identified as crystalline phase.

The components of the concrete sample are identified by XRD as calcium carbonate, $CaCO_3$ (JCPDS#01-086-2334) and calcium-magnesium carbonate, $CaMg(CO_3)_2$ (JCPDS#00-036-0426), silica, SiO_2 (JCPDS#01-078-1253) and sodium aluminosilicate, $NaAlSi_3O_8$ (JCPDS#00-009-0466) (Fig. 3).

Usually the main problem of reusing CDW wastes is their high aluminum content, which indicates necessity of high temperatures for vitrification. Jordan et al. [18] reported the elaboration of soda-lime type glass at temperatures around 1100 °C from natural zeolite with comparable aluminum content to that observed for our brick and glazed tile samples. Based on this study, and on the fact that the compositions of the waste materials, either bricks and

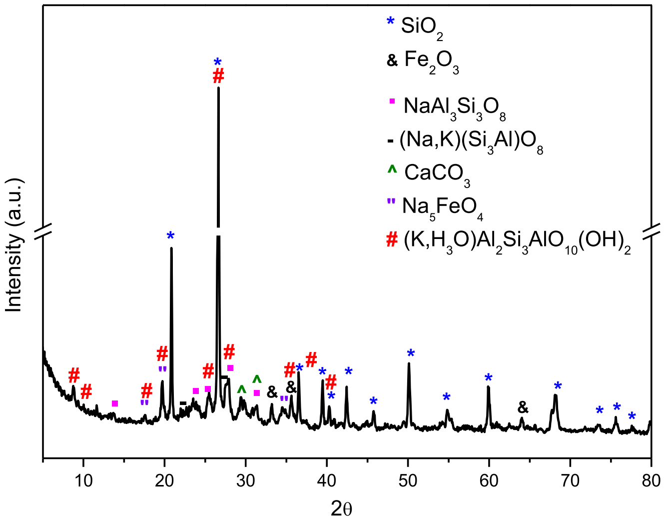

Fig. 1. Diffractogram of brick sample.