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Effect of limestone fines content in manufactured sand on durability of low- and high-strength concretes

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ABSTRACT

This paper investigates the effect of limestone fines content in manufactured sand (MS) on compressive strength, chloride ion permeability and freeze–thaw resistance of both low- and high-strength concretes. The abrasion resistance of concretes and sulfate attack of mortars were also tested. The results show that for low-strength concretes, the increment of limestone fines from 0% to 20% improved the resistance to chloride ion penetration, but decreased the resistance to freezing. For high-strength concretes, the increment of limestone fines from 0% to 15% did not affect the chloride ion permeability and freeze–thaw resistance. Furthermore, the sulfate resistance was increased by the increment of limestone fines, and the amount of 7% and 10% fines resulted in the highest abrasion resistance. It can be concluded that the durable concretes can be made from MS with at least 10% limestone fines.

1. Introduction

The use of manufactured sand (MS) has been increasing in China because good quality natural sand is not economically available in many areas. Because of the crushing process, MS differs from natural sands in its grading, particle shape, and texture; and typically has between 10% and 20% fines (the particles passing the 75 μm sieve). In MS these fines usually are most likely smaller size fractions of crushed aggregate, while in natural sands the fines can be clays or other deleterious particles. The current Chinese National Standard GB/T 14684-2001 specifies that the limit of the rock fines content in MS is, respectively, 3%, 5% and 7% [1], based on the used concrete strength grade (defined as the 28d compressive strength standard value) such as higher than 60 MPa, between 60 and 30 MPa and lower than 30 MPa. Such specifications severely limit the amount of fines that can be used, even though higher fines contents can improve the properties and the performance of the resulting concrete and reduce the cost of the mixture in which they are used as research in China and abroad has shown. In other countries, limits of up to 25%, and commonly around 15%, have been established [2–4].

The effect of inclusion of limestone fines in MS on fresh and hardened concrete has been a major research topic for many years. It has been established that 10–15% of limestone fines could be allowed in MS without harmful effects on the physical and mechanical properties of concrete [5–12]. However, little work has been done so far on the effect of fines in MS on the durability of concrete. Therefore, this paper reports the results of an experimental investigation on the influence of limestone fines as replacement of fine aggregate on concrete compressive strength and durability.

2. Experimental program

2.1. Materials

Two ordinary Portland cements of 32.5 and 52.5 grades were, respectively, used for preparing low- and high-strength concretes. The properties of the cements are shown in Table 1. Two coarse aggregates, crushed limestone from same mineralogical sources were selected with different maximum size (31.5 and 25 mm for low-strength and high-strength concretes, respectively). The manufactured sand was made from pre-washed crushed limestone, however, not all the fines were removed by washing and the residual fines content after washing was 3.0%. Table 2 presents a summary of properties of the manufactured sand. The limestone fines used as partial replacement of sand were those obtained by sieving the manufactured sand below 75 μm. Chemical composition of limestone fines are given in Table 3. Its bulk density and Blaine specific surface areas were 2.72 g/cm^3 and of 279.8 m^2/kg. For the limestone fines and 32.5 ordinary Portland cement, particle size distribution was measured with laser diffraction (Fig. 1). As shown in Fig. 1, the limestone fines was coarser material compared with the cement, with a median size of 16 μm. Two commercially available sulphonated naphthalene formaldehyde superplasticizer of JG-2 and JG-3 were used in all mixes, which were mixed according to 1:1 by weight.

2.2. Mix proportions

Two series of mixture proportions were, respectively, made for low-strength concretes with constant water/cement (w/c) ratio of 0.55 (Series L) and high-strength concretes with constant w/c ratio of 0.32 (Series H). The limestone fines

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Table 1
Physical performances of the cements.

Cement	Specific gravity	Blaine fineness (m^2/kg)	Consistency (%)	Setting time (h:min)		Soundness	Flexural strength (MPa)		Compressive strength (MPa)	
				Initial	Final		3d	28d	3d	28d
P·O 32.5	3.10	345.0	28.2	3:31	4:06	Qualified	3.8	7.9	19.0	44.8
P·O 52.5	3.13	438.3	27.6	1:50	2:19	Qualified	5.9	9.0	31.1	56.8

Table 2
Physical characteristics of manufactured limestone sand.

Fineness modulus	Fines content (wt%)	Specific gravity	Density of rodded particle packing (g/cm^3)	Rodded voids (%)	Methylene blue value (g/kg)	Crushing value (%)	Surface roughness (s)
3.4	3.0	2.665	1.799	32.5	1.35	17.0	17.0

Table 3
Chemical composition of limestone fines.

Oxide	CaO	SiO_2	Al_2O_3	Fe_2O_3	K_2O	Na_2O	MgO	Loss on ignition
%	49.08	5.05	1.62	0.61	0.52	0.04	1.59	40.88

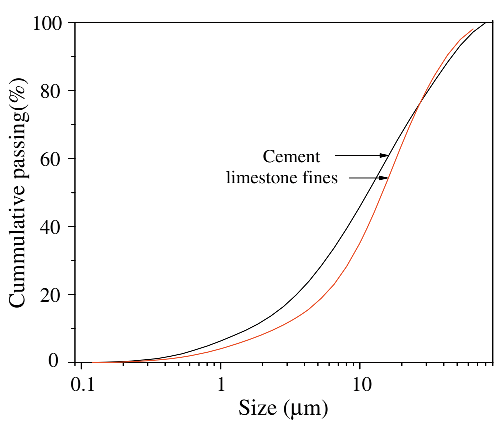

Fig. 1. Particle size distribution of limestone fines and cement.

were used as part of the fine aggregate, the rate of fines is adjusted to 0%, 3%, 5%, 7%, 10%, 15%, and 20% by weight of fine aggregate. Table 4 shows the detailed mixture proportions and measured slump.

2.3. Experimental methods

Performances of fresh concrete were tested according to GB/T50080-2002 [13]. Compressive strength was determined by testing 150 mm × 150 mm × 150 mm cubes according to the GB/T50081-2002 [14]. Chloride ion permeability was measured using 100 mm × 100 mm × 50 mm specimens by NEL method based on Nernst-Einstein equation and electric testing apparatus for diffusion coefficient of chloride ions of concrete, according to the Chinese Engineering Construction Society Standard CECS 01-2004 [15]. Freezing and thawing resistance test is carried out on 100 mm × 100 mm × 400 mm prisms according to the Chinese Electric power Trade Standard DL/T 5150-2001 [16]. Abrasion loss was tested using concrete specimen of size 150 mm × 150 mm × 30 mm in accordance with the Chinese Communication Trade Standard JTG E30-2005 [17].

The sulfate resistance was tested in accordance with GB2420-81 [18]. Mortar prisms of size 40 mm × 40 mm × 160 mm were prepared using 52.5 grade ordinary Portland cement with the w/c ratio of 0.5 and the sand/cement (s/c) ratio of 3.0. The specimens were air cured for 24 h and then they were water-cured for 27 days at temperature 20 ± 2 °C. After the 28-day initial curing the specimens were immersed in a 5% Na_2SO_4 solution at 20 ± 2 °C, and the solution was periodically exchanged by the new one. The changes in flexural and compressive strengths of specimens were recorded at regular intervals up to 1 year.

3. Results and discussion

3.1. Workability and compressive strength

The test results for workability of MS concretes are shown in Table 4. It can be observed that with the increment of limestone fines content in MS, the slump for series L is increased and the cohesiveness and segregation of fresh concretes are improved, and the slump for series H is little influenced, but the slump flow value falls down gradually. It is suggested that when the fines content is, respectively, 10% to15% for series L and 7% to 10% for series H, the mixes achieved better workability.

The 7- and 28-day compressive strength data for various mixtures are illustrated in Fig. 2. The increment of limestone fines improved the compressive strength for both series L and H concretes. For series L, there was a slight increase of strength when the limestone fines were added. It could be found that up to 20% limestone fines do not affect strength performance of the MS concrete. For series H strength was improved with the increment of limestone fines content. The most promising results were achieved with con-

Table 4
Concrete mixture proportions (kg/m^3).

Mixture	L-0	L-3	L-5	L-7	L-10	L-15	L-20	H-0	H-3	H-5	H-7	H-10	H-15
Cement	327.5	327.5	327.5	327.5	327.5	327.5	327.5	530	530	530	530	530	530
Water	180	180	180	180	180	180	180	170	170	170	170	170	170
Manufactured sand (>75μm)	816	791.5	775.2	758.9	734.4	693.6	652.8	756	733.3	718.2	703.36	680.4	642.6
Fines as fine aggregate	0	24.5	40.8	57.1	81.6	132.2	163.2	0	22.7	37.8	52.9	75.6	113.4
Coarse aggregate	1127	1127	1127	1127	1127	1127	1127	1044	1044	1044	1044	1044	1044
Superplasticizer	1.64	1.64	1.64	1.64	1.64	1.64	1.64	6.36	6.36	6.36	6.36	6.36	6.36
w/c Ratio	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.32	0.32	0.32	0.32	0.32	0.32
Rate of fines (%)	0	3	5	7	10	15	20	0	3	5	7	10	15
Slump (mm)	120	140	150	175	180	190	160	210	220	220	210	210	205
Slump flow (mm)								520	540	550	510	480	400

Note: Rate of fines expressed as percent of fine aggregate weight.