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Development of a fly ash-based geopolymeric concrete with construction and demolition wastes as aggregates in acoustic barriers

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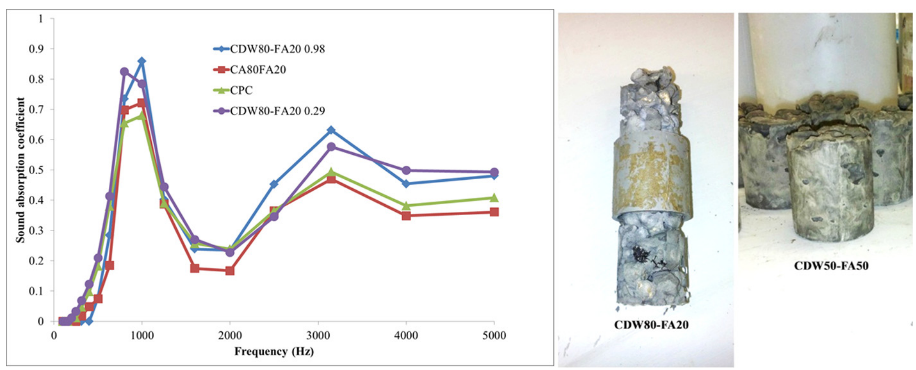
HIGHLIGHTS

- Double objective: to recycle residues and reduce the noise in geopolymer concrete.
- Two residues: fly ashes and construction and demolition waste in great proportions.
- Sound absorption and mechanical properties similar to commercial products.

GRAPHICAL ABSTRACT



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ABSTRACT

The present study aims to determine and evaluate the applicability of a new product consisting of a fly ash-based geopolymeric porous concrete with construction and demolition wastes as aggregates in the field of road noise barriers. In this work the main physical, mechanical and acoustic properties of a fly ash-based geopolymeric concrete were analyzed. To develop a porous matrix that absorbs the sound energy, two different aggregates were studied, crushed granite (usually utilized in concretes) and construction and demolition waste. The geopolymeric concretes were prepared using sodium silicate and sodium hydroxide in two different proportions in order to study the influence of the Na_2O/SiO_2 ratio in the properties. The geopolymer/aggregate ratio was studied as well. The construction and demolition waste used as aggregate in geopolymeric porous concretes presents better mechanical and acoustic properties than the crushed-granite aggregates in geopolymeric concretes. The activating solution in the geopolymerization of the fly ash has a significant influence in the mechanical properties mainly but not in the acoustic properties. From an environmental point of view, the use of fly ashes and construction and demolition waste in these materials do not present any leaching problem.

1. Introduction

Generation of residual combustion products is a worldwide problem with implications in the human health, the environment and the industry. Fly ash is the main coal combustion waste, which has applications in many fields, mainly in the construction industry [1] due to the good pozzolanic and cementitious properties [2,3]. The recycling rate of fly ash is quite low, only 43% of the ash produced in Europe in 2010 was used (see www.ecoba.com) [4], principally in the cement and concrete industry, as a low cost material resource for the cement industry, but the crisis of

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construction sector in Spain has diminished the Spanish cement consumption and the fly ashes recycled in this field, so it is necessary to explore new applications of medium/high value, where the fly ash can be used.

A considerable and growing amount of construction and demolition waste (CDW) is produced in Europe each year; in 2006 around 970 million tonnes [5] were generated. Despite the reduction of the CDW volume due to the economic crisis, in 2009 the EU produced approximately 530 and Spain approximately 35 million tonnes of CDW [6]. As a result, special attention must be paid to CDW management at the European level, which is having implications for national-level policies. CDW management is steered in particular by the EU Waste Framework Directive (2008/98/EC) [7], which sets a target for the recycling of non-hazardous CDW at a minimum of 70% of its weight by 2020. According to this, the politic strategies of the European Commission to move towards more a circular economy envisages measures to stimulate markets in recycled materials derived from construction and demolition waste [8]. The tendency in the field of construction is to consider CDW as inert waste to be deposited in landfills, and, in some cases, in uncontrolled dumps. Accordingly, the recycling of the CDW has other problem, its transformation into a potential new material used in construction has a higher cost than the natural source materials that the CDW aims to replace. Thus, CDW management requires a tendency change towards prevention of the generation of waste and, failing this, towards waste recycling and re-use and/or energy recovery [9]. Some of the environmental impacts of generation of CDW are: generated volume, contamination of soil and water resources by uncontrolled landfills, deterioration of the landscape, and above all, waste elimination without recycling or re-using the material. Another important aspect in order to properly manage CDW is the classification, for example, concretes, bricks, tiles or ceramics are the most representative components according to the National Plan of Construction and Demolition Waste (Spain ME 2001) [10]. Kourmpanis [11] used the European Environmental Agency statistics (EEA 2002) [12] to characterize CDW and to establish a management system in order to control waste in demolition works. Other authors [13] characterize CDW waste according to American and Japanese classification lists in order to establish a methodology for the reuse of gypsum and wood. Although the reutilization of CDW wastes as coarse aggregates in concrete production has been studied previously [14–17], it use in structural concrete is not a common practice [14]. Because of this, it is necessary to found new specific engineering applications of non-structural concretes with recycled aggregates to improve its recycling and to prevent the disposal and thus to save natural resources.

Geopolymers are new materials produced in the reaction between a solid aluminosilicate and an activating solution of alkaline silicate or hydroxide at ambient temperature or at slightly high temperature [18]. Geopolymers present an enormous potential as a source of products with a wide spectrum of applications [19], mainly in the construction field where geopolymers are competitive with the cement based product [20]. Some of these properties are high compressive resistance and high structural integrity [21], high level of resistance to acid and salts attack [21,22], low permeability [21] and good resistance to thaw-freeze cycles [23,24]. Although the construction world crisis would affect both, cement use and geopolymer use, the amount of fly ash utilized in geopolymeric materials (80%) are higher than in ordinary cement (30–40%), so the possibilities of recycling fly ash are incremented.

Another environmental problem, which is becoming an increasingly significant concern because of its negative impact on human health, is noise pollution. The source of most outdoor noise worldwide is mainly transportation systems, including motor vehicle, aircraft and rail noise. The World Health Organization (WHO) report says that each year Europeans lose at least one million healthy life-years due to disability or disease caused by traffic noise. Changes in the Regulations have led to the creation of programs under the European Directive on the Assessment and Management of Environmental Noise [25], which are likely to lead to growth in the use of noise barriers as a way of reducing traffic noise.

Conventional acoustics barriers are generally designed to reflect a large proportion of traffic noise, which creates a problem when a minimization of sound reflection towards noise sensitive areas adjacent to the highway is required. Therefore, there is a need for traffic noise barriers to absorb noise, leading to major developments in the field of sound absorbing materials [26]. One of the most common materials used for highway noise barrier applications is the porous concrete, which is made by mixing large aggregate material with mortar, creating lots of voids in the cast concrete. As a result, the pores inside the material absorb sound energy through internal friction [27]. The porous concrete has been made with different materials: lightweight aggregate (expanden clay, perlite and vermiculite) [27–31], coarse aggregate [27,32–35], recycled aggregate [36], fiber [27,37–41], entrapped air [42], vegetal material [43,44] and waste materials such as rubber [45–49], petrolatum coke [50], expanded shale [35] and others [51,52].

The purpose of this research has a double environmental aspect. From one side, recycling an industrial by-product, and to the other hand, reducing traffic noise pollution levels. The objective of this study is to design a porous geopolymeric concrete so that it can be applied in the field of road noise barriers. In order to achieve the greatest acoustic insulating behaviour of the product, the influence of the fly ash/aggregate ratio, the type of aggregate (gravel or construction and demolition waste) and the Na_2O/SiO_2 ratio of the activating solution have been studied.

2. Materials and methods

2.1. Materials

Fly ash (FA) from the combustion of high quality pulverized coal in one of the largest coal power plants in the south of Spain (Los Barrios, Cádiz (550 MW_e)) was used as geopolymeric precursor. Two aggregates are used as filler, a coarse aggregate (CA) in form of crushed granite (Fig. 1) and a construction and demolition waste (CDW) (Fig. 1) from the Environmental Complex Mancomunidad de la Vega, Seville, Spain. The CDW used in this work is a product from the sieve refuses at 5 mm prior separation of wood, plastic and metals. As can be seen, type of surface of both aggregates is very different, CA presents a rounded shape, while CDW presents an irregular surface. The chemical composition of the materials was determined after chemical attack and dissolution at 750 °C (ASTM D-3682-78) [53] using atomic absorption spectroscopy and the data are given in Table 1. Fly ashes present low calcium contents and they can be classified as ASTM class F [54].

CA is mainly composed by SiO_2 and the CDW have SiO_2, CaO and Al_2O_3. LOI in CDW is higher than that of natural aggregates due to the Portland cement and gypsum contained in recycled aggregates. The specific gravity is measured according ASTM C 127-93 (1993) [55] and is detailed in Table 1. As can be seen, the recycled aggregate specific gravity is lower than that of natural aggregates, as a consequence of the mixture of materials (Portland cement, gypsum) that forms the CDW. The grain size distribution of materials was determined and detailed in Fig. 2. One of the most important problems of CDW is its very heterogeneous composition, but in previous studies [56] the particle size is the most important factor in the acoustic properties of porous concretes, more than the chemical composition. The producers of CDW aggregates produce