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Study on the Hydration Behaviour of the Coral Sand Powder-Ground-Granulated Blast Furnace Slag-Portland Cement Ternary System

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ABSTRACT

Recently, the studies on the application of coral sand in concrete construction attracted wide attention, especially in China. Coral sand and coral sand powder (CSP) can be used as fine aggregate and mineral admixture in concrete, respectively. The main component of CSP is calcium carbonate ($CaCO_3$), up to 96%. However, the utilization of CSP in cement mortar will cause performance degradation. Ground-Granulated Blast Furnace Slag (BFS) be used to improve the property of CSP-Portland cement mortar. In this study, the coral sand powder-blast furnace slag-Portland cement (CSP-BFS-PC) ternary system had been used to produce cement paste and mortar. The hydration product of the CSP-BFS-PC ternary system are researched fundamentally by X-ray diffraction, and compressive strength are tested at different curing age. The results show that CSP can suppress consumption of C_3A. 15wt.% BFS can offset the strength loss of cement mortar due to the substitution of CSP for cement (CSP less than 15wt.%), especially 7-28 days.

1. INTRODUCTION

With the continuous development of ocean engineering, the building materials are lack, especially in the sea island. The coral reef is formed from the shell secreted by coral insect during many years. And the main chemical ingredient is calcium carbonate ($CaCO_3$) [1]. On the premise of protecting the island environment, it is applicable that coral waste and debris are utilized to make concrete. And this also can reduce the construction cost.

Recently, researchers do many researches on the coral aggregate in concrete. As fine aggregate, coral waste owns higher porosity and water absorption, lower strength and coarser surface than river sand. Coral aggregate has larger contacts area with cement paste than river sand [2]. Therefore, the coral concrete has higher splitting tensile strength and close interfacial transition zone (ITZ). Reportedly, the coral aggregate can improve the early cement hydration, strength development and resistance to chloride ion penetration because its porous and high absorbent property brings internal curing function, and it is also same reasons that this would lead to certain negative effect such as high porosity and poor durability of concrete [3].

Except as aggregate, coral reef can be ground to powder as mineral admixture (CSP). The replacement of cement by CSP not only uses local coral waste reasonably, but also decreases overall cost and carbon emission. Recently, some works have been investigating the effect of CSP on the properties of cement and concrete. Shi et al. [4] found that the addition of CSP accelerates and advances early-age cement hydration, and reduces the total hydration heat release. Wang et al. [5] utilized CSP and metakaolin (MK) to produce cement mortar. It was concluded that the activity of CSP can be motivated by MK because is can provide a higher aluminate environment in cement. That promotes the formation of hemicarboaluminate (Hc) and monocarboaluminate (Mc) [6]. But excessive aluminate restrains the formation of Mc. Although CSP can be used in cement, high replacement level of CSP will lead to lower strength and poor pore structure of cement-based material. Blast furnace slag (BFS) is by-product that it has high pozzolanic activity. Reportedly, the addition of BFS in cement can decrease the hydration heat and early compressive strength, but the strength remarkable increase in the mid to late [7]. It can be used to produce cement mortar and paste with coral sand powder.

At present, the effects of CSP and BFS on the properties of cement-based material are lack studied. Based on above literature view, the aim of this paper is to investigate the hydration of the CSP-BFS-PC ternary system. The replacement of PC by CSP and BFS is up to 40% by weight. The mechanical property of this ternary is also investigated.

2. Materials and methods

2.1 Raw materials

P.O 42.5 Portland cement (PC) was from CUCC, China. Blast furnace slag (BFS) was obtained from JINTAICHENG Inc, China. Coral sand powder (CSP) was produced in laboratory: coral sand was ground to powder by ball mill and then through the 75 μm sieve. The chemical compositions of raw materials are presented in Table 1. Fig 1. shows the XRD pattern of CSP. It can be observed that the main mineral phases of CSP are $CaCO_3$ and (Ca, Mg) CO_3.

Table 1. The chemical compositions of CSP, PC and BFS (wt. %).

	CSP	PC	BFS
Cao	50.52	65.47	30.11
SiO2	0.939	19.82	30.79
Al2O3	0.121	4.66	16.69
MgO	2.04	0.84	9.92
SO3	0.409	2.29	1.15
Fe2O3	—	3.03	0.210
TiO2	—	0.16	0.696
Cl	0.112	—	0.0482
K2O+Na2O	0.4078	0.74	0.858
LOI	44.73	3.34	1.46

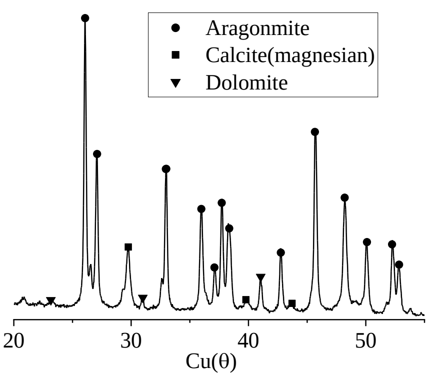


Figure 1. XRD pattern of CSP

2.2 Mixture proportion and specimen preparation

All cement pastes and mortars were designed with a water/cement (w/c) ratio of 0.5. The replacement level of cement by BFS is 15% by the weight of total binder. The content of CSP in this ternary system is 5 wt.%, 15 wt.%, 25 wt.%, respectively. The mixture proportions used in this study are given in Table 2.

Table 2. The mixture proportion used by this study (wt. %).

Sample name	CSP	BFS	PC
Blank	0	0	100
C5B15	5	15	80
C15B15	15	15	70
C25B15	25	15	60

The cement paste samples for XRD test were made according to European standard EN197-1. These samples were cast in plastic pipes and sealed at 20±2 ºC. At the curing age of 1 day, 3 days, 7 days and 28 days, the hardened samples were crushed into small species and stopped hydration by immerging into ethanol for 24 h and drying for 12 h at 40 ºC in vacuum drying oven. Then the dried specimens were ground into powders which can pass through 75 μm sieve.

The cement mortar samples for compressive strength test were cast in 40×40×160 mm molds and cured at 20±2 ºC and 95% relative humidity. All specimens were demoulded after 24 h and cured in water at 20±2 ºC.

2.3 Experimental methods

2.3.1 Compressive strength

The compressive strength of cement mortars at 3, 7, and 28 days were measured with an AEC-201-type automatic cement strength testing machine according to Chinese standard GB/T 17671. The average value was given based on three parallel samples.

2.3.2 XRD analysis

The prepared samples were determined by A Rigaku Smart Lab 3000A diffractometer with Cu Ka radiation source (wave length = 0.154 nm). The tested parameters of instrument were Cu target, 40 kV, 35 mA, 5-65º, 5 per minute with the step of 0.01 º.

3. Results and discussions

3.1 The compressive strength of the CSP-BFS-PC ternary system

The values of the compressive strength of all specimens at different curing ages are illustrated in Fig 2. As expected, the compressive strength of each mixture increases with the increase of curing age due to the continuous hydration of cement and reactions of BFS.

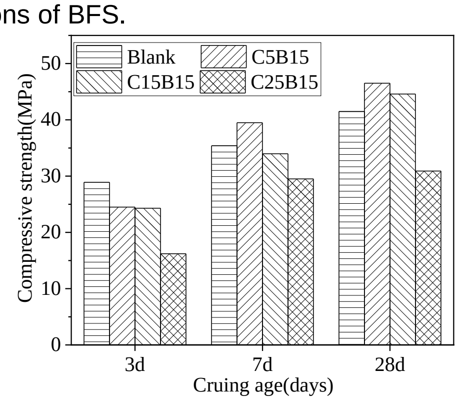


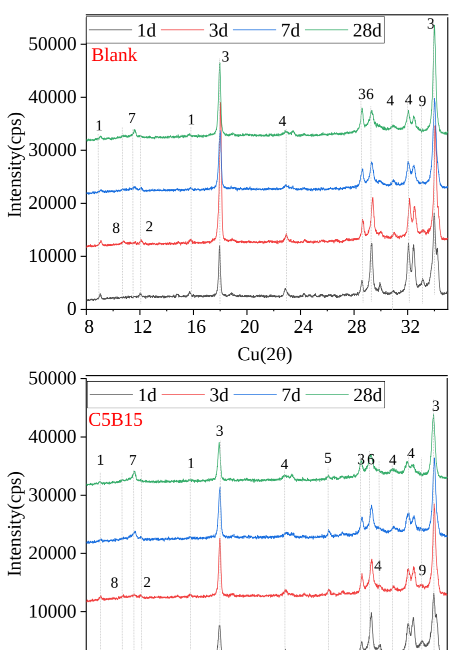
Figure 2. Compressive strength of cement mortar blended with CSP and BFS

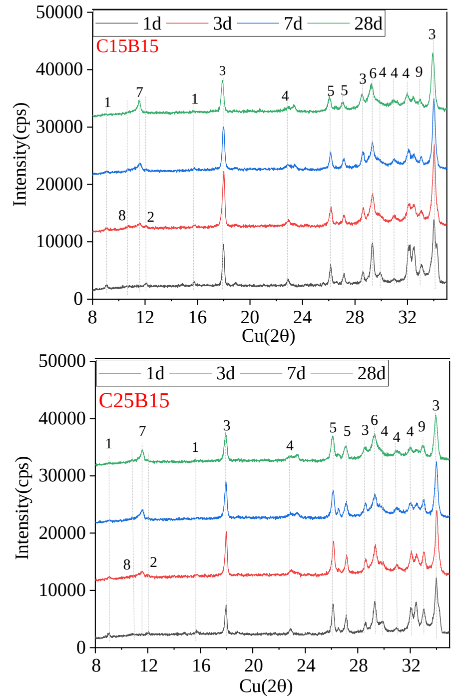
At 3 days, the additions of BFS and CSP decrease the compressive strength of cement regardless of the content of BFS and CSP. This illustrate that BFS and CSP all show low activity at 3 days. C5B15 and C15B15 have similar compressive strength. C25B15 has the lowest compressive strength value than other samples because cement replecement level is the largest. After 7 days, it can be seen that C5B15 has a higher compressive strength than blank sample due to hydraulic activity of BFS. The C15B15 and C25B15 have lower compressive strength than

blank sample. The increasement of CSP dosage decease compressive strength.
At 28 days, C5B15 and C15B15 have a higher compressive strength than blank sample. It is worth mentioning that the compressive strength of C25B15 has no obvious change from 7 days to 28 days. It shows that the hydraulic activity of BFS can improve the strength loss from CSP cement morart when CSP dosage is less than 15wt.%, after 7days of curing.
For all above, in the CSP-BFS-PC ternary system, BFS can well offset the strength loss due to CSP replacement. When the replacement of BFS and CSP is less, it has positive effect on compressive strength of cement mortar. On the contrary, the compressive strength of cement mortar is low with 40wt.% cement replaced by BFS and CSP.

3.2 The hydration of the CSP-BFS-PC ternary system

The XRD patterns of the cement paste mixed with CSP and BFS at 1, 3, 7 and 28 days are shown in Fig 3. The main characteristic peaks are ettringite (AFt), Aragonite ($C\bar{C}$), Portlandite (CH), tricalcium silicate (C_3S) and dicalcium silicate (C_2S). The characteristic peaks at 10.7 º and 11.7º are the hemicarboaluminate (Hc) and monocarboaluminate (Mc). Hc and Mc are formed by the reaction of calcium carbonate ($C\bar{C}$), tricalcium aluminate (C_3A) and calcium hydroxide (CH) (Equation (1), (2) [6, 8]). In blank sample, the existing of Hc and Mc is due to the addition of limestone power during the production of cement.





1-AFt; 2-C_4AF; 3-CH; 4-C_2S; 5-$C\bar{C}$; 6-C_3S; 7-Mc; 8-Hc; 9-C_3A

Figure 2. patterns of cement paste blended with CSP and BFS at different ages.

As the content of carbonate and alumina increasing, Mc diffraction peak is detected earlier. This affirms CSP be more active due to a more alumina content in system [5]. It's worth noting that the C_3A diffraction peak is still exsits with the addition of CSP, and the more dosage of CSP contribute to stronger C_3A diffraction peak. This reason is the present of CSP to restrain the transformation reaction from AFt to AFm and then reduction of C_3A consumption [9] (Equation (3)). The phenomenon is ascribed to Mc and AFt more stable than AFm when the presence of $C\bar{C}$ [10].

$$C_3A + C\bar{C} + 11H \rightarrow C_4A\bar{C}H_{11}(MC) \quad (1)$$

$$C_3A + 0.5C\bar{C} + 0.5CH + 11.5H \rightarrow C_4A\bar{C}_{0.5}H_{11}(HC) \quad (2)$$

$$2C_3A + C_6A\bar{S}_3H_{32}(AFt) + 4H \rightarrow 3C_4A\bar{S}H_{12}(AFM) \quad (3)$$

4. Conclusions

This study investigates the influence of CSP and BFS on the hydration products and compressive strength of Portland cement at curing ages up to 28 days. The change of hydration products and compressive strength were analyzed. Based on the discussion above, the conclusions are as follows:
1) The present of CSP restrain consumption of C_3A. Meanwhile, the addition of BFS can motivate CSP reaction activity.
2) the low addition of CSP (less than 15wt.%) has little effect for cement mortar strength, and the present of BFS can offset this influence. The compressive strength of low CSP content samples better than blank group at 7 and 28 days. However, with 25wt.% CSP dosage, the strength loss still is bigger even though the addition of BFS.

Acknowledgements
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