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Influence of rice husk ash on strength and permeability of ultra-high performance concrete

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HIGHLIGHTS

- Rice husk ash (RHA) enhances compressive strength and refines pore structure of UHPC.
- Permeability of UHPC cylinder increases with the higher vertical load.
- RHA decreases permeability of UHPC upon the load of 0–70% ultimate strength.

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ABSTRACT

This paper aims to investigate the effects of rice husk ash (RHA) on strength and permeability of ultra-high performance concrete (UHPC). RHA was manufactured by calcining rice husk at temperature of 500 °C and incorporated in UHPC mixture to replace different ratio of silica fume (SF) by weight. Flowability and air content of fresh mixture and the compressive and flexural strength at different curing ages were measured. Permeability before and after loading were assessed by water absorption and chloride ion penetration. The pore structure was also evaluated for selected samples by using mercury intrusion measurement. The results show that the addition of RHA to replace SF decreases the fluidity of fresh UHPC mixture and entraps more air bubbles. The addition of RHA enhances the compressive strength and impermeability of UHPC due to the refined pore structure. The permeability of cylindrical specimen increases notably with the increasing vertical loading and the lateral loading has an insignificant influence on the water absorption. When the loading level is lower than 70% of ultimate strength, the RHA added sample presents a lower water absorption and chloride ion penetration than the control one. Therefore, RHA is a promising substitute for SF in UHPC production.

1. Introduction

Ultra-high performance concrete (UHPC) is regarded as one of the latest advances in concrete technology due to its high compressive strength and durability [1], which has been developed into many attractive applications in construction industry in Europe, Asia and North America [2–4]. UHPC is commonly characterized by large quantities of Portland cement, silica fume (SF) and fine aggregates with steel fibers for reinforcement, presenting outstanding flowability and a close-packed state in spite of a very low water to binder ratio (*w*/*b*), with the addition of a high superplasticizer dosage [5–7]. Depending on ingredient composition and manufacture procedure, compressive strength of UHPC typically ranges from 150 MPa to 800 MPa [8,9], and in China, UHPC is defined as a concrete with 28-day compressive strength over 100 MPa [10].

Rice husk ash (RHA) is the solid residue after burning rice husks (RHs), an agricultural waste widely produced all over the world [11]. Mehta [12] and Nair [13] studied that RHA prepared in appropriate procedures has high pozzolanic reactivity and proves competent to be a promising supplementary cementitious material. Xu [14] reported that RHA possesses porous microstructure, high specific surface area and very high content of amorphous nanosilica, using modern testing and analyzing techniques such as Scanning Electron Microscope (SEM), Transmission Electron Microscope (TEM), X-ray diffraction (XRD). SF plays a crucial role in

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UHPC, being attributed to its excellent physically filling and chemically pozzolanic effects [15]. However, high cost and limited availability also give rise to some disadvantages especially in some regions which lack resources. RHA is economical, widely available and highly pozzolanic as a supplementary cementing material, which is a promising substitute replacing SF in UHPC production.

The principal objective of this work is to investigate the effects of RHA on the strength and permeability of UHPC. Amounts of experimental research on the strength and permeability of mortar or ordinary concrete incorporating RHA have been reported [16–18]. With regard to UHPC with RHA, the strength was studied for many years and relevant literature was easily available on the Internet. Van found that UHPC containing RHA possesses comparable compressive strength compared with that of UHPC containing SF [19]. Nguyen studied the compressive strength development of UHPC versus time and concluded that the compressive strength of the RHA modified sample is higher than that of the control sample at later ages (i.e. beyond 7 days) or even after 3 days [20]. However, limited research on permeability is available arising from high density and refined porosity of UHPC. Moreover, most structures are exposed to different loading in service such as bridge piers, wharfs and dams and the permeability will have an outstanding influence on the durability of these structures. The permeability of UHPC in real structures will vary with loading level and little research in this field can be found in literatures. Therefore, it brings us the ideas to study the strength and permeability of UHPC while replacing SF with RHA by different ratio, and furthermore, to study the permeability of UHPC after being loaded in two directions, vertical and lateral respectively.

2. Materials and methods

2.1. Materials

The cement used in this study is ordinary Portland cement with strength grade of 52.5 in accordance with Chinese standard GB 175-2007 [21]. As a fine mineral admixture in UHPC, the SF powder consists of spherical particles with theoretical size from 0.1 μm to 1 μm and BET specific surface area (SSA) of 17.3 m^2/g. The RHA is produced by burning rice husk in a programmable temperature at a rate of 10 °C/min to 500 °C for 2 h and then grinding the calcined residue in a vibrating mill for 15 min. The appearance and the particle size distribution of ground RHA are shown in Fig. 1, it can be found that the mean particle size of ground RHA is about 11 μm. The XRD analysis shown in Fig. 2 indicates that both SF and RHA contain mainly amorphous silicon dioxide. The chemical and

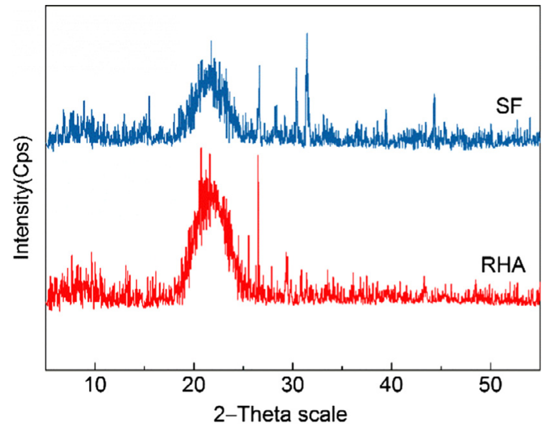

Fig. 2. XRD patterns of RHA and SF.

Table 1
Chemical and physical properties of cementing materials.

	Cement	SF	RHA
Chemical analysis (wt%)			
CaO	66.45	0.63	1.07
SiO_2	17.84	87.67	91.56
Al_2O_3	4.26	0.28	0.19
Fe_2O_3	3.58	0.60	0.17
MgO	2.14	3.41	0.65
Na_2O	0.16	1.30	0.16
K_2O	0.96	4.12	3.76
SO_3	4.10	0.84	0.47
Physical properties			
Apparent density (g/m^3)	3.10	2.25	2.19
Blaine (BET) SSA (m^2/g)	0.36	17.30	64.70
Pozzolanic activity index	–	108.6	123.7

physical properties of cement, SF and RHA are given in Table.1. The chemical components of three cementing materials were measured by X-ray Fluorescence, and the pozzolanic reactivity index were measured in accordance with Chinese standard GB/T 12957-2005 [22]. As shown in Table 1, RHA possesses a larger value of BET SSA, higher content of amorphous silicon dioxide and pozzolanic reactivity index compared to SF. The SEM images shown at two different magnifications (500× and 10,000×) in Fig. 3 reveal the layered and porous microstructure of RHA, as described in earlier research [14]. The Barrett-Joyner-Halenda (BJH) testing shown in Fig. 4 verifies the existence of nano-pores

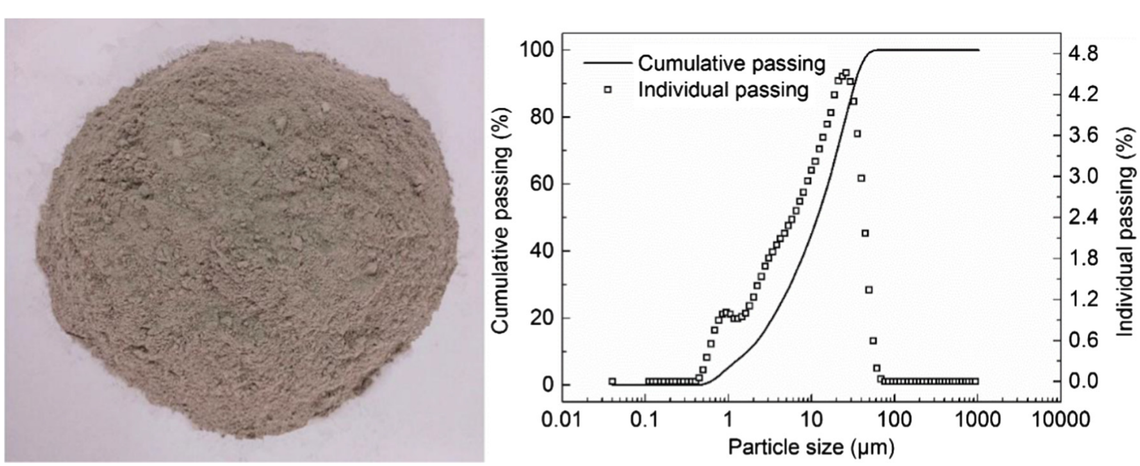

Fig. 1. Appearance and particle size distribution of ground RHA.