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Optimizing design of high strength cement matrix with supplementary cementitious materials

Jun Zhang *, Qing Wang, Zhenbo Wang

Department of Civil Engineering, Tsinghua University, Beijing 100084, China

HIGHLIGHTS

- Design of high strength cement matrix with supplementary cementitious materials.
- Effect of silica fume, slag and fly ash on strength of low water to binder ratio matrix.
- Tensile properties of PVA-steel hybrid fiber reinforced high strength cementitious composite.

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ABSTRACT

In present paper, high strength cementitious matrix, special for high strength engineered cementitious composite (ECC) is designed using two kinds of cement, ordinary Portland cement (OPC) and calcium sulfoaluminate cement (SAC), two sand types (fine and coarse sand) and three supplementary cementitious materials (SCMs), silica fume (SF), slag (SG) and fly ash (FA). Optimized binder proportion with the addition of SF, SG and FA of high strength matrix are obtained through three series compressive and bending tests. The tensile performance of ECC utilizing above high strength matrix is investigated through uniaxial tensile tests. The test results show that through optimizing on the binder composition with SCMs, compressive and bending strength of the low water to binder ratio cement matrix is significantly increased. With a similar fluidity of the fresh mortar and under general curing condition, the compressive strength at 3, 7 and 28 days changes from 25.5, 43.0 and 59.8 MPa to 35.4, 61.9 and 85.6 MPa for SAC mortar with fine sand before and after binder optimization. For OPC fine sand mortar, the compressive strength at 3, 7 and 28 days changes from 45.0, 57.8 and 77.9 MPa to 62.0, 80.6 and 108.0 MPa. Similar trend is observed on the bending strength of those mortars as well. Based on the present study, the optimized binder composition with SF, SG and FA additions in weight are cement:SF:SG:FA = 0.7:0.1:0.1:0.1. Using present optimized binder as cementing matrix, the primary tensile results on polyvinyl alcohol (PVA)-steel hybrid fiber reinforced composites show the tensile strength and strain can achieve 7.3 MPa, 0.6% and 8.1 MPa, 0.5% respectively for SAC and OPC cementing system.

1. Introduction

Concrete is a typical brittle material representing as first cracking in tension is accompanied by immediate localization of deformation followed by decreasing load. To overcome the brittle nature of concrete, a class of high performance fiber reinforced cementitious composite, called engineered cementitious composites (ECCs), has been developed in recent years [1]. This material has a unique property that after first cracking, tensile load-carrying capacity continues to grow, resulting in strain-hardening accompanied by multiple cracking. For each individual crack, the crack width first increases steadily up a certain level and then stabilizes at a constant value. Further increase in strain capacity is resulted from the formation of additional cracks until the cracking reaches a saturated state with crack spacing limited by the stress transfer capability of the fibers. After that, a single crack localizes and the load slowly drops with increased deformation. Typically, strain localization occurs at a tensile strain of 3–5%, with crack spacing of 3–6 mm and crack width around 60 μm [1]. Cracks of such a small width will have little effect on the water permeability of the material [2]. With slight degradation in transport properties under high deformation, the durability of the structure can be maintained.

* Corresponding author.
E-mail address: junz@tsinghua.edu.cn (J. Zhang).

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Table 1
Chemical composition of the cementitious materials used in tests (wt%).

No	SiO_2	CaO	Al_2O_3	Fe_2O_3	MgO	K_2O	Na_2O	SO_3	LOI
SAC	6.19	42.9	24.16	1.04	1.96	0.48	0.08	12.91	8.91
OPC	23.67	59.98	7.21	3.07	2.07	0.62	0.17	2.14	1.01
Silica fume (SF)	90.56	0.81	0.41	0.52	0.95	1.59	0.63	–	3.72
Fly ash (FA)	47.02	5.08	35.06	3.88	1.36	1.30	1.18	0.89	1.85
Slag (SG)	38.83	38.70	12.92	1.46	4.63	0.37	0.28	0.60	0.06

However, in order to obtain this strain-hardening and multiple cracking behaviors, only a small amount of fine sand and relatively low strength of the matrix are allowed to be applied in order to control fracture toughness of matrix [3]. Generally, cement matrixes with compressive strength lower than 50 MPa are used in ECC [3–6]. Even though the ability of crack width controlling of ECC is strong, a number of applications, such as permanent formwork for concrete structures, steel-concrete composite bridge decks [7–9], still wish the material has a relatively higher strength, meanwhile the material has adequate ductility. In these applications, material properties with low moisture transport coefficient, high freezing resistance and high permeability are required as well apart from ductility [9]. Therefore, high strength cement matrixes for a new generation of ECC focus on above applications are essentially needed to be developed. In addition, the cement content in ECC matrix is higher compared with conventional concrete, the possibility to use supplementary cementitious materials, such as silica fume, grounded granulated blast furnace slag and fly ash, in these high strength matrixes is of great interesting as well in the view of energy saving and sustainability of the materials.

In the present paper, high strength ECC matrix is designed using two kinds of cements, two types of silica sand and three kinds of supplementary cementitious materials (SCMs). The impacts of cement, sand and SCMs on compressive and bending strength of the matrix are experimentally evaluated. Optimized mix proportions with the addition of silica fume (SF), slag (SG) and fly ash (FA) of high strength cementitious matrix using two types of cement respectively are obtained. The tensile performance of ECCs utilizing above high strength matrixes is investigated through uniaxial tension tests. The results are discussed at the end of the paper.

2. Experimental program

The purpose of this test program is to investigate the effect of supplementary cementitious materials on compressive and bending strengths of high strength cement matrix, and finally to obtain the optimizing composition of high strength matrix binder. To achieve this target, three kinds of supplementary cementitious materials, silica fume (SF), grounded granulated blast furnace slag (SG) and fly ash (FA) were used in the experiments. To investigate the impact of sand size, two kinds of silica sands with particle size of 0.075–0.150 mm (fine sand) and 0.212–0.425 mm (coarse sand) were used respectively in the tests. To investigate the effect of cement type on the mechanical performance of the matrix, two cement types, Portland cement (OPC) and calcium sulfoaluminate cement (SAC) that has extra high early-age (in hours) strength [10], were used respectively as cementing materials. In order to obtain optimized proportions of the binder, three series tests,

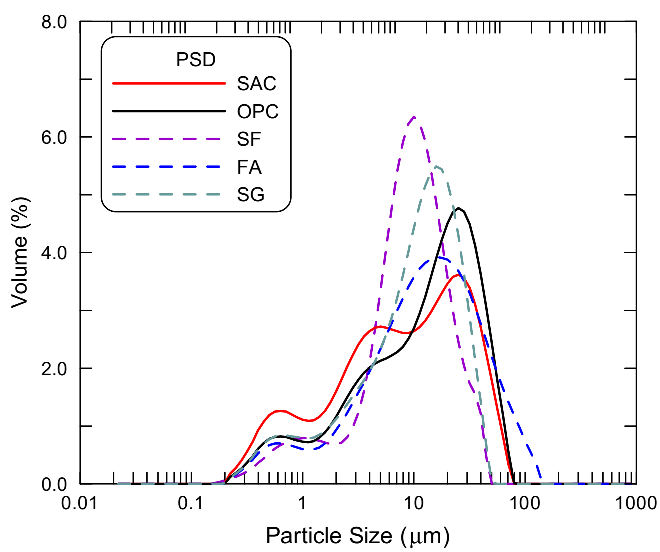

Fig. 1. Particle size distribution of the five fine cementitious materials.

Table 2
Properties of PVA and steel fibers.

	Density (g/cm^3)	Tensile strength (MPa)	E (GPa)	Diameter (mm)	Length (mm)
PVA fiber	1.2	1620	42.8	0.039	12
Steel fiber	7.8	2750	210	0.200	13