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Alumina filler waste as clay replacement material for unfired brick production ☆

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ABSTRACT

This paper presents the results of an investigation for the application of alumina filler wastes and coal ash waste for unfired brick production. Mechanical test and durability assessment were carried out on unfired brick test specimens made using marl clay soil and alumina filler waste as a target material, and 70% mix of coal ash waste were used as commercials additive (Portland cement and Lime) replacement. The laboratory results demonstrate that the compressive strength resistance of the unfired bricks reduced as the clay replacement level increased. The unfired brick test specimens made with the blended mixtures containing coal ash waste and lime tended to achieve higher strength values when compared with the coal ash waste and Portland cement blends. The unfired brick test specimens were able to withstand the repeated 48-hour freezing/thawing cycles. The results obtained suggest that there is potential to manufacture unfired bricks from alumina filler waste and coal ash waste.

1. Introduction

In order to boost environmental technologies while strengthening economic growth and competitiveness, the development of products, techniques, services and processes that reduce carbon dioxide emissions and promote resources efficiently is on the increase worldwide. This has accounted for the research and development interests on the possible utilization of a wide range of waste streams arising from the biomass sector, quarrying and construction activities. For example, one well-established way of using waste and by-product materials is for soil stabilization. This technique is often used to improve the geotechnical properties of the soil, through the addition of waste and by-product materials and cementing agents like Portland cement, lime, and asphalt. Replacement of natural soils, aggregates, and cement with solid industrial by-product is highly desirable. In some cases, the waste and by-product materials are inferior to traditional soil stabilizing materials. However, if adequate performance can be achieved, due to its lower cost, waste and by-product materials make an attractive alternative.

More recently, there is a growing number of companies specializing in the integral management of waste and by-product materials, producing new environmentally friendly construction products from recycled waste and by-product materials from the industry. However, during their recycling process, secondary waste materials arise, that have no particular application. Because of the scarcity of land and the high costs associated with the disposal of these secondary wastes, research studies to tackle these problems and finding beneficial uses for these secondary wastes in a controlled and safe manner, are now ongoing. For example researchers within the faculty of advance technology, University of Glamorgan have done extensive research work on the development of unfired masonry bricks, blocks and mortar using various waste streams and by-product materials, and full-scale trials have been carried out (Kinuthia et al., 1999; Oti et al., 2009; Oti, 2010). The short and long-term strategy is to reintroduce these secondary wastes into the product cycle by making bricks, blocks and mortar. Others studies on the use of waste and by-product materials such as Fly ash, Ground Granulated Blast-furnace Slag (GGBS), lime or different cement mixtures for making stabilized bricks have also been carried out by several researchers (Weng et al., 2003). In addition to lime and cement, other solidifying agents such as calcined gypsum and dextrin (A polymer of D-glucose) have been added in the various production processes.

In all the reported studies on the possible utilization of waste and by-product materials for building bricks production, there have been no reported cases on the use of alumina filler waste as clay replacement material for unfired brick production. This research was designed to address to the following main objectives: (1) to obtain the best alumina filler waste and coal ash waste mixtures for unfired brick production, (2) to investigate the water absorption of the unfired clay bricks, (3) to investigate the compaction effort and compressive strength resistance of the unfired bricks and (4) to assess the durability of the unfired bricks by means of repeated 48-hour freezing/thawing cycles.

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2. Experimental investigation

2.1. Materials used

The materials used for the experimental investigation consisted of Gray Marl (GM) clay soil, Alumina Filler (AF) waste, Portland Cement (PC), Natural Hydraulic Lime (NHL-5), Calcareous Lime (CL-90-S) and Coal Ash (CA) waste. The basic characterization of these materials was carried out in accordance with the British and European Standards and other internationally accepted engineering standards.

2.1.1. Gray Marl (GM) clay soil

For this work, a fine-grained plastic soil with high clay content (Gray Marl clay soil) was used throughout. It was supplied by a construction company located in the North of Span. Gray Marl clay soil is a very changeable material when it comes in contact with the atmosphere, which is one of its main features, coupled with its low load-bearing capacity. This greatly limits its application in civil engineering. The chemical and XRD analysis of Gray Marl clay soil, gave a mineralogical composition of 51% calcite, 20% illite, 15% quartz, 5% kaolinite, 5% attapulgite and 4% ankerite. Its physical properties are illustrated in Table 1.

2.1.2. Limes

Two different types of lime were used in this research — Natural Hydraulic Lime (NHL-5) and Calcareous hydrated Lime (CL-90-S). The Natural Hydraulic Lime (NHL-5) used in this practical study is obtained from burned non-pure limestone and manufactured in accordance with the Spanish Standard UNE-EN 459-1 (2002). The numerical designation of an NHL corresponds to a nominal compressive strength in MPa of the material after 28 days of hydration and is indicative of hydraulicity, or ability to set underwater. NHL-5 has a nominal strength of 5 MPa at 28 days with a hydraulic index of around 0.47. The hydraulic properties are due to the presence of silicates that are predominantly in the di-calcium silicate form (belite), with only trace amounts of the highly reactive tri-calcium silicates (alite). For this reason, the hydraulic lime has a slower setting time and gain in strength overtime. On the other hand, the Calcareous hydrated Lime (CL-90-S) used in the study is obtained from burned pure limestone and manufactured in accordance with the Spanish Standard UNE-EN 459-1 (2002). The physical and chemical properties of both limes are shown in Tables 1 and 2 respectively.

2.1.3. Portland Cement (PC)

Portland Cement (PC), manufactured in accordance with the Spanish Standard UNE EN 197-1 (2000), marketed under the trade name of CEM II B-M VL 32.5 N BS EN 197-1, 2000, was used throughout. A single batch of the cement was used throughout this research program. Some physical properties and chemical composition of the PC are also shown Tables 1 and 2.

Table 2
Chemical properties of PC, CL-90-S, NHL-5, AF waste and CA waste.

Oxides	Portland Cement (PC)	Calcareous Lime (CL-90-S)	Natural Hydraulic Lime (NHL-5)	Alumina Filler waste (AF)	Coal Ash waste (CA)
CaO	65	–	–	1	1
$Ca(OH_2)$	–	53	90		
MgO	1	–	–	6	1
Al_2O_3	3	10	–	70	28
SiO_2	25	12	–	8	52
Fe_2O_3	0.5	–	–	–	11

2.1.4. Alumina Filler (AF) waste

Alumina Filler (AF) waste is generated during the valorization of aluminum salt slags. The AF waste used for this study was supplied by Befesa, located in Valladolid, Spain. This company specializes in the recycling of aluminum waste and salt slag. During the recycling process, around 110,000 tonnes per year of AF waste is generated as secondary waste. Salt slag is generated in the Aluminum Foundries plant, where this salt is necessary for the smelting process. Once used, this salt is cleaned for its reutilization. During this process the alumina filler waste is generated. Tables 1 and 2 show some physical and chemical properties of AF waste.

2.1.5. Coal Ash (CA) waste

Coal Ash (CA) waste used in this investigation was collected from an open dumping ground located in Escucha (Teruel), Spain. Its physical and chemical properties are shown in Tables 1 and 2 respectively. CA waste has been used as a key ingredient because of its availability. Its use can reduce the environmental impact that arises from dumping CA waste, and reduce the utilization of the commercial stabilizer for unfired brick manufacture. Coal ash has been used in this study without any pre-treatment. Converting specific waste streams such as CA waste to a usable resource could be viewed as resource preservation and environmental enhancement from a visual impact and amenity point of view. Furthermore, the embodied energy in recovering and reusing such waste for use in making non-fired bricks is less than the embodied energy used in quarrying clay.

2.2. Mix design proportion, test specimen preparation and laboratory tests

2.2.1. Mix design composition and test specimen preparation

Table 3 reports the details of the mix compositions of the different additives used during the experimental trials. For the entire practical trial, 950 unfired clay mini bricks were prepared and tested. Twelve major blended mixtures were considered for this trial. All the blends were designated with a word and two numbers. The words were used to designate the blend of binder used and the two numbers indicated the blending ratio for the target materials (clay and AF waste). Blends made using CA waste combined with Portland cement were designated PC. Those made using CA waste and Hydraulic Natural Lime were designated with NHL-5 and those made with CA waste and

Table 1
Physical properties of the Gray Marl, PC, CL-90-S, NHL-5, AF and CA.

Physical properties	Clay	Portland Cement (PC)	Calcareous Lime (CL-90-S)	Natural Hydraulic Lime (NHL-5)	Alumina Filler waste (AF)	Coal Ash waste (CA)
Bulk density (kg/m3)	1750	1100	500	950	1200	900
Hydraulic Index	–	0.47	–	0.35	–	–
Blaine Value (m^2/kg)	–	360	700	650	–	–
Granulometry					<100 μm	<1 m
Insoluble residue (%)	–	0	4	2	–	–
Liquid Limit (%)	39	–	–	–	–	–
Plastic Limit (%)	26	–	–	–	–	–
Plasticity Index (%)	13	–	–	–	–	–
Colour	Gray	Gray	White	Beige	Gray	Gray