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Communication

A feasibility study on the utilization of r-FA in SCC

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Abstract

Self-compacting concrete requires a high powder content or a viscosity agent (VA) to increase its segregation resistance. This paper presents the results of a preliminary study on the utilization of rejected fly ash (r-FA) as part of the powder content. r-FA is unsuitable in the production of blended cements simply due to its coarseness. Preliminary results suggested that r-FA could be used to replace VAs in the production of self-compacting concrete (SCC) and, possibly, with additional benefits. A detailed research project is under development based on results of this study.

Keywords: Fly ash; Self-compacting concrete; Concrete; Compressive strength

1. Introduction

Self-compacting or self-consolidating concrete (SCC) can be regarded as a high-performance material, which flows under its own weight over a long distance without the need of using vibrators to achieve consolidation. The rheology of fresh concrete is most often described by the Bingham model, which is characterized by its limiting yield stress and plastic viscosity. The rheological properties of SCC are targeted to have (a) near zero yield stress, so that it behaves like a Newtonian fluid and (b) low, but 'adequate', viscosity to minimize segregation potential. To achieve these properties, the mix design of SCC must satisfy the criteria on filling ability, passability and segregation resistance [1]. Test methods on these three criteria and their limiting values have been discussed and summarized [2].

A high powder content in the range of 500–600 kg/m^3 of concrete is often needed to minimize the segregation potential of the flowing concrete. Powder generally refers to particles of cement and fillers with sizes less than 125 μm [3].

In concrete production, mixes generally have cementitious materials of 350–450 kg/m^3. Thus, filler in the order of 100–200 kg/m^3 is needed to satisfy the powder requirement. Limestone powder has been the traditional filler used in the production of SCC. Besides limestone, mineral powders [4,5] have been considered. In Hong Kong, viscosity agents (VAs) are commonly used because limestone powder has to be imported, often at a cost similar with that of Portland cement. Opportunity exists to replace VAs or limestone powder with low-cost materials such as wastes that are locally available. The concept of utilizing wastes in SCC has been exploited in Singapore [6,7].

About one million tonnes of fly ash, as a by-product in electricity generation, is produced annually in Hong Kong. The finer fraction (f-FA) produced by passing the raw ash through a classifying process is routinely used in the production of blended cements for construction. This ash conforms to BS3892 [10], which has a fineness requirement of not more than 12% by mass retained on the 45-μm test sieve and a maximum loss-on-ignition limit of 7%. However, the remaining proportion, in the order of 200,000 tonnes, is rejected as a construction material, simply due to its large particle size. In Hong Kong, this rejected fly ash (r-FA) has to be disposed of in large lagoons, creating an ever-increasing environmental hazard. Similar disposal problems could be expected in other coal-fired power stations.

The pozzolanic properties of r-FA in cement pastes have already been reported earlier, with encouraging results [8]. Current project explores the potential of this r-FA as part of the powder content for increasing the segregation resistance of SCC. If results are found promising, a more detailed study will be followed to identify limitations and to optimize benefits of this material, such as its effects on rheological properties, heat of hydration, strength development, defor-

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Table 1
Properties of Portland cement (OPC), classified fly ash (f-FA) and rejected fly ash (r-FA)

	OPC	f-FA	r-FA
Specific gravity	3.16	2.28	2.19
Blaine fineness (m^2/kg)	352	400	119
Initial set (min)	150	–	–
Final set (min)	195	–	–
Loss on ignition (%)	2.97	0.89	8.06
Sieve, cumulative % passing			
1.18 mm	–	–	100
0.06 mm	–	–	99.1
0.03 mm	–	100	95.6
0.15 mm	100	99.9	87.7
0.075 mm	98.6	97.5	61.7
0.045 mm	95.0	94.7	50.2

mation characteristics and durability requirements. It is hoped that the results presented in this paper, although limited, will generate discussions in the utilization of this material as a valuable resource.

2. Experimental

2.1. Characterization of materials

The materials used in this study were locally available. Their properties and grading, supplied by local producers, are presented in Tables 1 and 2. As indicated, particles of r-FA are much coarser than that of f-FA, with some 50% retained on a 45-μm test sieve. The coarse aggregates are crushed granite with a maximum size of 20 mm. River sand used was relatively coarse, with less than 50% passing through the 0.60-mm sieve.

2.2. Mix proportions

A total of four SCC mixes were produced, and their details are presented in Table 3. These mixes were proportioned for (a) free water-to-binder ratio of 0.38 and (b) minimum characteristic strength of 45 MPa. In this paper, binder refers to the total amount of Portland cement and classified fly ash (f-FA) used. Mixes 1-v and 2-v are currently being considered for application in construction projects in Hong Kong. In this feasibility study, rejected ash at a fixed loading of 150 kg/m^3 was used. It is recognized that the optimum loading could lie somewhere between 100 and 200 kg/m^3.

Table 2
Properties of aggregates

	Coarse aggregates	Natural sand
SSD density (kg/m^3)	2630	2640
Water absorption (%)	0.85	0.87
Sieve, cumulative % passing		
37.5 mm	100	–
20.0 mm	94	–
14.0 mm	64	–
10.0 mm	52	–
5.00 mm	8	100
2.36 mm	2	94
1.18 mm	0	75
0.60 mm	–	46
0.30 mm	–	19
0.15 mm	–	2
Pan	0	0

Table 3
Summary of mix proportions (kg/m^3)

Mix	OPC	f-FA	r-FA	Coarse aggregate	Sand	Water	SP	VA
1-v	350	115	–	735	785	175	7.8	0.56
1-r	375	125	150	660	690	190	9.7	–
2-v	270	145	–	750	870	160	9.7	3.60
2-r	300	160	150	700	700	175	11.3	–

Note that Mix Series 1 and 2 incorporated chemical admixtures from two different sources. According to manufacturers, the VA for mix 1-v was based on a high-molecular-weight hydroxylated polymer having a specific gravity of 1.20. For mix 2-v, the VA was based on an amorphous silicon dioxide with a specific gravity of 1.17. Water reducers were both new-generation superplasticisers (SP) containing polycarboxylated ether polymers with specific gravities of around 1.05.

Tests and suggested limits for SCC summarized earlier [1,2] were simplified, but tightened for this exercise to comply with local specifications such that:

(a) Minimum final slump-flow value of 700-mm diameter, within 1 min.
(b) Above slump-flow requirements to be maintained over 2 h.
(c) Minimum blocking ratio of 0.85 determined from L-box measurements.

3. Results and discussion

3.1. Fresh concrete properties

By replacing the VA with 150 kg/m^3 of r-FA (mixes 1-r and 2-r) and with appropriate mix adjustments, the final flow time (T_f) and flow diameter were maintained. All of the above

Table 4
Results on fresh concrete properties

Mix	Time (h)	T_f (s)	Flow diameter (mm)	Blocking ratio	Redosed with SP (l)	Wet density (kg/m^3)	Air (%)
1-v	0	33	755	–	–		
	2	39	720	0.89	1.0	2160	7.0
1-r	0	30	770	–	–		
	2	29	750	0.97	No need	2210	4.5
2-v	0	45	705	–	–		
	2	45	715	0.90	1.9	2200	6.0
2-r	0	43	720	–	–		
	2	36	760	0.98	0.5	2200	5.0

Table 5
Properties of hardened concrete

Mix	Compressive strength of cubes (MPa)				Elastic modulus	Scc/Nml
	1-day	3-day	7-day	28-day	(GPa)	
1-v	7.0	26.5	38.0	48.5	28.5	0.96
1-r	15.5	35.5	44.5	63.5	31.0	0.97
2-v	7.5	33.5	37.0	64.5	33.5	0.96
2-r	4.0	31.5	45.0	71.0	32.0	0.96

mixes satisfied the minimum flow property requirement of 700 mm. Comparatively, the r-FA mixes had improved properties, as indicated by the lesser flow time to achieve higher slump flow diameters. During production, it was observed that for mixes incorporating VAs (mixes 1-v and 2-v), they tend to be relatively viscous with concrete sticking onto the slump cone when lifted. As a result, the entrapped air in these 1-v and 2-v mixes had greater difficulty rising to the surface, and this could explain the higher air content of these mixes compared with their corresponding r-FA mixes. In most cases, a redose of SP was required to maintain the slump flow after 2 h. There were no visual signs of bleeding or segregation for any of the mixes. The blocking ratios were well within the limit required (Table 4).

As expected, r-FA mixes required a higher dosage of SP compared with their corresponding mixes with VAs. Care should be taken in the selection of SP if there is a structural requirement on early strength because excessive retardation can occur. During trial mixes, it was found that for the SP used in Mix Series 2, a dosage higher than 12 l/m^3 of concrete was not practical because the specimens could not be demoulded even after 24 h.

3.2. Hardened properties

The development of compressive strength for the corresponding mixes was comparable. Their elastic modulus was also similar. Their values increased with increasing compressive strength. To assess the self-compactability of these mixes, six 100-mm-diameter cylinders in each mix were produced. Three were SCC specimens, while the other three were produced with a consolidation process similar with that of normal concrete (Nml). The compressive strength ratio of the samples (Nml/Scc) with and without consolidation were compared and presented in Table 5. As indicated, the results were similar with consolidated samples showing a slight increase in strength of up to 4%. This is lower than the maximum limit of 5% suggested by researchers at the National University of Singapore [2,9].

4. Conclusions

Based on the materials used in this study, the results suggested that it is technically feasible to utilize r-FA as part of the powder content in the production of SCC. Besides environmental benefits, there could be some technical and financial advantages as well. More research is needed to optimize the loading of r-FA in improving the segregation resistance of SCC and to evaluate its compatibility with selected SP. Further research should cover the influence of r-FA on the rheology of the fresh concrete, strength development, heat of hydration, deformation characteristics and durability of the hardened concrete. These results are essential in generating confidence to specifiers in the use of new materials.

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