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CIVIL INFRASTRUCTURE

Agricultural Waste as a Cementitious Material — Rice Husk Ash

To reduce global CO2 emissions, researchers have been exploring various materials to replace Portland cement. Rice husk ash has been considered a promising alternative due to its widespread availability and increased production. However, the current process of using rice husk ash in construction involves burning the husks at high temperatures (700-900 °C), which is energy-intensive and generates CO2 emissions. In this study, we investigated the use of unprocessed rice husk ash, burnt at 400°C, as a replacement for Portland cement in concrete. We used rice husk ash at 10%, 20%, and 30% by mass and conducted tests to measure its reactivity, mechanical strength, and durability. Preliminary results indicate that the pozzolanic reactivity of unprocessed rice husk ash is similar to that of fly ash and other supplementary cementitious materials. However, the main peak of hydration is delayed compared to that of Portland cement. Mechanical strength and durability were found to be influenced by curing age, with samples cured for 90 days showing improved tensile strength. Furthermore, higher rice husk ash content at 90 days of curing resulted in lower chloride penetration, a parameter often used to describe the corrosion potential of cementitious matrices. Overall, our findings suggest that unprocessed rice husk ash can be a promising replacement for Portland cement in concrete, as it offers similar reactivity to other supplementary materials and has the potential to improve the durability of the resulting cementitious matrix.

Keywords:
Agricultural waste, concrete, strength, durability.

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INTRODUCTION

Concrete is one of the most used materials in the world and its production accounts for significant environmental issues (i.e. transportation, fuels used calcination, carbon footprint). Typical constituents of concrete are aggregate (crushed stones and sand) and Portland cement. The latter is responsible for over 8% of the anthropogenic CO_2 emissions [1].

One way of mitigating greenhouse gas emissions associated to the production of concrete is by replacing Portland cement with waste materials and by-products with similar chemical composition, and capable of providing structural resilience and mechanical performance. Such materials, knowns as supplementary cementitious materials (SCMs), have been proposed in construction since 1970's. The most common SCMs are pulverized fuel ash (PFA), a waste material generated from the coal industry, ground granulated blast furnace slags (GGBS), a by-product of the steel industry, and silica fume, or micro-silica (SF), associated with the production of silicon and ferro-silicon [2]. Such materials have a mineralogical composition that satisfy the requirements to improve fresh and hardened properties of conventional concrete.

However, forthcoming shortages in fly ash availability, and global projected increase of cement production of 4.38 Gt by 2050 [3], has led researchers to investigate other pozzolanic materials, such as rice husk ash.

Rice husk ash (RHA), a by-product of the agriculture industry can be used as a filler or binder to produce sustainable concrete [4], [5]. RHA exhibits a high pozzolanic index when burnt at around 700 °C, where most of the organic carbon is removed. However, such high calcination temperatures make the RHA an energy-intensive material. Zerbino et al. (2010) studied the effect of RHA without further processing (grinding), showing that natural RHA concrete achieved similar mechanical performance of natural RHA [6].

The effect of RHA grinding on the concrete strength resulted in refined particle size and subsequent pozzolanic activity [4], [7].

RHA as a binder replacement influences the mechanical performance of the hardened concrete. Increasing the RHA content to up to 30% by mass resulted in a loss of compressive, flexural and tensile strength [8]. However, due to its pozzolanic index, RHA develops strength beyond the nominal 28 days, typical for conventional Portland cement concrete [9].

Whilst structural performance and physical properties of RHA concrete have been extensively investigated, durability properties of un-processed RHA in concrete have not yet been fully investigated.

This work present preliminary studies on unprocessed RHA, produced at a calcination temperature of 400 °C to minimise their energy demand. The effect of increasing cement replacement with RHA at 10, 20 and 30% was investigated by measuring the concrete tensile strength and surface electrical resistivity at different curing ages.

MATERIALS AND METHODS

Concrete specimens were prepared by mixing Portland cement (CEM II, A-L, class 32.5 MPa) with a content of 400 kg/m^3, fine and coarse aggregate, respectively river sand (680 kg/m^3) and crushed limestone (920 kg/m^3), at a water to binder (w/b) ratio in the range of 0.42 – 0.62. Portland cement was replaced (by mass) with rice husk ash (RHA) supplied by E-COCO Products UK Ltd and sourced from Malaysia. To produce RHA, rice husk was burnt at 400 °C, and no further refinement (grinding) was conducted. The mix design at varying cement replacement levels is reported in Table 1.

Series	Cem	RHA	f/b	c/b	w/b
Control	100%	0%	1.7	2.3	0.42
RHA10	90%	10%			0.50
RHA20	80%	20%			0.62
RHA30	70%	30%			0.62

Table 1. Mix design details with mass content (%) of Portland Cement (Cem), rice husk ash (RHA), sand to binder (f/b) ratio, coarse aggregate to binder (c/b) ratio and water to binder (w/b) ratio.

Samples were cast into cylindric (100 mm in diameter and 200 mm in height) moulds, following the standard BS EN 12390-2:2019 [10]. After 24 hours, specimens were demoulded and cured in water at 20 °C for either 28 days or 90 days. After mixing, 300 g of fresh concrete was sampled from the mixer and the heat of hydration was measured by using an isothermal calorimeter (Calmetrix, I-Cal 8000 HPC, USA) at a constant temperature of 20 °C for 168 hours. After curing, specimens were first tested for surface electrical resistivity by using a Wenner probe (SURF, Giatec, Canada) [11], [12] the surface resistance and the uniaxial resistance measurements provide equivalent measures of resistivity once geometry is appropriately taken into account. However, cementitious systems are not always homogenous. This article compares bulk and surface resistance measurements in cementitious materials intentionally composed of layered materials (i.e., layers with different resistivities followed by tensile strength measurements. Physical and mechanical properties were measured on three samples at each curing age (28 and 90 days), and the average value was recorded.

RESULTS AND DISCUSSIONS

The heat of hydration of representative samples with 10, 20 and 30% of RHA replacement is shown in Fig. 1, and compared to the hydration of concrete made with 100% Portland cement (Control). For all mixes, the first peak appears at around 10 – 20 hours from mixing, in line with previous studies [13], [14]. However, when compared to the control sample, the RHA series exhibit a delay in hydration, due to the high carbon content and subsequent dissolution, resulting in a lower hydration degree [4].

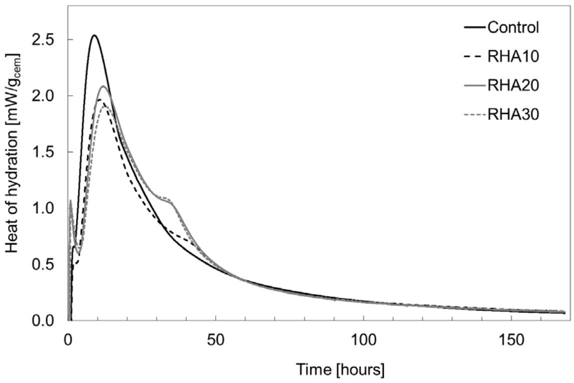

Fig. 1. Heat of hydration of selected samples at 10, 20 and 30% RHA content and compared to the control series.

The tensile strength measurements showed that an increase in RHA content resulted in decrease in mechanical strength, as reported in Fig. 2; samples cured for 28 days showed a reduction of approximately 50% in tensile strength (RHA30).

However, longer curing ages (90 days) resulted in an improved strength on samples with the lower RHA content (RHA10), an average of 3.1 MPa, approximately 32% less than the control samples. The tensile strength values are lower than those reported in literature for the same RHA content [14], [15]. This is due to the nature of RHA used in this work; as previously stated, refinement processes of RHA such as grinding and calcination temperature influence the overall mechanical performance of concrete. However, whilst the tensile strength values suggest that RHA cannot be used for structural applications, other civil engineering applications (pre-cast concrete, pavement elements, cladding material) are deemed suitable.

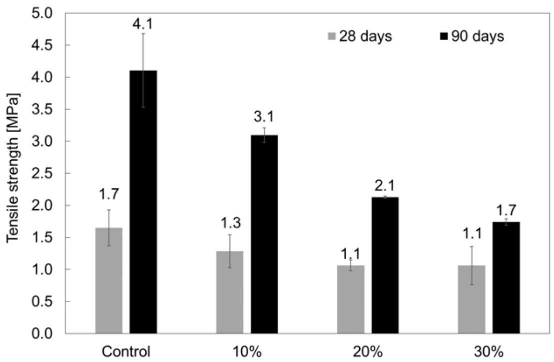

Fig. 2. Tensile strength at 28 days and 90 days. Error bars represent the standard deviation.

In concrete, one of the most studied durability parameter is the corrosion potential, as a result of chloride ingress [16]. Factors such as porosity, permeability and pore size distribution affect the chloride diffusivity of the cementitious matrix, often measured by rapid chloride penetration tests or indirect investigation, such as electrical resistivity measurements [11]. In this study the surface electrical resistivity of cylindrical specimens was measured and compared to the 56-day chloride ingress potential. The highest the surface resistivity, the lowest the chloride diffusivity. Values of surface resistivity in < 10 kΩcm indicate a high chloride penetration, whilst values in the range of 10 – 15 kΩcm indicate a moderate chloride diffusivity.

Results presented in Fig. 3 show that an increase in RHA resulted in a lower chloride penetration when samples were cured for 90 days. RHA content at 20% (RHA20) and 30% (RHA30) improved the chloride penetration by 32% and 35% respectively when compared to the control mix (RHA 0%).

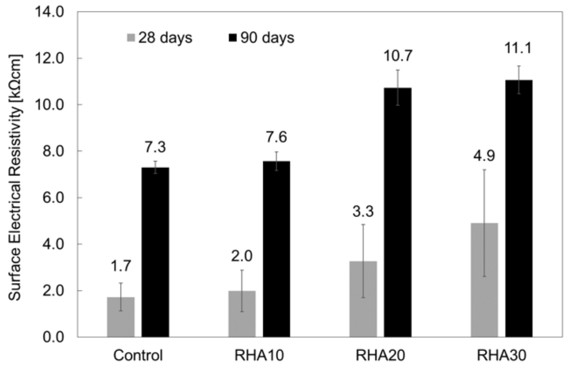

Fig. 3. Surface electrical resistivity of concrete samples at 28 days and 90 days of curing. Error bars represent the standard deviation.

According to Eurocodes, the choice of concrete grade must ensure durability requirements in different environments. Hence, with their varying grades, different concrete mixes can be utilised for various civil engineering applications such as paving or small walls (RHA30) and foundations or flooring (RHA20). Although the initial results indicate minor differences in surface electrical resistivity among the various mixes, it suggests that the proposed concretes can maintain their resistance to chloride ingress. This indicates a similar corrosion risk, which is a crucial aspect of Eurocodes recommendations. Therefore, it is believed that these mixes can be employed in a broader range of applications once their corrosion potential is better explored.

CONCLUSIONS

This work presents a preliminary investigation into the use of unprocessed rice husk ash as a replacement for cement in concrete. Rice husk ash produced at 400 °C is less energy-intensive than conventional rice husk ash, resulting in a minimized carbon footprint. The mechanical strength values of concrete with rice husk ash content up to 30% by mass suggest that it can be used in construction as a non-structural material. However, increasing the rice husk ash content results in decreased chloride penetration, which is often used to quantify the corrosion potential.

Future work will include investigating the water transport properties and conducting a detailed life cycle assessment to evaluate the environmental benefits of unprocessed rice husk ash in construction.

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Conflicts of interest
The authors declare no conflict of interest.

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