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Design and characterisation of ternary cements containing rice husk ash and fly ash

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HIGHLIGHTS

- The system RHA-FA has been used as SCMs in the design of the new blended cements.
- The mortars designed compliant with the requirements laid down in European standard.
- There is synergistic effect in the system RHA-FA.
- The optimal RHA-FA replacement is 15%.
- The addition of RHA-FA to the mortars lowers the total heat of hydration.

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ABSTRACT

This study explored the interaction between rice husk ash (RHA) and fly ash (FA) as partial (0%, 15% or 30%) additions in new ternary cements designed to reduce cement industry energy consumption and greenhouse gas (GHG) emissions by lowering their clinker content. To that end, the effect of the introduction of mixed RHA and FA on the pozzolanicity of the RHA-FA/lime system was assessed and its impact on the chemical, physical, rheological, mechanical, calorimetric and microstructural properties of the new ternary cements analysed. The joint use of these additions revealed mixture synergies, with an initial rise in FA pozzolanicity in the presence of RHA, although this effect declined over time. The inclusion of the RHA-FA mixture prompted changes in the pore structure of mortars that after 90 d translated into 2% lower compressive strength than the control in mortars with 15% addition and a 19% decline in materials containing 30% waste. That notwithstanding, the new cements were European standard EN 197-1-compliant for cement types II/A-M, II/B-M and IV-A. Furthermore, the mortars prepared with 15% RHA-FA released 5.67% less total of hydration than OPC and the materials containing 30% of the addition 13.54% less than the reference. In light of the foregoing, the new cements were found to be apt for use in construction, particularly in structures where large volumes of concrete are needed, for the reduction of the thermal gradient lowers the likelihood of surface cracking.

1. Introduction

The reduction of greenhouse gases in general and CO_2 in particular is one of the primary challenges facing the cement and concrete industry today. In 2009, it accounted for 5% of the total CO_2 emitted worldwide [1]. That year, the International Energy Agency and World Business Council for Sustainable Development defined four strategic measures geared to emission abatement in the industry by 2050: i) improve thermal and electrical efficiency; ii) seek alternative fuels; iii) reduce clinker content; and iv) develop CO_2 storage and capture systems. Of the four, the third yields the most immediate results, with 25%–30% lower CO_2 emissions [2].

Sights are being trained now more than ever on supplementary cementitious materials (SCMs) to replace clinker in cement manufacture in an attempt to produce new, higher performing cements with less embedded energy and longer effective service lives [3]. European standard EN 197-1 [4] regulates the use of SCMs such

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as fly ash, blast furnace slag and silica fume in the design of cements CEM II, III, IV and V to ensure good performance. Nonetheless, the accessibility of such additions is geographically limited compared to the yearly demand of cement and concrete for new builds and rehabilitation works. Consequently, the viability of using any available glassy or amorphous material as an SCM should be researched with a view to lowering the clinker content in cement and concrete [5].

One waste material whose valorisation in construction has recently roused a good deal of interest is the husk generated during rice processing. According to Food and Agriculture Organisation (FAO) data, rice production amounted to 712.5 million tonnes in 2014, approximately 20 wt% of which consists in husk. Incineration reduces that mass by 80% to around 28.5 million tonnes of rice husk ash (RHA) [6,7], a by-product that has been the object of considerable research and used as a mineral addition in the cement [6,8] and concrete [9–11] industry. Its effect on the physical and mechanical properties and durability of the fresh and hardened product has been associated primarily with its origin, combustion process and particle size.

In today's socio-economic context the development of ternary cements containing several additions such as fly ash or rice husk ash with other industrial by-products or waste (silica fume [12], cement kiln dust [13], sugar cane bagasse ash [14], nano-TiO_2 [15], oxygen furnace slag [16], ground granulated blast furnace slag [17] and paper sludge [18]) is attracting ever greater interest. The joint introduction of several SCMs has consistently been shown to be beneficial, providing a satisfactory balance can be struck between replacement ratio (which depends on the specific surface, chemical composition and other characteristics of the additions) and performance.

Research on the joint valorisation of fly ash (FA) and rice husk ash (RHA) as cement constituents is incipient, with very scant literature on the subject to date. The studies published primarily address the effect of these additions on conventional [19] and high-strength [20] concrete and mortar durability, mechanical strength and corrosion resistance [21,22]. All show pozzolan percentages of over 20% to induce a slight decline in end performance, directly dependent upon on the intrinsic characteristics of the additions, rice husk ash in particular.

The relevance of this study stems from the present gap in scientific and technical knowledge of cement-fly ash-rice husk ash ternary cementitious systems. Its innovation lies in the scientific verification, based on the mechanical, rheological and calorimetric properties of RHA-FA, of the aptness of this waste for manufacturing eco-efficient ternary cements.

The aims were to assess the pozzolanic properties of the fly ash / rice husk ash mixture, analyse the synergies of the two wastes in (15%–30%) pozzolan/(85%–70%) cement systems and determine the chemical, rheological, mechanical, calorimetric and microstructural properties of new, low clinker content ternary cements.

2. Materials and methods

2.1. Materials

One of the additions used, fly ash (FA), is standardised and the other, rice husk ash (RHA), non-standardised. The latter was obtained by incinerating rice husk at 600 °C for 3.5 h (ΔT = +10 °C/min for 40 min; T = 400 °C for 25 min; ΔT = +10 °C/min for 25 min; and T = 600 °C for 2 h), the optimal regime, according to the literature [6,23]. It was subsequently ground and sieved through a 63 µm sieve. Rice husk morphology is depicted in Fig. 1. Fig. 1a.1 shows the husk as received at the laboratory, with its elongated, fibrous particles. The SEM micrographs of the husk surface at different magnifications in Fig. 1a.2–a.3 show its papillae and branches of different sizes, all arranged in a profile characterised by neatly aligned linear ridges and furrows. Overall, it exhibited a honeycombed structure. The changes attributable to calcination and sieving are visible in Fig. 1b.1–b.3, particularly the changes in colour (from yellowish to white) and morphology. These micrographs revealed a general breakdown of the rice husk structure into small, irregularly shaped fragments, along with a certain degree of porosity.

A 50 wt% mix of these additions (RHA:FA ratio = 1:1), labelled RHA-FA, was mixed in a blender for 15 min to ensure uniformity.

The commercial OPC used in this study, defined in European standard EN 197-1 [4] as CEM I 42.5R, was supplied by Lafarge, a manufacturer in the Spanish province of Toledo. The XRF chemical composition of the cement is given in Table 1.

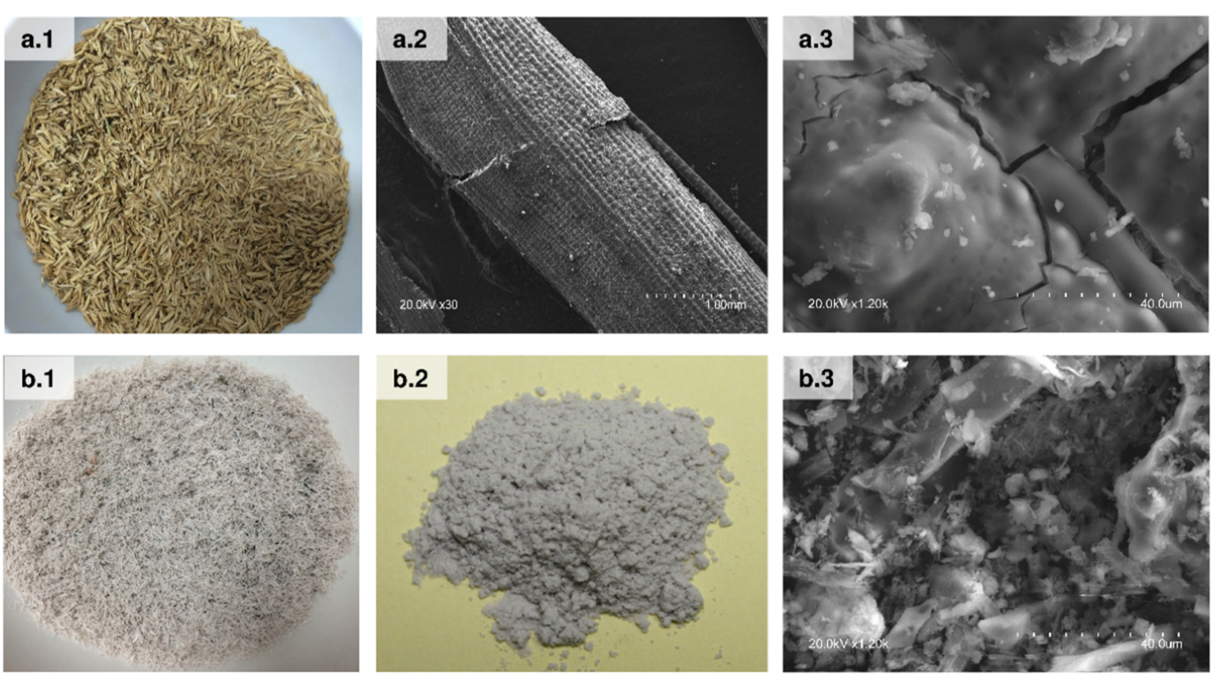

Fig. 1. Rice husk morphology (to the naked eye and under the SEM): a.1) pre-incineration rice husk; a.2) SEM micrograph of pre-incineration rice husk at 30×; a.3) SEM micrograph of pre-incineration rice husk at 1200×; b.1) post-incineration (600 °C) husk; b.2) post-incineration husk < 63 µm; b.3) SEM micrograph of post-incineration husk at 1200×.