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Characteristics of fired bricks with co-combustion fly ashes

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ABSTRACT

This paper studies the feasibility of utilizing co-combustion fly ashes for the production of eco-friendly fired bricks. The fly ashes from co-combustion of coal and pet coke in a Spanish Power Plant were used as raw material to replace clay to make fired bricks. The effect of fly ash with high replacing ratio (from 0 to 80%) of clay on properties of bricks was analysed. The specimens, cylinders with 32.5 mm diameter and 50 mm length, were manufactured by compressing at 10 MPa. Different firing temperatures, 800, 900 and 1000 °C, were studied. The fired bricks with high volume ratio of fly ash present a high compressive strength and a low water absorption capacity. With increase in firing temperature, the compressive strength increased and the water absorption decreased. With increase in replacing ratio, the compressive strength decreased and the water absorption ratio increased. The bricks no present environmental problems according to the leaching study.

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1. Introduction

The recycling of by-products and wastes is an increasingly major problem for the future of humanity. One of the major by-products is coal fly ash, which is produced in significant amounts in both Spain and the rest of the world. Currently, only a small percentage of fly ash is utilized (42% according to the European Coal Combustion Products Association (ECOBA)) [1]. However, most of the rest is sent to landfill, which is unsatisfactory solution both from ecological and economic point of view. Therefore, there is continuing interest in establishing suitable processes in which fly ashes can be efficiently reused.

The production of conventional ceramics can be an important application for fly ash, bearing in mind the large quantities of raw materials needed for ceramic production [2]. The ceramic industry consumes large quantities of natural raw materials. A ceramic factory of medium size uses 500 t of raw materials per day. The major constituents of fly ash are SiO_2, Al_2O_3 and Fe_2O_3 with some minor constituents such as CaO, MgO and other oxides. Therefore, these oxides have been mainly considered as a low cost material resource for the cement industry [3,4] but the crisis in the construction industry of Spain has diminished the Spanish cement consumption and the recycle of fly ashes.

Combustion of non-fossil fuels is carbon neutral and thus of interest from an environmental point of view. For this reason, governments have legislated to promote an increase in co-combustion at the large power stations in Spain and other countries. However, co-firing can produce fly ashes without the quality to be used in cement or concrete production.

There are some advantages using fly ash as raw material of bricks. For example firing energy can be saved because of the amounts of carbon contained in fly ash. Fired fly ash bricks were also studied and produced in Germany, England and China [5].

2. Materials and methods

In this study, fly ashes (FA) from the co-combustion of coke and coal from a Spanish power plant were used without any previous treatment. The chemical composition of co-combustion fly ashes and natural clay (NC) is shown in Table 1. The content of silica, alumina and magnesium oxide is strongly related to the vitrification process and the subsequent forming of a tough ceramic matrix when the sintering temperature has been reached [6]. The co-combustion fly ashes present a lower loss on ignition (LOI) content than NC. Clay has higher silica content than ashes. A higher silica content may improve the plasticity and hardness properties of the mixtures [7]. Regarding the specific density of the used materials, clay presents a similar specific gravity to ashes.

The particle size distribution of the raw materials is shown in Fig. 1. Ash particles are much finer than the particles of clay. It is evidenced by the average particle size D_{50}:20 µm for FA and

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Table 1
Chemical composition of fly ashes and clay.

	LOI	CaO	SiO_2	Al_2O_3	Fe_2O_3	Na_2O	K_2O	MgO	Ti_2O	P_2O_5	SO_3	specific gravity (g/cm^3)
FA	1.14	2.26	48.72	24.26	7.91	0.7	3.69	0.07	1.5	0.35	0.02	2.36
NC	3.37	1.47	77.56	11.25	3.26	0.19	3.55	1.18	3.37	< 0.01	< 0.01	2.32

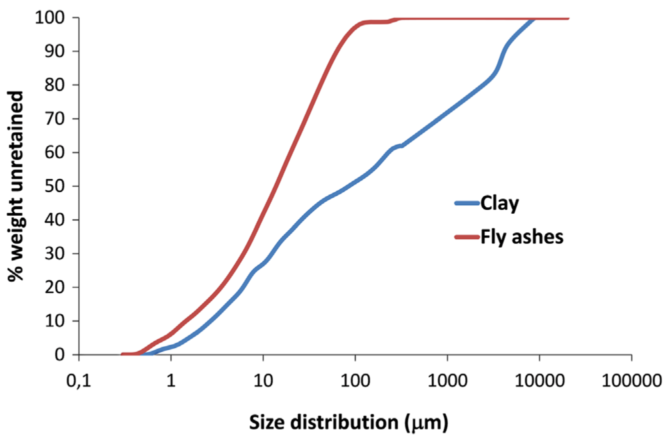

Fig. 1. Size distribution of fly ashes and clay.

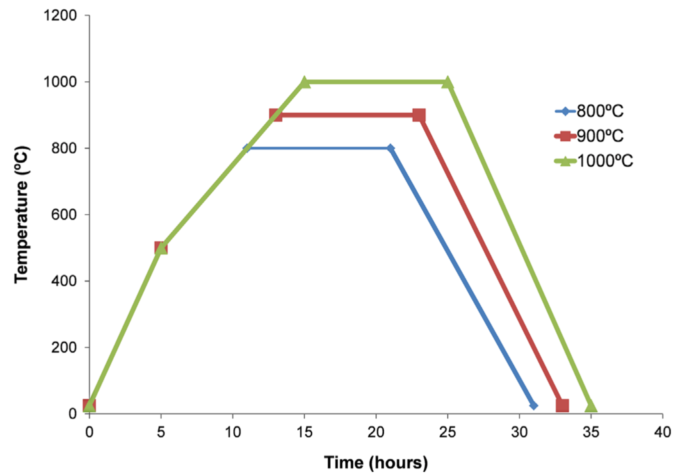

Fig. 2. Heating program of bricks.

86 µm for NC. Therefore, the different particle size of ashes and clay causes a lack of homogeneity in the mixes.

In order to study the replacement of clay by co-combustion fly ash in the properties of ceramic bricks, different ash/clay ratios have been tested. The compositions of the tested mixtures are shown in Table 2, as well as the mixing water requirements (WR = 100 · mass water/mass solids). The WR value increased with the proportion of fly ashes due to the plasticity of the mix decreased with the increment of the proportion of fly ashes.

The specimens, cylinders with 32.5 mm diameter and 50 mm length, were manufactured by compressing at 10 MPa. Moulding pressure values in the range of 5–50 MPa are typically presented in the literature [7]. The employed moulding pressure was chosen based on previous results [8], When the moulding pressure is increased, the distance between the particles decreases and the number of contact points increases. As a consequence, the compressive strength enhances and the total porosity decreases. But an excessive pressure may lead to the development of pressure gradients and other defects that can affect the quality of the bricks after pressing and firing [9]. The specimens were immediately removed from the moulds and dried at 60 °C until constant weight was achieved. Then, samples were fired in an electric furnace according to the designed heating program shown in Fig. 2. This heating program is based on similar programs found in the literature [5]. The heating rate in tunnel kilns for facing bricks is 100–200 °C/h [10], higher than this study. The heating rate was 100 °C/h below 500 °C and 50 °C/h from 500 °C to the selected maximum temperature. The maximum temperature was held during 8 h. This heating program ensures that all the material reaches the selected firing temperature, and it permits the total combustion of the carbon contained in the ash and the organic material that the clay could contain. Three different firing temperatures (800, 900 and 1000 °C) were studied in order to analyse the effect of this temperature on the properties of the final products.

Table 2
Tested compositions.

Nomenclature	Clay (wt%)	Fly ash (wt%)	WR (water/solids) (wt%)
C-0	100	0	16.8
C-20	80	20	17.2
C-40	60	40	17.9
C-60	40	60	18.9
C-80	20	80	19.5
C-100	0	100	20.2

The fly ash-based ceramic materials studied were characterised by measuring the bulk density, water absorption, shrinkage, efflorescence, compressive strength and leaching behavior. The obtained results have been compared to a control mixture based solely on clay.

The material density (ρ) was measured by measuring weight and volume (dimensions). Four specimens of each type were measured. The water absorption capacity (A) was measured according to UNE 67027 [11]. Four specimens of each type are tested. An efflorescence study was carried out. The specimens were immersed in water for 24 h and after dry in shade. After this treatment, the presence of soluble salts in the bricks was determined.

The compressive (R_c) strength of the samples were evaluated, according to EN 772-1 [12], using a compression test machine (Suzpecar, MEM-102/ 50 t). The compressive strength tests were performed on 40 mm-high, 32.5 mm-diameter cylinders. Three samples of each type were tested. The results of compressive strength have been standardized to a ratio height/diameter = 2 according with previous studies [13].

The leaching study, is carried out to characterize the fly ash and to evaluate the possible applications was determining according to EN 12457-4 [14]. Clay was subjected to the same test in order to compare the leaching results.

3. Results

3.1. Shrinkage

Figs. 3 and 4 show photographs of the samples after firing. All the samples presented a low shrinkage; lower than 4% for all the compositions. Previous results with combustion fly ashes shown that above 1000 °C, a partial sintering can be observed in bricks