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Drying shrinkage cracking of concrete using dune sand and crushed sand

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HIGHLIGHTS

- The drying shrinkage cracking of concrete using dune sand and crushed sand was studied.
- The mixture of dune sand to fine aggregate ratio of 20% had the highest strength.
- The net time-to-cracking decreased as dune sand to fine aggregate ratio increased.
- Aggregate volume fraction with aggregate type could affect the drying shrinkage cracking.
- The range of the restraint factor of dune sand and crushed sand could be calculated.

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ABSTRACT

In this study, experimental results are presented to evaluate the properties of drying shrinkage cracking of concrete using dune sand (DS) and crushed sand (CS) as fine aggregate (FA). Concrete mixtures were made to meet the target workability with the variation of DS to FA ratio (DS/FA ratio) and water content.

The results showed that the highest compressive strength and the highest tensile strength were shown in concrete mixtures of DS/FA ratio 20% and the strength decreased with the increase of DS/FA ratio when DS/FA ratio was over 20%. The lower water content led to higher net time-to-cracking. Also, the increase of DS led to decrease of CS and the increase of coarse aggregate (CA) in the mixture and this change led to decrease of the net time-to-cracking. It indicates that aggregate volume fraction could affect the drying shrinkage cracking under same total aggregate volume. Based on the changes of aggregate volume and the net time-to-cracking in this study, the restraint factor of CS could be calculated to minimum 54% of the restraint factor of CA and the restraint factor of DS could be less than that of CS.

1. Introduction

In the Middle East and North Africa, dune sand (DS) is partially or wholly used as fine aggregate (FA) of concrete due to the scarcity of natural aggregate having satisfactory quality. The main purpose of the use of DS is the grading correction of crushed sand (CS) because CS has mostly coarser particles in the fine aggregate size range. Although the particle size of DS is different depending on the region, it is very fine, mostly in the range of 0.15–0.6 mm, and its grading helps to correct poor grading of CS [1]. Also, the shape of DS particles is spherical and it can be beneficial to workability of concrete. But very fine particle size and large surface area of DS can make concrete cohesive and can lead to requirement of more water to meet suitable workability. Therefore, the important point for the use of DS is how much the replacement of DS can extract the optimum properties of concrete.

Several researches have been carried out to study the properties of DS concrete and optimum DS to FA ratio (DS/FA ratio) have been suggested [2–7]. The studies reported that use of DS improved the workability of the mix up to a certain limit and the limit was various with the characteristics of DS. However, there were different results in the mechanical properties of DS concrete; strength decreases with the increase of DS replacement [2,3] or maximum strength is achieved at a certain use of DS [4,5].

The suitability of the use of DS has been investigated focusing mainly on workability and strength as mentioned above. However, the region using DS as concrete fine aggregate generally has desert climate. This climate is characterized by strong sunlight, high temperatures and dry air. These features of environment are the worst conditions in the drying shrinkage cracking of concrete. Therefore, the investigation of drying shrinkage is needed for DS concrete as well as the investigation for workability and strength. In this study, the drying shrinkage cracking of concrete using DS and CS was

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investigated. For this, concrete mixtures that can meet the target workability with variation of DS/FA ratio and water content were presented and their experimental results of drying shrinkage cracking were discussed.

2. Experimental plan and methods

2.1. Experimental plan

Table 1 shows the experimental plan of this study. In concrete mix conditions, W/C ratio was 0.4 and target slump was 180 ± 25 mm. Two different water contents of 170 kg/m^3 and 160 kg/m^3 were set. As fine aggregate, DS and CS were mixed together with four DS/FA ratios; 10, 20, 40 and 60%. In order to evaluate mechanical properties of concrete, compressive strength and tensile strength were tested. Also, restrained drying shrinkage cracking was evaluated.

2.2. Materials and mixture proportions

Table 2 shows the details of the materials. Ordinary Portland cement (OPC) was used as a binder. In aggregates, crushed aggregate with maximum size of 20 mm was used as coarse aggregate and binary sand of CS and DS was used as fine aggregate. The appearances of CS and DS are presented in Figs. 1 and 2. In particular, DS had rounded particle shape as shown in Fig. 3.

Fig. 4 presents the particle size distribution of binary sand. Standard range of particle size distribution of fine aggregate is generally presented in KS F 2526 [8] (ASTM C 33 [9]). However, CS and DS did not meet the standard range of particle size distribution. Also, even if DS/FA ratio was changed 10–60%, the particle size distribution of binary sand did not meet the standard range. The fineness modulus of CS and DS were 3.6 and 0.7, respectively, and did not meet the limit value of 2.3–3.1 of KS 2526 (ASTM C 33). However, the fineness modulus of binary sands with DS/FA ratio of 20% and 40% were 3.02 and 2.44, respectively, and they met the standard range of the fineness modulus.

DS mainly consists of quartz and calcite, and the chemical composition is shown in Table 3.

To select concrete mixtures, lab trial mixing tests were carried out. S/a ratio and admixture content were adjusted through trial mixing to meet target slump. At the beginning of this study, there was an attempt to find a concrete mixture using only CS without DS. However, although fine aggregate ratio and admixture content were highly adjusted, its slump did not meet the target slump. DS replacement of minimum 10% was needed to meet the target slump. For this reason, the concrete mixture without DS was excluded in this study.

Table 4 shows the selected concrete mixture proportions with variation of water content and DS/FA ratio.

2.3. Test methods

Compressive strength and split tensile strength were tested at ages of 3, 7, 14, 28 days according to KS F 2405 [10] (ASTM C 39 [11]) and KS F 2423 [12] (ASTM C 496 [13]).

Table 2
Physical properties of materials.

Material	Physical properties
Cement	▪ Ordinary Portland cement (OPC) ▪ Density: 3.15 g/cm^3 ▪ Fineness: 3440 cm^2/g
Coarse aggregate (CA)	▪ Crushed aggregate ▪ Max size: 20 mm ▪ Density: 2.70 g/cm^3 ▪ Absorption ratio: 0.77%
Crushed sand (CS)	▪ Max size: 5 mm ▪ Density: 2.61 g/cm^3 ▪ Fineness modulus: 3.6 ▪ Absorption ratio: 1.53%
Dune sand(DS)	▪ Density: 2.61 g/cm^3 ▪ Fineness modulus: 0.7 ▪ Absorption ratio: 1.19%
Admixture	▪ Naphthalene based ▪ Density: 1.23 g/cm^3 ▪ pH: 6.79

Fig. 1. Crushed sand (CS).

To evaluate the properties of drying shrinkage cracking, restrained drying shrinkage test was conducted according to ASTM C 1581 [14]. Fig. 5 shows the test apparatus.

It was mainly composed of outer ring, inner ring and base plate and they were all manufactured by steel. To minimize the friction, the top of base plate was covered with two layers of polyethylene (PE) film. The thickness of the inner ring is 13 mm and the outside diameter is 330 mm. The inside diameter of outer ring is 405 mm. The height of rings is 150 mm. To make test specimen, coarse aggregate of size of over 13 mm was removed from fresh concrete

Table 1
Experimental plan.

W/C	Slump (mm)	Cement type	Water content (kg/m^3)	DS/FA ratio[a] (%)	Tests
0.4	180 ± 25	OPC	170 160	10 20 40 60	• Compressive strength • Tensile strength • Restrained drying shrinkage cracking

[a] Volumetric replacement ratio in fine aggregate.