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Use of sandstone powder as a mineral additive for concrete

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HIGHLIGHTS

- Potential use of sandstone powder as a mineral additive in concrete was explored, the optimal specific surface area was suggested.
- Alkali silica reaction of concrete with reactive sandstone aggregate was characterized by addition of sandstone powder as mineral additive.

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ABSTRACT

The potential use of sandstone powder as a mineral additive to replace cement in concrete was studied. The effect of sandstone powder addition on compressive strength and alkali-silica reaction was investigated. The parameters included the specific surface area, the cement replacement ratio and the silica fume hybrid. It was found that the increase in specific surface area of sandstone powder could improve the strength gain. Although the addition of sandstone powder might reduce the compressive strength, the maximum reduction was less than 35% when 50% replacement of cement was employed. The hybrid of sandstone powder with 5% silica fume had demonstrated an effective way to enhance the strength. Because of the pozzolanic behavior, the sandstone powder can effectively reduce alkali silica reaction in concrete with reactive sandstone coarse aggregates. In case that sandstone is the only aggregate source and there is no supplementary cementitious material available in the area, the sandstone powder, ground sufficiently fine, can be used as partial replacement of cement to improve the durability of concrete.

1. Introduction

In some area of Southwestern China, there is large amount of sandstone powder accumulated as by-product of coarse aggregate production. This sandstone powder is finer than 100 μm and is usually land-filled. It is not only a waste of resource but also generates pollution to the environment. At the same time, mineral admixtures such as qualified slag and fly ash in those areas are rare. It is therefore environmentally and economically beneficial if the locally-produced sandstone powder can be utilized as a mineral additive for concrete material.

Different stone powders make distinctive contributions to the performance of concrete. It was found that concrete containing mixed granite and marble powder had shown the highest compressive strength while concrete containing only marble powder had the lowest compressive strength in the production of self-compacting concrete (SCC) [1]. This was because granite powder had possessed weak pozzolanic reactivity but marble powder had none [1]. The use of silica fume with waste stone powders in ternary blended cements could effectively improve the concrete strength. The study also indicated that the use of waste marble powder in the self-compacting concrete as a mineral admixture made no contribution to strength [1]. For limestone powder, the conclusion on its reactivity was not consistent. Coo and Pheeraphan [2] showed that the strength of concrete was significantly reduced by the replacement of cement by limestone filler since limestone powder served as an inert filler in cement replacement. However Bentz et al. [3] believed that limestone powder was soluble to certain degree, leading to the formation of carboaluminate hydration products. The work from Thongsanitgarn et al. [4] also showed that the reaction between limestone powder and Portland cement was evident by Thermogravimetry (TG) results in the reduction of $CaCO_3$ content. Their work also suggested that finer particle size of limestone powder accelerated the early age hydration rates while no significant effect was found when the limestone powder was used with large particle size. According to Goldman

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and Bentur [5], for mineral admixture with fine particles, the microfiller effect was also of great significance to strength enhancement due to the modification of aggregate-cement interfacial zone. It is indicative that grinding a mineral to certain fineness may change the chemical reactivity. Research had shown that grinding of waste glass to 38 μm can convert an initially alkali-reactive material into a pozzolanic material [6]. Size effect may play critical role in promoting beneficial reaction. The use of sandstone powder as additive in concrete is not a common practice. The high content of alkali in sandstone had the potential to promote the cracking sensitivity and damage of cement-based material [7,8]. It is interesting to know if sandstone powder collected from the same aggregate quarry can be used as mineral additive to partially replace cement and reduce the alkali silica reaction (ASR) generated from the same but coarser sandstone aggregates. If successful, there are significantly economic and environmental advantages. Both fine powder and coarse aggregates are locally produced. The finely ground powder will be used as mineral additive for cement to improve the concrete strength and control the ASR expansion. The size effect is worth of a study.

The purpose of this study is to examine the feasibility of using sandstone powder as mineral additive to improve the compressive strength and to suppress expansion of ASR in concrete with coarse sandstone aggregates. The effect of specific surface area and replacement ratio of sandstone powder are also investigated.

2. Experimental

2.1. Materials

The sandstone powder was obtained as by-product from production of coarse aggregate and manufactured sand in Southwestern areas of China. Ordinary Portland cement (OPC) was used as binder and silica fume was introduced as performance enhancer. Chemical compositions of cement (C), sandstone powder (SP) and silica fume (SF) are exhibited in Table 1, and the physical properties of cement and silica fume are shown in Table 2. The alkali content in SP is 3.83% and the silica content reaches 63%. It is important to know the soluble alkali content which may have effect on ASR and the soluble silica content which may show pozzolanic behavior.

2.2. Methods

2.2.1. Grinding method

Based on a published work of fineness evaluation methods for different stone powder [9], the combination of Blaine method and laser particle size method is suitable for the characterization of SP fineness. This work used a grinder (Pulverisette 7 Premium Line, FFRITSCH, Germany) with constant grinding time of 5 min, and with rotating speed of 48 rpm, 500 rpm and 720 rpm respectively to obtain the SP with different fineness. Blaine method was adopted for specific surface area measurement using an automatic specific surface area meter (FBT-9, Hebei Dahong instrument Company, China). The results are shown in Table 2. Specific surface areas of 403 m^2/kg, 610 m^2/kg and 816 m^2/kg were graded as SP-400, SP-600 and SP-800. The particle size distribution of above three fineness of SP was determined using a laser diffractometer (Mastersizer 2000, Malvern Instruments Ltd, UK). The result is shown in Fig. 1. D_{50} value of SP-400, SP-600 and SP-800 are 10.526 μm, 8.451 μm and 8.327 μm, respectively.

2.2.2. Compressive strength

To evaluate effect of sandstone powder on cementitious materials, compressive strength tests were performed. Silica fume (SF) was used as performance enhancer. The effect of silica fume on cement-based materials was discussed in the references [10–12]. Table 3 shows the mixture proportion of the pastes. The experiments included control batch, SP batches with different replacement ratios and specific surface areas, SP and SF hybrid batches, and SF batch as reference. The cement replacement by SP was in a range of 20%, 25%, 30% and 50% by mass, respectively. The hybrid batches were the blend of 5% SF with either 25% or 50% SP to investigate whether the highly reactive silica fume could promote chemical reaction of SP in pastes. Specific surface area of the cement was 350 m^2/kg, and different grades of specific surface areas of SP included SP-400, SP-600 and SP-800 were also used. The water to binder ratio was 0.4, and the size of samples was 100 mm × 100 mm × 100 mm. After casting, the samples were cured in molds under standard condition within the first 24 h, and then demolded with water curing of 3 d, 7 d and 28 d for compressive tests.

Table 2
Physical properties of cement (C), sandstone powder (SP) and silica fume (SF).

Material	Density (kg/m^3)	Specific surface area (m^2/kg)
C	3050	350
SP-400	2653	403
SP-600	2650	610
SP-800	2648	816
SF	2203	20,000

2.2.3. Tests on soluble alkali and silica in sandstone powder

To determine the reactivity of sandstone powder, it is important to know the solubility of alkali and silica in SP. Method of hot-water extraction was adopted to evaluate alkali release content of SP. Based on reference [13], saturated $Ca(OH)_2$ (CH) solution was chosen to simulate pore solution of concrete with solid to liquid ratio of 1:10. The extraction temperature was fixed at 80 °C. For each SP with different specific surface area, 2 g samples were mixed with 20 ml distilled water in an ampoule. Then the ampoule was placed in a chamber with continual vibration at a constant temperature of 80 °C. After 7 d and 28 d, 5 ml top clear liquid was collected and put into 100 ml volumetric flask. Then after acidification and calibration, K^+ and Na^+ were measured respectively with flame photometer.

To evaluate soluble silica of SP, titrimetric method was used in the test [14]. Before the test, 0.5 g SP was mixed with saturated CH solution of 200 ml. After circulation flow of the solution for 2 h, soluble silica dioxide was available. In detail, the excessive F^- and K^+ were used to firstly produce H_2SiO_3 in the solution. Then K_2SiF_6 sediment was formed. It would transfer into HF in boiling water. Finally, HF was titrated with NaOH solution of certain concentration to indirectly calculate silica dioxide content in the solution. Followings are the equations involved.

$$SiO_2 + H_2O = H_2SiO_3 \quad (1)$$

$$H_2SiO_3 + 6HF = H_2SiF_6 + 3H_2O \quad (2)$$

$$H_2SiF_6 + 2KNO_3 = K_2SiF_6 + 2HNO_3 \quad (3)$$

$$K_2SiF_6 + 3H_2O = 4HF + H_2SiO_3 + 2KF \quad (4)$$

$$HF + NaOH = NaF + H_2O \quad (5)$$

2.2.4. Test on CH consumption by sandstone powder

To evaluate the pozzolanic reactivity of sandstone powder, lime absorption method was adopted [15] to examine the reactivity of sandstone powder of different specific surface areas with CH. In order to simulate the alkalinity in pore solution of cement-based materials, a solution with 0.7 mol/L Na^+ or K^+ concentration for reaction was prepared. Each sample containing 2 g of sandstone powder and 1 g of CH was mixed with 10 ml alkali solution in an ampoule. The ampoule was then placed in a chamber with continual vibration at a constant temperature of 80 °C for 7 days. Before the reaction, CH content was 33% and it was marked as $CH_{\text{React-before}}$. After 7 days, the mixture powder was dried at 105 °C, and analyzed with TG for the mass of CH content. It was marked as $CH_{\text{React-after}}$. Therefore, the reacted CH content can be calculated by $CH_{\text{React-before}} - CH_{\text{React-after}}$.

Table 1
Chemical composition of cement (C), sandstone powder (SP) and silica fume (SF).

Oxide (Wt.%)	CaO	SiO_2	SO_3	Fe_2O_3	MgO	Al_2O_3	K_2O	Na_2O	*R_2O
C	61.84	20.25	1.88	5.14	4.40	3.25	0.35	0.10	0.33
SP	1.83	63.74	0.25	6.02	2.39	18.67	3.54	1.50	3.83
SF	0.20	98.42	0.311	–	0.26	0.32	0.24	0.11	0.27

Note: *R_2O represents of equivalent of sodium alkali content, $R_2O = Na_2O + 0.658K_2O$.