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Effect of very fine particles on workability and strength of concrete made with dune sand

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HIGHLIGHTS

- Sand to cement ratio can affect properties of dune sand concrete (DSC).
- Dune sand grain with size smaller than 175 μm (VFP) can affect the hydration.
- VFP increases strength of DSC due to nucleation and pozzolanic effects.
- DSC and river sand concrete have comparable engineering properties.
- Australian dune sand can be used as fine aggregates for making concrete.

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ABSTRACT

This paper presents the study on the properties of concrete made with dune sand from Australian desert. With constant water–cement ratio of 0.5, dune sand concrete (DSC) and the corresponding reference samples (concrete made with river sand) were prepared with sand–cement (*S/C*) ratio ranging from 0.91 to 2.28. In comparison to river sand, dune sand possesses a higher amount of very fine particles (VFPs) with grain size smaller than 175 μm. These VFPs are found to modify the properties of concrete by different mechanisms depending on the level of *S/C* ratio. At low level of *S/C* ratio ($S/C < 1.41$), VFPs can fill the porosities between cement pastes and aggregates and has no negative effect on workability and, the highest slump (105 mm) for DSC was found at *S/C* ratio of 1.18. Moreover, at low level of *S/C* ratio, the strength of DSC is comparable or even higher than that of river sand concrete (RSC); the higher strength of DSC can be attributed to the heterogeneous nucleation and pozzolanic effect brought by VFPs which enhances cement hydration. At high level of *S/C* ratio ($S/C > 1.41$), excessive VFPs absorb large quantities of water on their surface and lead to the reduction in workability for DSC. As a result, more air bubbles are introduced during compaction, leading to higher air content in DSC compared to RSC. The air bubbles increase porous space in cement paste and thereby reducing the strength of DSC.

1. Introduction

Concrete manufacturing requires a large amount fine aggregate which is generally natural sand exploited from river channel and floodplain [1]. However, with the ever-increasing demand of aggregates due to the booming infrastructure development, river mining has led to serious environmental impacts, including dust arising, riverbank erosion, shifting of river course, suspended-solids contamination and flooding, etc. [2]. Besides, the mining activities can also lead to the loss of coastal ecosystem, damage to infrastructure (e.g. roads and bridges) and potential destruction of tourism archaeological site, etc. [3]. Under the circumstances, the use of alternative materials for replacing river sand becomes vitally important for making concrete in an environmentally friendly manner. As one possible solution, the dune sand from desert regions is abundant in some parts of the world, especially some Africa and Middle East countries. In those regions, there are also problems associated with increasing shortage of coarse sands traditionally used in concrete. Therefore, if dune sand can be utilised, this situation will be somewhat ameliorated.

Due to the environmental benefits, the topic on cementitious materials made with dune sand has aroused increasing interest. During the past decade, a number of researches have been conducted to study the characteristics of dune sand as well as the properties of cementitious materials incorporating it. Al Harthy et al. [4] have investigated the properties of concrete made with Sharkiya (Oman) dune sand which was partially introduced (10–100%) as fine aggregate. It was found that the optimum replacement ratio was around 50%, at which the concrete has its

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best workability whilst the reduction in compressive strength was less than 25%. Zhang et al. [5] have investigated the complete use of dune sand as fine aggregate for making concrete. They have studied the performance of mortar and concrete made with Tenggeli (China) dune sand and attempted to improve the workability of dune sand concrete (DSC) by using superplasticizers. It was found that the superplasticizer could improve not only compressive strength but also workability of DSC. A recent research by Jin et al. [6] has explored the feasibility of using dune sand from Maowusu sandy land (China) in high-strength concrete and a compressive strength in excess of 65 MPa was reported. The above authors concluded that the dune sand can be used in making concrete for structural application. Besides, dune sand concrete also provides competent performance to other end-use applications. Wang et al. [7] and Qin et al. [8] have investigated the mechanical properties of concrete-filled tube made with dune sand (in China); results showed that the dune sand concrete-filled tube had higher flexural strength than that made with river sand. Khay et al. [9] have examined the feasibility of using dune sand concrete for pavement application. The sand was from Tunisian Sahara (Tunisia). It was found that the mixing of 60% dune sand and 40% crushed sand as fine aggregate produced competent concrete for pavement application.

As discussed above, various properties of concrete made with dune sand from different desert regions have been investigated in previous studies and it was concluded that dune sand may provide a readily available alternative material for use as fine aggregate in concrete. However, the results from previous studies show a possible degradation in compressive strength when dune sand is completely used as fine aggregate in concrete [4,6]. This is generally attributed to the poor gradation of dune sand, which makes it different from normally-used sand for making concrete. In general, dune sand consists of a considerable amount of very fine particles (VFP). Typically 25% by weight of grains in dune sand are smaller than 150 μm; in contrast, this fraction is generally less than 6% as specified in ASTM C33 for fine aggregate used in concrete.

It is interesting to note that VFP is also a major component in mineral admixtures such as silica fume and fly ash. These pozzolanic mineral admixtures have been used as a partial substitution for Portland cement for many years. The effects of these admixtures on properties of concrete have been extensively studied [10,11]. In general, these admixtures present binding activity because they can enhance cement hydration. Two major effects are observed on enhancement of cement hydration when these mineral admixtures are used in cementitious materials [12–15].

The first effect is heterogeneous nucleation which is a physical process leading to a chemical activation of the hydration of cement. It is related to the nucleation of hydrates on foreign mineral particles, which catalyses the nucleation process by reducing the energy barrier. Qualitatively, if the surface of the solid substrate matches well with the crystal, the interfacial energy between the two solids is smaller than the interfacial energy between the crystal and the solution, and nucleation may take place at a lower saturation ratio on a solid substrate surface than in pore solution without mineral admixture. The mineral powder used does not have to be reactive itself since its principal function is to provide nucleation sites for hydrates. This effect becomes significant for VFP as the decrease in particle size favours nucleation.

The second effect is pozzolanic effect which is a chemical process leading to the increase in compressive strength. The mineral admixtures having pozzolanic activity will, in finely divided form and in the presence of water, react chemically with calcium hydroxide at ordinary temperature to form additional calcium silicate hydrates. These reaction productions fill in pores and result in a refining of the pore structure leading to improved strength and durability. This effect is principally dependent on the fineness of materials and the amount of soluble amorphous silica in materials.

A recent study [16] on cement paste containing dune sand powder has identified the occurrence of pozzolanic reaction. This is further confirmed by Alhozaimy et al. [17] that autoclaved curing can promote the pozzolanic reactivity of dune sand and therefore greatly increases the concrete strength. Therefore, when used to make concrete, dune sand should not be merely considered as inert fillers as normal fine aggregate but rather as an active component due to its pozzolanic reactivity and the heterogeneous nucleation effect. In this respect, the amount of VFP plays an important role in optimising the properties of concrete made with dune sand, which has received little attention.

Therefore, the aim of this paper is to investigate the engineering properties of DSC with various VFP content. The investigated properties include air content, workability, compressive strength, tensile strength and elastic modulus. Also, it is worth mentioning that the dune sand used in this study is red dune sand from central Australia for the following reasons: (1) dune sand from different regions can exhibit quite different properties and there is no previous research on the use of Australia dune sand in concrete and (2) desert fields cover 40% of mainland Australia and are widely spread around the central continent, which provides abundant and easily available dune sand. Moreover, construction sites in central Australia are far from aggregates production quarries, making it uneconomical for aggregate transporting. Therefore, the results obtained in the current research also provide a guideline for the use of dune sand in concrete whenever suitable sand materials are not economically available in these areas.

2. Experimental program

2.1. Materials

In this study, ASTM C150 Type I Ordinary Portland cement was used for all the concrete mixtures. The chemical compositions of cement were analysed by X-ray Fluorescence (XRF) as shown in Table 1.

Crushed basalt with size ranged from 2.36 to 12.5 mm was used as coarse aggregate. The measurement of bulk specific gravity (G_{sb}), surface-saturated-dry (SSD) bulk specific gravity ($G_{sb,SSD}$), apparent specific density (G_{sa}) and the water absorption on coarse aggregates were performed in accord-dance with ASTM C127-88 as shown in Table 2. The grain size distribution and other physical properties of coarse aggregate are shown in Fig. 1 and Table 2, respectively.

Two types of natural sands, namely desert sand (DS) and river sand (RS), were used as fine aggregates. The selected DS was referred to as red dune sand from central Australia as previously mentioned and the NS was commonly-used sand from local supplier for casting reference concrete. The measurement of bulk specific gravity, SSD bulk specified gravity, apparent specific density and the water absorption on fine aggregates were performed in accordance with ASTM C128-12 as shown in Table 2. Sieving analysis was performed in accordance with ASTM C136-06 and the grading curves, fineness modulus, coefficient of uniformity and average grain size were determined as shown Fig. 1 and Table 2 respectively. The surface area of fine aggregates was determined by B.E.T. Nitrogen Adsorption technique in accordance with ASTM D5604 and the results are presented in Table 2. The chemical compositions of dune sand and river sand were analysed by X-ray Fluorescence (XRF) as shown in Table 1.

Table 1
Chemical composition of cement and fine aggregates.

Constituent	Cement (%)	DS (%)	NS (%)
SiO_2	19.9	94.8	96.7
Al_2O_3	4.7	2.00	1.05
Fe_2O_3	3.4	0.66	0.56
K_2O	0.5	0.34	0.12
Na_2O	0.2	0.06	0.12
CaO	63.9	0.23	0.08
MgO	1.3	0.11	–
SO_3	2.6	–	–
Cl	–	–	–
Loss on ignition	3.0	0.83	0.29