Construction and Building Materials 95 (2015) 585–591

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Technical specifications for highway noise barriers made of coal bottom ash-based sound absorbing concrete

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HIGHLIGHTS

- We manufacture a product composed of 80% of coal bottom ash.
- It is applied to develop highway noise barriers at semi-industrial scale.
- Acoustic properties of recycled product similar to commercial materials.
- It complies with the European specifications for highway noise barriers.

ARTICLE INFO

Article history:
Received 20 January 2015
Received in revised form 16 June 2015
Accepted 14 July 2015
Available online 25 July 2015

Keywords:
Bottom ash
Industrial waste
Traffic noise reducing device
Sound absorption coefficient
Reverberation room
Airborne sound insulation

ABSTRACT

This paper focuses on developing a highway noise barrier prototype mainly composed of bottom ash from the traditional pulverised coal combustion at semi-industrial scale, following a simple and low-cost manufacturing procedure similar to that used to cast commercial concrete noise barriers. In order to obtain good sound absorption coefficients, a multilayer product was designed, with a porous layer in the incident noise face followed by the finest material in the back layer. The characterisation of the recycled multilayer product was carried out in accordance with the current European standard for road traffic noise reducing devices and the results have been compared to the specifications stated by the regulations. The acoustic performance has been evaluated by determining the sound absorption coefficient and the airborne sound insulation in a reverberation room. Regarding the non-acoustic performance, the physical (open void ratio, unit weight), mechanical (compressive strength, Young's modulus, flexural strength, fracture energy, indirect tensile strength, characteristic length, impact strength) and fire resistance properties were determined. From the results obtained, bottom ash from traditional pulverised coal combustion can potentially be recycled by manufacturing a multilayer product that complies with the specifications required for road traffic noise reducing devices according to the European standards, and that reaches the same acoustic category as other commercial products used for the same application.

1. Introduction

Waste is a pressing environmental, social and economic issue. Increasing consumption and developing economies continue to generate large amounts of waste, with more effort required to reduce and prevent it. The Spanish Law on Waste and Contaminated Soil [1], based on the Waste Framework Directive from the European Parliament [2], promotes the reuse, recycling and extracting of value from waste, reflecting on the waste management shift away from disposal towards recycling and recovery. Thus, while waste was viewed as disposable in the past, today it is increasingly recognised as a resource.

Large amounts of materials and natural resources are demanded by the building sector, which has become a sector with enormous potential for the use of waste, both from its own activities and those from other sectors. The use of recycled materials based on solid waste in construction activities helps not only to reduce the demand of non-renewable natural products but also to reduce the amount of waste landfilled without extracting any value from it. In particular, the concrete industry consumes large amounts of natural resources that cause substantial environmental, energy and economic losses as it exploits 50% raw material, 40% of total energy as well as generating 50% of total waste [3].

Although the use of industrial waste as a source of aggregate for the production of concrete has become more and more common in recent years, low recycling rates are found for some specific waste and what is more important, very few products developed by

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http://dx.doi.org/10.1016/j.conbuildmat.2015.07.107
0950-0618/

researchers at laboratory scale have been competitive compared to commercial products traditionally used for the same application. Some of the difficulties found for recycling industrial waste in products that compete with the commercial products are: (a) the absence of specific technical regulations about recycling industrial waste in the building sector; (b) the industrial waste is characterised by a wide range of chemical compounds, depending on the process by which they are generated; (c) comparing the properties of the recycled products with the commercial versions, casting prototypes at semi-industrial scale are required; (d) previous treatments usually required by the waste materials increases the total cost of the process, making it difficult to compete in price with other products available on the market.

The use of coal bottom ash as a substitute for coarse aggregate for the development of porous concrete with sound absorbing properties has been the main subject of several investigations carried out by the authors in recent years [4–7]. The properties of a sound absorbing porous concrete mainly composed of bottom ash has been rigorously analysed at laboratory scale. The results obtained showed that recycled porous concrete made of 80% of bottom ash presents similar properties to other conventional materials used for sound absorbing applications [5]. Moreover, the origin of the bottom ash (pulverised coal combustion, coal and pet-coke co-combustion or gasification, biomass combustion) does not affect the sound absorption behaviour of the recycled concrete provided that the size distribution is similar, but determines the leaching properties of the final product. The leaching properties state whether the product represents any risk to human health or the environment [7].

The main scope of this work is to study the potential application of the bottom ash-based porous concrete with sound absorbing properties to develop highway noise barriers, facing two environmental problems. Furthermore, the work focuses on developing a prototype at semi-industrial scale following a simple and low-cost manufacturing procedure similar to that used to cast commercial concrete noise barriers. The final target has been to describe the technical specifications of the bottom ash-based noise barrier that could validate its use at an industrial scale whilst competing with the traditional concrete barriers usually applied for reducing road traffic noise. For this purpose, the recycled product has been characterised according to the parameters stated by the European standards for road traffic noise reducing devices.

2. Experimental work

2.1. Materials

The bottom ash used in this work comes from the traditional pulverised coal combustion in Los Barrios power plant (Cádiz, Spain). In order to manufacture the porous concrete, bottom ash has been mixed with Portland cement type II, CEM II/B-L according to the European standard EN 197-1 [8].

The chemical composition, loss of ignition (LOI) and specific gravity of the bottom ash (BB) are showed in Table 1. The chemical composition has been determined following the standard ASTM D3682-01:2006 [9] for measuring major and minor elements in combustion residues from coal utilisation properties, based on atomic absorption spectroscopy. The major components in bottom ash are silicon oxide, aluminium oxide and iron oxide. Trace amounts of MgO, CaO, Na_2O and K_2O are also detected. According to the LOI, the bottom ash used presents a relatively high content of unburned matter, which proves the porous nature of the bottom ash [10].

The specific gravity [11] of the bottom ash is low, due to the porosity of the particles. This property gives an indication of the density of the final product. The bottom ash presents a lower specific gravity than traditional natural coarse aggregates (2.55–2.75 g/cm^3) [12,13], which is beneficial for reducing the final weight of the barrier.

Table 2
Leaching test EN 12457-4:2003 results compared to the European landfill normative.

(mg/kg)	BB	Inert	Non-hazardous	Hazardous
Hg	<0.01	**0.01**	**0.2**	**2**
Se	<0.05	**0.10**	**0.5**	**7**
Sn	<0.03	–	–	–
Pb	<0.06	**0.50**	**10**	**50**
Ba	0.63	**20.00**	**100**	**300**
Cd	<0.01	**0.04**	**1**	**5**
Sb	<0.06	**0.06**	**0.7**	**5**
Co	<0.01	–	–	–
Cr	<0.01	**0.50**	**10**	**70**
V	0.32	–	–	–
As	<0.03	**0.50**	**2**	**25**
Mo	0.97	**0.50**	**10**	**30**
Ni	<0.01	**0.40**	**10**	**40**
Zn	0.38	**4.00**	**20**	**50**
Cu	<0.01	**2.00**	**10**	**50**

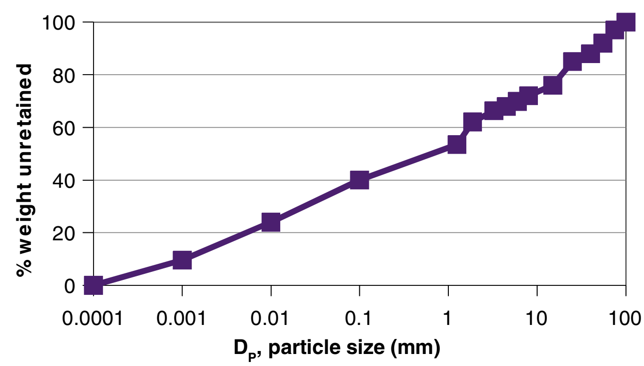

Fig. 1. Particle size distribution of the bottom ash.

Bottom ash was submitted to the leaching test described in the European standard EN 12457-4 [14] in order to evaluate whether it represents any risk to human health or the environment. The results have been compared to the European landfill normative [15], which establishes limits to classify any waste as inert, non-hazardous or hazardous. This is a compulsory classification in order to landfill any waste. According to the results presented in Table 2, the bottom ash could be classified as inert waste, but the content of Mo is slightly above the limit for inert waste, so the bottom ash is classed as non-hazardous waste. However, this leaching test represents the most unfavourable conditions applied to the raw material but not to the mortar.

The particle size distribution of the bottom ash is shown in Fig. 1, and it corresponds to the material as it was received without any previous treatment. Bottom ash particles range in size from a coarse gravel to a fine sand, requiring a previous sieving process in order to enhance the sound absorption of the recycled concrete, which is strongly related to the particle size of the aggregate [5].

2.2. Mortars composition

Previous studies of the authors were focused on the study of the optimal bottom ash/cement ratio which develops the greatest sound absorption with acceptable compressive strength [5,7], looking for recycling the maximum amount of waste. From the work carried out at laboratory scale, it was concluded that bottom ash is potentially suitable for developing a sound absorbing porous concrete with high proportion of bottom ash as aggregate (80%). In order to obtain good sound absorption coefficients, a multilayer product has to be designed with a porous layer in the incident noise face followed by the finest material in the back layer. From the results obtained so far, and taking into account the importance of recycling the entire material and minimising the cost of the manufacturing process, bottom ash was sieved into two fractions: coarse (D_P > 2.5 mm) and fine (D_P < 2.5 mm). Therefore, a composite product made of bottom ash was designed to manufacture a highway noise barrier prototype. The composition of the coarse (BBC) and fine mortars (BBF) is presented in Table 3.

Table 1
Chemical composition, loss of ignition (LOI) and specific gravity of the materials used.

	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	SO_3	P_2O_5	LOI (750 °C)	Specific gravity (g/cm^3)
BB (%)	64.45	15.89	7.77	2.45	3.92	0.89	1.60	<0.01	<0.01	11.86	2.00