Construction and Building Materials 54 (2014) 369–377

Contents lists available at ScienceDirect

Construction and Building Materials

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

Total shrinkage, chloride penetration, and compressive strength of concretes that contain clear-colored rice husk ash

A.L.G. Gastaldini *, M.P. da Silva, F.B. Zamberlan, C.Z. Mostardeiro Neto

Federal University of Santa Maria, Av. Roraima 1000, 97105-900 Santa Maria, Rio Grande do Sul, Brazil

HIGHLIGHTS

- Clear-colored rice husk ash (RHA) does not change the color of concrete and enables its use in ready-mix concrete.
- Replacement of Portland cement (PC) with 5% RHA reduces the cost per m^3 of concrete.
- Increasing the RHA content in concrete increases its total shrinkage and compressive strength.
- Greater replacement levels reduce the concrete's total passing charge.
- The chloride penetration evaluated before and after shrinkage by sprinkling $AgNO_3$ exhibited the opposite behavior.

ARTICLE INFO

Article history:
Received 14 August 2013
Received in revised form 4 December 2013
Accepted 16 December 2013
Available online 19 January 2014

Keywords:
Rice husk ash
Total shrinkage
Chloride penetration
Compressive strength
Concrete

ABSTRACT

This study investigated total shrinkage, which is a rarely examined property, as well as the penetration of chlorides before and after shrinkage and the compressive strength of concretes containing clear-colored rice husk ash substituted for 5%, 10%, 20%, and 30% of their Portland cement and subjected to wet curing periods of 3 and 7 days. The results showed that increasing the RHA content increased the concrete's total shrinkage and compressive strength, as well as the penetration of chlorides after shrinkage. A cost analysis of the concrete used at ready-mix concrete companies was performed. The study concluded that concretes containing 5% RHA replacement and compressive strength levels between 35 and 55 MPa had a lower cost/m^3 than that of the reference concrete containing 100% Portland cement.

1. Introduction

The research literature has recently highlighted increased and uncontrolled environmental pollution as being responsible for global warming, and it has also focused on the exhaustion of natural resources due to population growth and worldwide urbanization.

Population growth is accompanied by an increased demand for housing and infrastructure, which require natural resources and produce waste that increase environmental pollution. The growth in the number of existing buildings, which are typically constructed from concrete due to its relatively low cost, excellent durability, and mechanical properties when properly designed and constructed [1], has the disadvantage of increasing the use of Portland cement, which is responsible for substantial carbon dioxide emissions during its manufacturing process.

To reduce the release of CO_2 into the atmosphere, conserve raw materials involved in the production process, eliminate wastes that impact the environment, and improve the technical properties of concrete, previous studies have demonstrated the feasibility of replacing cement with agro-industrial sub-products. One such example is the ash obtained from burning rice husks, as rice is one of the most cultivated grains in the world [2–7].

Research has shown that rice husks can improve concrete's mechanical properties [8] and durability [9], even if they have a dark color due to the presence of uncombusted carbon. However, the husks require greater amounts of superplasticizer additives when this carbon content is large [4,8].

When rice husks are burned, the resulting ash can vary in color as a result of the combustion process, the impurities present, and the structural transformations that occur in the material according to variations in the burn temperature.

Another important factor contributing to the ash's behavior is the process by which it is ground. This process modifies the physical properties of the ash, including its specific surface area and

* Corresponding author.
E-mail addresses: gastaldn@ct.ufsm.br, gastaldini@terra.com.br (A.L.G. Gastaldini).

0950-0618/$ - see front matter
http://dx.doi.org/10.1016/j.conbuildmat.2013.12.044

grain size, which are also responsible for the material's behavior [10,11].

Despite the large quantities of rice husks available in the world today, their dark color after burning hinders the technical community's acceptance of their addition to concrete. Furthermore, achieving amorphous ash requires it to be burned in ovens with temperature controls, which are often unavailable. The cost is further increased by the grinding required to improve the RHA's pozzolanity [12], which increases its commercial value. Reducing the material's grain size can activate its pozzolanic properties, even when in a crystalline form [13].

The optimal RHA replacement level to achieve maximum compressive strength has been calculated to be approximately 20% [14,15]. However, tests that evaluated the chloride penetration according to ASTM C 1202 [4,15–17] (or even the electrical resistivity) [18] have shown that increasing the RHA replacement content in concrete improves its performance. This behavior can be explained by the decrease in the electrical conductivity of the pore solution with greater replacement levels, as demonstrated in [18]. The specimens in all of these studies (tested for compressive strength, chloride penetration, and electrical resistivity) have been stored in a humid chamber for long periods of time [4,6,8,10,11,14,16,19] before testing (at 28 or 91 days), which does not reflect the reality of the construction industry, where concrete is typically cured for 3–7 days. These published works have also used superplasticizer additives [4,5,8,14,16,20–22], which increase the final cost of the concrete and can make its use by ready-mix concrete companies unfeasible. It has also been reported that increasing the RHA replacement content in concrete requires an increase in the superplasticizer additive content to obtain similar workability due to the rice husk ash's high surface area, which also increases costs.

It is also known that concrete cracking influences the corrosion initiation process. Cracks are a rapid route for aggressive agents to penetrate into the concrete reinforcement, and they facilitate the reinforcement's access to oxygen and moisture, both of which are essential factors for corrosion initiation. Few studies have focused on the influence of the rice husk ash content on concrete shrinkage or chloride penetration after shrinkage.

The rice husk ash used in this study was obtained by controlled burning (a process currently being patented), which generated energy for a cooperative's activities.The surplus of this energy was sold to a power company. The ash, which has a low graphitic carbon content, is clear in color and is currently being marketed to ready-mix concrete companies. The total shrinkage and chloride penetration of concrete containing different percentages of RHA and subjected to curing periods of 3 and 7 days were investigated using different methods. A cost analysis for concrete containing rice husk ash is presented, and a description of the optimal replacement content for use by concrete plants is given.

2. Experimental program

2.1. Materials and concrete mixes

The binders used in this experiment included high-early-strength Portland cement. The rice husk ash, of low graphitic carbon content, was obtained by controlled burning, which was performed at an electric power generation plant and produced ash that was clear in color. The silica fume came from a national supplier. The physical and chemical characteristics of the different cementitious materials are shown in Table 1. Chemical analyses indicate that RHA and SF are composed of SiO_2. Fig. 1 presents X-ray diffractograms of the rice husk ash (consists of a large quantity of amorphous materials) and silica fume and Fig. 2 shows the colors of the cementitious materials.

The fine aggregate used in the experiment was a natural sand composed of quartz with a specific weight of 2.66 g/cm^3, unitary mass of 1.62 g/cm^3, fineness modulus of 1.85, and maximum size of 1.2 mm.

Table 1
Properties of cementitious materials.

Constituent/property	Portland cement	Rice husk ash	Silica fume
SiO_2 (%)	19.19	93.54	94.20
Al_2O_3 (%)	5.16	0.52	0.27
Fe_2O_3 (%)	2.95	0.20	0.15
CaO (%)	62.64	0.79	0.61
MgO (%)	2.75	0.49	0.57
SO_3 (%)	2.52	0.05	0.11
Na_2O (%)	0.12	0.03	0.15
K_2O (%)	0.64	1.65	0.40
Graphitic carbon (%)	1.93	0.41	–
Loss on ignition (%)	3.39	2.32	2.03
Specific gravity (kg/dm^3)	3.13	2.11	2.20
BET – specific surface (m^2/g)	1.14	18.89	18.83
Compressive strength (MPa)			
1 day	14.3	–	–
3 days	33.0	–	–
7 days	36.8	–	–
28 days	49.2	–	–

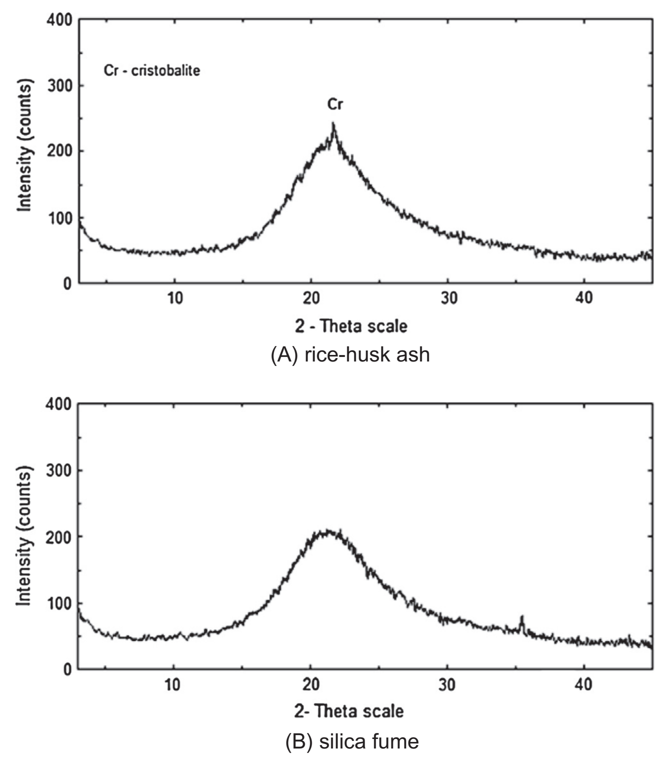

Fig. 1. X-ray diffraction spectra of rice husk ash (A) and silica fume (B).

Fig. 2. Colors of the cementitious materials under study.

The coarse aggregate consisted of crushed stone with a specific weight of 2.48 g/cm^3, unitary mass of 1.38 g/cm^3, fineness modulus of 6.92, and maximum size of 19.0 mm.