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Effect of different sand grading on strength properties of cement grout

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HIGHLIGHTS

▶ Three different refined sand grading were used in prepare of cement grout (CG).
▶ Finer sand filler contributes to higher mechanical strengths of CG.
▶ CG with finer sand is more durable when exposed to tropical air condition.
▶ Cubes' compressive strength was lower compared to that of one-half prisms.

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ABSTRACT

This paper aims to study the consistency and strength properties of cement grouts prepared with three different sand grading namely 100% passing through 1.18 mm sieve (P1.18 mm), 0.90 mm sieve (P0.90 mm) and 0.60 mm sieve (P0.60 mm), respectively. The measured flowing time indicated that the specimens with the finer sand grading had lower flowability than those of the coarser sand grading. As the results, the finer sand grading specimens required a higher water to cement ratio to achieve an equivalent workability. The specimens with the coarser sand grading obtained higher 7 and 28 days compressive strengths than those of the finer sand grading when the lower water to cement ratio was adopted (0.61–0.63). However, when the higher water to cement ratio (0.65–0.67) was used, the specimens with the finer sand grading achieved higher long-term compressive, flexural and splitting tensile strengths than those of the coarser sand grading.

1. Introduction

The application of grout materials and grouting technique are common for construction sector nowadays. Records abound, cement-based grout or self-compacting repair mortar have been widely used since the 1800s and even earlier [1,2]. Grouting is a process of fluids injection that set into fissures, cracks or voids [3,4]. Nowadays, several types of grout materials have been used, including cement, cement and sand, clay–cement, slag cement, gypsum–cement, epoxy–polymer, clays–asphalt, pulverized fuel ash and a large number of colloid and low viscosity chemicals [5]. Cement grout with a high flowability is widely used in the concrete remedial works due to its flowable and self-compacting behaviors. It can easily flow into fine cracks and fissures attributed to its fluidity. High fluidity of cement grout is a vital requirement of high cohesion or segregation resistance during flow to form a uniform and homogeneous mix. As the fluid cement grout can be fully compacted without vibration, the application of the self-compacting cement grout/mortar can therefore reduce labor and machinery costs, improve compaction and hence enhance durability of the critical cover zone of a structural member [6]. Relatively few detailed studies have been reported on the influence of different grading of sand filler on the properties of cement mixes especially self-compacting cement mortar. De Schutter and Poppe [7] noticed that sand type has a significant effect on the cement mortar properties. The authors observed that geometrical parameters of sand based on the grading curve, like fineness modulus, relative specific surface and apparent weight, can be correlated with the water demand of the sand in the mortar, and may also influence the hardened properties of mortars. Westerholm et al. [8] found that the viscosity of mortar was influenced by the fines content of fine aggregates, which may increase with the increased total surface area of the fine aggregates. According to Haach et al. [9], the cementitious-based mortars (cementitious to sand ratio = 1:3;

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cementitious = solely Portland cement or Portland cement + lime) prepared with the finer sand filler (passing through 1.18 mm sieve) required a higher w/c than that of the coarser sand filler (passing through 4.75 mm sieve) to achieve an equivalent consistency. Reddy and Gupta [10] observed that the cementitious-based mortar prepared with the finer sand filler required 25–30% more water to achieve the desired consistency than that of the coarser sand filler. The compressive strength does not seem to be affected by the sand grading. However, the sand grading could influence the dimensional stability and modulus of elasticity in compression of the cementitious-based mortars [9,10]. From the foregoing, there are still limited studies on the effect of sand grading on the characteristics especially long-term strengths of self-compacting cement mortar (CG). Therefore, it is of necessity to further study the effect of sand grading on the strength properties of CG for a concrete remedial work. This paper studies the effectiveness of using three different sand fillers namely P1.18 mm, P0.90 mm and P0.60 mm on workability and strength properties of CG.

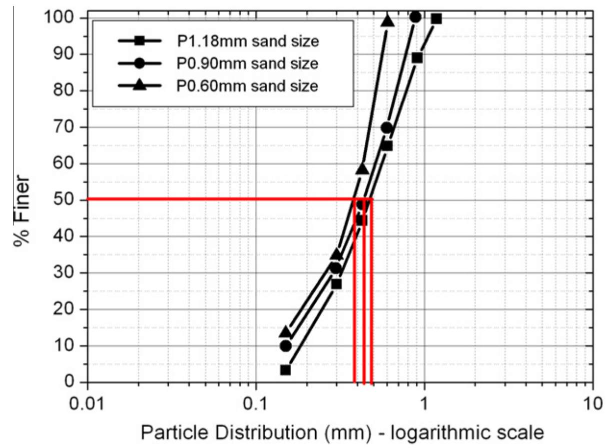

Fig. 1. Particle size distribution curves for P1.18 mm, P0.90 mm and P 0.60 mm sand samples.

2. Experimental program

2.1. Materials

The production of cement grout (CG) in this study was carried out by using raw materials namely ordinary Portland cement (OPC), oven dried river sand of different grading, and clean tap water. The different batches of sand samples were subjected to varying degrees of tropical natural weathering exposures. As a result, the samples may contain different initial moisture content. To standardize the preparation procedures of the specimens, it was necessary to oven dry the sand samples at 105 °C for 24 h to remove the total moisture content. It is easier to control the w/c ratios used in this study by using the oven-dried sand than the natural sand samples with inconsistent moisture content. Localized OPC manufactured by YTL Cement was used as a binder. It complies with the Type I Portland cement in accordance with ASTM C150 [11]. Table 1 shows the chemical composition and the physical properties of the YTL branded OPC. Fig. 1 shows the grading curves of the oven dried refined river sand samples used in this study. Three categories of refined sand grading were used, namely 100% passing through 1.18 mm sieve (P1.18 mm), 0.90 mm sieve (P 0.90 mm) and 0.60 mm sieve (P0.60 mm), respectively. The sand fillers used are classified as zone 4 fine sand with the fineness modulus in the range of 1.48–2.01 (refer to Table 2, the dominant sizes of the sand fillers ranged from 0.30 to 0.60 mm, specific gravity = 2.60) in accordance with BS 882:1992 [12].

2.2. Mix proportions

Firstly, the OPC and oven-dried sieved sand were blended thoroughly until a uniform dry mix was obtained. Water was then added into the dry mix, and was mixed thoroughly in a concrete mixer until a uniform fresh cement grout was obtained. The whole process of mixing took about 5–10 min. The fresh cement grout was used to cast the different types of specimens. Laboratory trials (series 1) for three different types of CG mixtures prepared with the predetermined sand grading (P1.18 mm, P0.90 mm and P0.60 mm) were carried out in accordance with ASTM C 938 [13]. The laboratory trials aimed to obtain the optimum w/c of respective mixtures that corresponded to the optimum strength without compromising its flowability and workability. The cement to sand ratio (c/s) was kept at unity. The trial w/c ratios for the respective mixtures ranged from 0.61 to 0.67 with an interval of 0.02. Table 2 (series 1) shows a summary of the trial mixes details.

Table 1
Chemical composition and physical properties of YTL branded OPC.

	OPC
Chemical constituents	
Silicon dioxide (SiO_2) (%)	21.1
Aluminium oxide (Al_2O_3) (%)	5.2
Ferric oxide (Fe_2O_3) (%)	3.1
Calcium oxide (CaO) (%)	64.4
Magnesium oxide (MgO) (%)	1.1
Sulfur oxide (SO_3) (%)	2.5
Sodium oxide (Na_2O) (%)	0.2
Potassium oxide (K_2O) (%)	0.6
Titanium oxide (TiO_2) (%)	0.2
Phosphorous oxide (P_2O_3) (%)	<0.9
Carbon content (C) (%)	–
Physical properties	
Loss on ignition (LOI)	2.4
Specific gravity	3.15
Fineness in blaine (cm^2/g)	3170
Fineness (% passing 45 μm)	93.0

2.3. Specimens preparation

The cubic, prismatic and cylindrical specimens were prepared by using cubic mold with a size of $50 \times 50 \times 50$ mm, prismatic mold with a size of $40 \times 40 \times 160$ mm and cylindrical mold with a size of 100×200 mm, respectively. The specimens were demolded after 24 h of casting and then subjected to two different curing regimes as described below:

(i) Water: specimens were submerged in water with temperatures in the range of 25–28 °C until testing ages.
(ii) 7Water + Air: specimens were subjected to 7 days of initial water curing with temperatures in the range of 25–28 °C, and then were further exposed to air curing that in a sheltered outdoor environment with temperatures in the range of 29–33 °C and relative humidity in the range of 55–65% until testing ages.

2.4. Testing methods

2.4.1. Flowability

The flowability of the fresh mixed cement grout (CG) was determined by using flow cone method as described in ASTM C 939 [14]. A quick flowing time indicates a high fluidity/workability of fresh CG.

2.4.2. Compressive strength

Compressive strength was determined by using a Universal compression test machine with a constant loading rate of 1 kN/s in accordance with ASTM C 942 [15], which is equivalent to ASTM C 109/C [16]. The compressive strength was obtained by applying an axial compressive load on the $50 \times 50 \times 50$ mm cubic specimen.

2.4.3. Flexural strength and jig-section compressive strength

The prismatic specimens with a size of $40 \times 40 \times 160$ mm (width $\times$ depth $\times$ length) were subjected to the center-point loading flexural test in accordance with ASTM C 348 [17]. The test was conducted at a fixed rate of 0.1 mm/min by using Instron Testing Machine. The prismatic specimens were tested until they were broken into two halves and their flexural strength was computed. In addition, both portions from each broken prismatic specimen were used for compressive strength testing in accordance with ASTM C 349 [18]. The one-half prismatic specimen shall have a length of not less than 65 mm and free of crack, chipped surface or other obvious defects. The compressive strength of jig-section of the one-half-prismatic specimens was computed by dividing maximum imposed load with 1600 mm^2 of testing area (jig-section area).

2.4.4. Splitting tensile strength

Splitting tensile strength of cylindrical specimens with a size of 100×200 mm (diameter $\times$ height) was determined by using a Universal compression test machine with a constant loading rate of 0.5 kN/s in accordance with ASTM C 496 [19].