Construction and Building Materials 108 (2016) 67–73

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Experimental study on long-term compressive strength of concrete with manufactured sand

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HIGHLIGHTS

- Long-term compressive strength of concrete with manufactured sand (MSC) was examined.
- Explain effects of stone powder on workability and compressive strength development.
- Forecast model of long-term compressive strength of MSC are proposed.

ARTICLE INFO

Article history:
Received 8 October 2015
Received in revised form 11 January 2016
Accepted 15 January 2016

Keywords:
Concrete with manufactured sand (MSC)
Compressive strength
Stone powder
Forecast model

ABSTRACT

In this paper, experimental studies on compressive strength development of concrete with manufactured sand were carried out. Influences of stone powder content on long-term compressive strength of concrete with different water-to-cement ratios were analyzed. Tests results showed that when content of stone powder was less than 13%, it basically had positive correlation with the long-term compressive strength of MSC. Based on tests data, forecast model of long-term compressive strength of MSC considering curing age, water-to-cement ratio and cement's compressive strength and density are proposed.

1. Introduction

Compressive strength is one of the basic mechanical properties of concrete used for concrete structure design, which has the nature to be changed with time going. Compressive strength development of concrete is of great significance for the reasonable arrangement of construction procedure and the rational estimation of construction period, which is also related to the reliability of structure in service life.

As a new green building material used for replacing natural sand, manufactured sand (also called as machine-made sand, artificial sand or crushed-stone sand) has become important in researches, productions and engineering applications of premixed concrete [1–9]. With the progressive application, manufactured sand has been used from partially to completely replacing the natural sand in concrete [10,11], and the limitation of stone powder in manufactured sand has changed to an approved proper content [3–6]. Moreover, it has also been used for lightweight aggregate concrete [12], engineered cementitious composites [13] and masonry mortar [14].

Differ from natural sand, manufactured sand has special morphology features such as rough surface, irregular particle shape, angular edges and distinguish characteristics of stone powder contained, which has some special effects on the workability, basic mechanical properties and durability of concrete. For examples, with the same mix proportion as natural sand concrete, a lower flowability and easily segregated mixture was gotten for concrete with manufactured sand (MSC) [15–17], water dosage should be increased if the similar workability of fresh concrete was wanted [17–19]; commonly, proper content of stone power was beneficial to workability of fresh concrete and mechanical properties of harden concrete [6,19–21]. Compared with natural sand concrete, MSC had higher compressive strength [8,14,22,20,23] and fracture energy [24], and better bond property to steel rebar [25].

Currently, two methods named as natural environment test and laboratory test were adopted to study the long-term compressive strength of concrete. Natural environment tests include core boring or destructive detection on full-size models and true components settled in natural environment [26–28], which always last

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http://dx.doi.org/10.1016/j.conbuildmat.2016.01.028
0950-0618/

several years, or even the entire service life of the structure. Results are combinations of durability factors such as carbonation, freezing and thawing, wetting and drying cycles, harmful ion corrosion, loads multiple effects and other factors in the natural environment. Basic forecast models were using measured/standard value of compressive strength at 28 days multiplied by parameters considering the surrounding environment and inner hydration of concrete, which could forecast the compressive strength of concrete of structures/components in a similar environment to estimate the residual life of structure in active service. However, some limitations such as little flexibility between different environments and ambiguity physical parameters in these models, make it difficult to identify and quantify influences of different factors. Laboratory tests use concrete specimens to measure the compressive strength at different curing age in laboratory [29–33], in which impacts of different factors are easily considered such as raw materials and mix proportion of concrete, curing environment and other single or multiple factors on the compressive strength of concrete. However, tests were always limited within 90 days or 180 days periods [29–32]. What is more, no unified forecast model was proposed using this test method.

In view of the importance of long-term compressive strength, and based on the authors' former research results [29,30], tests of the long-term compressive strengths of MSC with different stone powder content were carried out and the forecast models of long-term compressive strength of MSC are proposed.

2. Experiment procedure

2.1. Raw materials

Cement: grade P.O. 42.5 ordinary silicate cement, the chemical composition and physical properties are listed in Table 1.

Crushed stone: mixed in proportion 2:5:2:1 by the series of 5–10 mm, 10–19 mm, 19–26.5 mm and 26.5–31.5 mm, the physical and mechanical properties are presented in Table 2.

Manufactured sand: crushed from limestone, approximately 0–4.75 mm particle size. The stone powder content in mass of manufactured sand was adjusted to 5%, 9% and 13%. The physical properties of manufactured sand are listed in Table 3.

Others: tap water and commercially available high-performance water reducer of FDN-1 with water-reducing rate as 19%.

The particle size distributions of cement, stone powder, manufactured sand and coarse aggregate are presented in Fig. 1.

2.2. Mix proportions of MSC

The water absorption of stone powder and larger density of manufacture sand are important affecting workability of fresh concrete. Proper content of stone powder will improve mixture workability with the same mix proportion [19]. Considering effects of manufactured sand on the mixture workability and the strength of hardened concrete, the mix proportion design of MSC was adjusted based on the Chinese technical code JGJ55-2011 [34]. Water-to-cement ratio (m_w/m_c) was calculated using the following Bolomey formula:

$$m_w/m_c = \alpha_a f_{ce}/(f_{cu,0} + \alpha_a \cdot \alpha_b \cdot f_{ce}) \quad (1)$$

where $f_{cu,0}$ is the preparation compressive strength of concrete, α_a and α_b are regression coefficients, f_{ce} is the compressive strength of cement at 28 days.

Table 2
Physical and mechanical properties of crushed stone.

Properties	Values
Apparent density (kg/m^3)	2730
Pile-up density (kg/m^3)	1440
Crushed index (%)	9.0
Mud content (%)	0.3
Content of needle-pieces (%)	4.9

Table 3
Physical properties of manufacture sand.

Manufactured sand		MS1	MS2	MS3
Stone powder content (%)		5	9	13
Fineness modulus		3.34	3.27	2.77
Apparent density (kg/m^3)		2720	2750	2750
Methylene blue value (g/kg)		0.75	0.85	1.00
Water absorption (%)		0.7	0.8	1.0
Bulk density (kg/m^3)	Loose	1550	1610	1610
	Close	1720	1820	1800
Porosity(%)	Loose	43.0	41.5	41.5
	Close	36.8	33.8	34.5

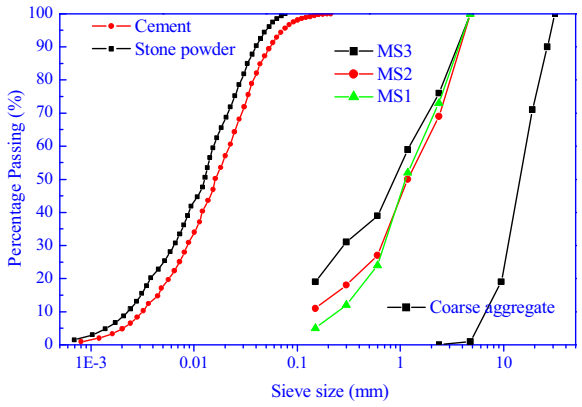

Fig. 1. Particle size distribution of the materials used.

According to previous studies [17,19], coefficients of formula (1) should be taken as $\alpha_a = 0.445$, $\alpha_b = 0.027$. To ensure the workability of MSC, the water absorbed by stone powder should be added as part of the initial admixing water, the sand ratio should be increased about 2% on the basis of the ordinary concrete with natural sand, and reduced 1–2% with the 2–3% increment of stone powder of manufactured sand. Detailed mix proportions are listed in Table 4.

2.3. Test methods

Tests for slumps of fresh concrete and compressive strength of hardened concrete were in accordance with the specifications of China Standards GB/T50080-2002 [35] and GB/T50081-2002 [36], which are identical to British Standards BS EN 12350-2-2009 [37] and British Standard BS EN 12390-3-2009 [38].

Table 1
Chemical composition, physical and mechanical properties of cement.

Chemical properties (%, by weight)									
LOI	SiO_2	Al_2O_3	Fe_2O_3	CaO	*f*-CaO	MgO	SO_3	K_2O	Na_2O
1.09	21.13	5.15	3.24	61.32	0.62	3.09	2.47	0.55	0.43
Physical and mechanical properties									
Density (kg/m^3)	Blaine fineness (m^2/kg)	Consistency	Setting time (min)		Flexural strength (MPa)		Compressive strength f_{ce} (MPa)		
			Initial	Final	3 days	28 days	3 days	28 days	
3130	367.2	29.2	185	295	5.4	8.0	29.5	46.8	