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Characterization of manufactured sand: Particle shape, surface texture and behavior in concrete

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HIGHLIGHTS

- The MS particle shape is characterized with digital image analysis based on big sample space.
- At the micro scale the surface roughness of MS is lower than RS.
- The sand's shape and roughness are no significant factors on its behavior in concrete.

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ABSTRACT

Full understanding on the characteristic and behavior of manufactured sand (MS) is very crucial to its application. The particle shape, surface texture and behavior of MS are characterized in this paper. Results indicate that MS has higher roundness and Length-width ratio, and wider distribution ranges of those parameters compared with river sand (RS), in the micro scale, most MS has lower surface roughness than RS unexpectedly. To obtain the similar workability, most MS concretes require higher water reducer dosage than RS concrete, and MSs with less stone powder and clay lump content require even lower water reducer. Nearly all MS concrete has higher strength than RS concrete with same paste composition. The particle shape and surface texture of MS has less significant effect on its behavior in concrete than the stone powder, clay lump content and the gradation of MS, so MS with suitable production process may have better behavior in concrete than RS.

1. Introduction

The market share of manufactured sand (MS) or artificial sand (AS) keeps increasing recently in China due to the shortage of natural river sand (RS) supply, whereas the MS is still widely regarded as a low quality succedaneum of RS [1–3] in China. It is well known that MS, in contrast to the natural river sand, comes from the mechanical crushing of virgin rock. It is different in shape, grading, and content of stone powder (micro fines) compared with RS, the properties (e.g. workability, water demand, mechanical properties) and durability of MS concrete are also different from those of RS concrete [4–7]. Basically the behavior of sand in concrete depends on its quality parameters [8–11]. Some of the quality parameters are related to the production process, e.g. the stone powder content, the clay lump content, even the gradation can be adjusted by manufacturing process. And some qualities mainly result from the resource of the sand, e.g. the particle shape, the surface texture, which are the substantive characteristics of the MS. Therefore, to understand the characteristics of MS concrete and assess its performance, it is very important to clarify how much the concrete properties are related to those characteristics. Visually, the particle shape of MS is angular while the RS has a rounded shape [7,12], the natural sand has a smoother surface than MS. As well known, the shape and the surface texture of aggregate particle influence the properties of the fresh concrete and the hardened concrete as well [13–16]. Since the particle shape and surface texture of MS is much different from those of RS, characterizing the shape and texture is a very important issue to understand the behavior of MS in the concrete and the properties of the MS concrete. The particle sizes distribution, particle shape and surface texture of MS are studied by some researchers [5,17]. It is widely accepted that the MS has higher surface roughness than the RS

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Table 1
The properties of cement.

Cement sort	PO 52.5
Normal consistency (%)	27.6
Initial Setting time (min)	104
Final Setting time (min)	176
3 d Strength (flexural/compressive) (MPa)	6.7/34.5
28 d Strength (flexural/compressive) (MPa)	9.5/55.2

Table 2
The chemical compositions of raw materials.

Chemical composition	P·O 52.5	Fly ash
CaO	60.68	4.51
SiO_2	21.96	56.70
Al_2O_3	5.86	26.12
Fe_2O_3	3.01	7.25
MgO	2.91	2.49
SO_3	2.38	0.83
Loss	1.34	1.57

Table 3
The size distribution of coarse aggregate.

Type of aggregate	Sieve size (mm)/accumulated screening rate (%)						
	26.5	19	16	13.2	9.5	4.75	2.36
10–25 mm	1.8	11.6	53	91	99.5	100	100
5–10 mm			1.9	12.2	62.2	99.6	99.9
Composite aggregate	0.9	5.8	27.5	51.6	80.9	99.8	100

and consequently has higher absorption capability (AC), it is true in the visual scale, however, the AC of sand is controlled by its roughness in the micro scale. Some widely accepted views make MS mostly treated as a low quality sand and just used in middle and low strength degree concretes, to scientifically assess the characteristics is a very important issue to the utilization of MS. In this paper, the particle shapes of MS and RS is studied by digital image analysis, coaxial laser confocal microscope is used to study the surface texture of MS and RS, the behavior of MS in a high performance concrete is assessed.

2. Experimental program

2.1. Materials

The 52.5 grade commercial Portland Ordinary cement (P.O 52.5) was used in this investigation. The properties of the cement are shown in Table 1. Chemical compositions of cement and fly ash are presented in Table 2.

Crushed limestone with two particle size grades, i.e. 10–25 mm and 5–10 mm were used, the particle size distribution is listed in Table 3, its crushing value is 18.6%, and the apparent density is 2720 kg/m^3.

Nine kinds of fine aggregates were used in this experimental investigation, i.e. a river sand (RS) and eight sorts of MS (Which includes different lithologies, e.g. MSA (Diorite), MSB (Metamorphic siltstone) and MSC (Altered diorite). See in Table 6), their physical properties and size distributions were listed in Tables 4 and 5 respectively. The XRD patterns of sands are presented in Fig. 1, the lithology is listed in Table 6.

A polycarboxylate superplasticizer was used in this investigation; its water-reducing ratio is 29.2%.

Table 5
Screening results of fine aggregate.

Sample No.	Accumulated retained (%)							Fineness modulus
	4.75	2.36	1.18	0.6	0.3	0.15	0.075	
MSA	0.6	24.7	43.1	58.8	68.3	77.2	84.1	2.71
MSB	0.2	19.9	42.8	62.9	72.5	79.5	83.6	2.77
MSC	1.1	9.2	30.3	52.3	64.6	72.4	83.1	2.26
MSD	0.7	11.0	32.0	60.0	77.4	90.5	95.1	2.69
MSE	0.0	14.1	36.5	55.9	66.3	75.3	82.3	2.48
MSF	2.4	31.6	50.7	66.9	74.8	81.6	86.2	3.01
MSG	0.1	15.3	38.1	58.8	84.4	91.9	96.7	2.88
MSH	3.7	42.5	65.9	83.1	87.1	95.3	97.7	3.69
RS	3.9	16.9	34.1	59.8	83.1	97.9	99.4	2.83

2.2. Experiment method

Particle shape irregularity manifests at three main scales: sphericity S, roundness R and roughness R (or smoothness) in dimensionless form [18]. In this work, a digital camera is used to obtain images of particles, so just 2D information is studied thus the 3D sphericity cannot be quantified, the image is analyzed with a program named Image Pro Plus 6.0, and two parameters, i.e., Length-width ratio and roundness (Fig. 2) are calculated to characterize the particle shape of sands.

Length-width ratio:

$$L/W = \frac{L}{W} \tag{1}$$

where L is the Length and W is the width of particles.

Roundness:

$$R = \frac{P^2}{4 \times \pi \times \text{area}} \tag{2}$$

where P is the perimeter and area is the square meters of the particles.

In this work, 100 particles are analyzed for each sand samples, the higher the value of the roundness are, the farther the particles are from round.

The roughness of the surface is obtained with a coaxial laser confocal microscope (VK-X200) by scanning the surface with a laser beam with a radius of 0.4 μm, the difference of this system comparing with the ordinary method is illustrated in Fig. 3.

R_a is calculated according to Eq. (3) (Fig. 4).

$$R_a = \frac{1}{L}\int_0^L |y(x)|dx \tag{3}$$

where L is the Length in μm, and y is the height in μm between the detecting point and the base face.

The high performance concrete was prepared in the laboratory with a testing forced mixer. The mixing times of each mixture are 3 min and the slump of the fresh concretes was controlled at the range of 180 ± 15 mm by adjusting the dosage of additive. The less water demand of the concrete, the less water reducer need. The workability of the concrete made with various sands could be qualified simply with the dosage of water reducer demand. The cubic concrete specimens were formed in 150 mm × 150 mm × 150 mm mold, then each group of molds were vibrated for 45 s till the concretes become consolidated. After being demoulded, cubic specimens were cured in a chamber with 100% relative humidity at temperature of 20 ± 2 °C. At the age of 7, 28 and 60 days, concrete specimens were tested for compressive strength respectively, three cubes were tested for each date point.

Table 4
Physical properties of fine aggregate.

ID	MSA	MSB	MSC	MSD	MSE	MSF	MSG	MSH	RS
Bulk density (kg/m^3)	1583.5	1513.5	1622.7	1505.5	1488.5	1537	1520	1636	1473.3
Close packing density (kg/m^3)	1854.5	1735	1830	1728	1652.5	1791	1770	1778	1659.7
Apparent density (kg/m^3)	2746	2741.5	2913	2647.8	2906	2750	2745	2700	2626.6
Bulk voidage (%)	42.33	44.79	44.3	43.14	48.78	44.11	44.63	49.41	43.91
Crushing value (%)	28.63	14.4	17.1	18.54	20.24	25.52	15.43	23.3	9.42
Powder content (%)	15.3	16.4	16.9	4.9	17.7	13.8	2.9	2.3	0.6
Clay lump content (%)	3.7	0.8	4.8	0.4	5.2	2.6	0.9	0.4	0
MB value (g/kg)	0.5	0.5	1.25	0.25	4.75	1.75	0.25	0.25	–