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Rheological properties of concrete using dune sand

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HIGHLIGHTS

- The rheological properties of dune sand concrete were evaluated by concrete rheometer.
- The lowest plastic viscosity was observed in mixtures with DS/FA ratio of 20%.
- The lowest yield stress was observed in mixtures with DS/FA ratio of 20% or 40%.
- The detailed DS/FA ratios which could lead to the lowest plastic viscosity and the lowest yield stress were calculated.
- The effect factor of aggregate on plastic viscosity could be analyzed.

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ABSTRACT

In this study, the rheological properties of dune sand (DS) concrete with various DS to fine aggregate (DS/FA) ratios and water contents were experimentally evaluated by using concrete rheometer recently developed. Also the effect of aggregate on the plastic viscosity of concrete was analyzed.

As a result, the lowest plastic viscosity was observed in mixtures with DS/FA ratio of 20% and increased as DS/FA ratio increased over 20%. The yield stress decreased as DS/FA ratio increased up to 20% or 40% and increased over those DS/FA ratios. The detailed DS/FA ratio which could lead to the lowest plastic viscosity and the lowest yield stress was calculated by regression. The DS/FA ratios for the lowest plastic viscosity were 33% in W170 mixtures and 28% in W160 mixtures. Also, the DS/FA ratios for the lowest yield stress were 32% in W170 mixtures and 37% in W160 mixtures, respectively. The effect factor of crushed sand (CS) on the plastic viscosity could be calculated the range of 49–57% in comparison with the effect factor of DS, and the range of the effect factor of coarse aggregate (CA) was 2–56%.

1. Introduction

Both dune sand (DS) and crushed sand (CS) are used as fine aggregate (FA) of concrete in some areas in the Middle East and North Africa. CS produced in these areas has typical characteristics of manufactured sand; angular shape, rough texture and poor grading. Especially, it has very poor grading due to coarser particle size. These characteristics of CS are disadvantageous for making concrete workable. However, the particle size of DS is very fine. Also, it has well-rounded shape and smooth surface [1,2]. These physical properties of DS can compensate the defects of CS and can improve the workability of concrete.

Several studies have been conducted to evaluate properties of mortar or concrete made with DS and to find out the optimum usage of DS [2–11]. These studies reported that the use of DS improved the workability of concrete and the optimum usage of DS was varying with the physical properties of DS. In evaluation of the workability, most studies have been carried out using conventional tests such as slump test or slump flow test.

Rheology is the study of deformation and flow of matter and is the appropriate tool to quantitatively describe the workability and mobility of fresh cement-based materials like cement paste, mortar or concrete [12–14]. Fresh concrete is most often assumed to behave like a Bingham fluid and the fluid is defined by two parameters; yield stress and plastic viscosity [15,16]. To determine the two parameters, rheometers or viscometers allowing measurements of shear stress and shear rate of fresh concrete have been developed.

The developments of rheological analysis method and measurement device have helped more quantitatively understand the workability properties of cementitious materials. Especially, the rheological analysis method is very useful to comprehend the workability or fluidity of high performance concrete, self-consolidating concrete (SCC) and engineered cementitious composite (ECC) [17,18]. The rheological parameters are also used to

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evaluate and to predict the properties of concrete pumping that is extensively used worldwide for construction [19].

Concrete rheology is affected by all of the components of concrete. Among the components of concrete, the aggregate having the largest volume significantly affects the concrete rheology. It is predicted that the yield stress and plastic viscosity of concrete will increases when very find sand having large amount of the surface area is used in making concrete. However, previous studies documented that the use of DS was beneficial for the workability up to a certain limit. For more quantitative and detailed evaluation of the optimum usage of DS and the effect of DS on concrete workability, the results from the conventional test are not sufficient and the rheological analysis of concrete as well as mortar is necessary.

In this study, the rheological properties of DS concrete with various DS to FA ratios (DS/FA ratios) and water contents were experimentally evaluated. To determine yield stress and plastic viscosity of concrete, a rheometer that has recently been developed was used. Also, fresh properties of concrete such as slump, air content and unit weight were tested. Finally, the effect of aggregate on rheological properties of concrete was analyzed.

2. Experimental plan and methods

2.1. Experimental plan

The experimental plan of this study is shown in Table 1. W/C ratio was set at the lowest value of 0.4 considering the durability requirements for sea water environment according to ACI 318 recommendations [20]. The target slump was fixed at 180 ± 25 mm considering the slump value used in many projects in the Middle East and North Africa. Three water contents and four DS/FA ratios were considered; water contents of 170 kg/m^3, 160 kg/m^3 and 150 kg/m^3, and DS/FA ratios of 10%, 20%, 40% and 60%. In order to evaluate fresh properties of concrete, slump, air content and unit weight were tested. Also, yield stress and plastic viscosity were evaluated.

2.2. Materials and mixture proportions

The details of the materials are shown in Table 2. For coarse aggregate (CA), crushed aggregate with maximum size of 20 mm was used. For fine aggregate, CS with fineness modulus of 3.6 and DS with fineness modulus of 0.7 were used. Figs. 1 and 2 present the appearances of CS and DS.

Fig. 3 shows the particle size distribution of binary sand. CS and DS did not meet the standard range of particle size distribution presented in KS F 2526 [21] (ASTM C 33 [22]). 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. These values did not meet the standard range of 2.3 ~ 3.1 suggested in KS 2526 (ASTM C 33). However, binary sands with DS/FA ratio of 20% and 40% showed the fineness modulus of 3.02 and 2.44, respectively, which met the fineness modulus limit.

Table 2
Properties of materials.

Material	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 (AD)	■ Naphthalene based ■ Density: 1.23 g/cm^3 ■ pH: 6.79

Fig. 1. Crushed sand (CS).

Concrete mixtures were selected by conducting lab trial mixing tests. To meet the target slump of 180 ± 25 mm, admixture (AD) content and sand to aggregate (S/a) ratio for every mixture were adjusted. Concrete mixtures using only CS did not meet the target slump, although AD content and S/a ratio were highly used. In conditions of this study, DS/FA ratio of minimum 10% was needed to meet the target slump. However, even in the condition of the DS/FA ratio of 10%, the mixture of the water content of 150 kg/m^3 did not meet the target slump. Therefore the mixtures using only CS and W150-DS10 mixture were excluded in this study. The selected concrete mixture proportions are presented in Table 3.

Table 1
Experimental plan.

W/C	Target slump (mm)	Cement type	Water content (kg/m^3)	DS/FA ratio[1] (%)	Tests
0.4	180 ± 25	OPC	170 160 150	10 20 40 60	• Slump • Unit weight • Air content • Plastic viscosity and yield stress

[1] Volumetric replacement ratio in fine aggregate.