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Behavior of concrete-filled steel tubular stub columns and beams using dune sand as part of fine aggregate

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HIGHLIGHTS

- We provide new test data for dune sand CFST stub columns and beams.
- We analyze strength and ductility indexes for dune sand CFST members.
- We check the feasibility of current codes for dune sand CFST members.

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ABSTRACT

The concrete using the dune sand as fine aggregate is usually regarded as having low workability and low ductility, although it has certain economic advantages. Using the dune sand concrete as the filling substance of tubular structures is possibly a way to use this kind of material, for the outer tube can provide confinement to its core concrete and thus enhance the ductility of the dune sand concrete. This paper is an attempt to investigate the behavior of concrete-filled steel tubular (CFST) stub columns and beams using dune sand as part of the fine aggregate. A series of CFST stub columns and CFST beams with 10% fine aggregate replacement ratio of dune sand are tested. For the stub column specimens, the main test parameters for stub column specimens are the steel ratio, the concrete strength and the cross-sectional type. For the beam specimens, the test parameter is the cross-sectional depth. The failure modes, load-deformation relation and the strain distribution of composite stub column and beam specimens are reported, and the strength and the ductility of test specimens are discussed using various indexes. The formulae for the compressive and flexural strength of normal CFST members are tentatively used to predict the strength of composite members using dune sand.

1. Introduction

River sand resources are excessively exploited against the background of the increasing demand of the fine aggregate in the concrete production. As one of the possible alternative options, the abundant dune sand from deserts may be used in the concrete mixtures instead of the river sand.

In China, the desertification area reaches nearly a quarter of the land area, and the dune sand has been used in constructions for approximately 100 years. In 1920, the dune sand concrete was used in building construction in China, and a specification of super fine sand concrete (BJG19-65) was published in 1965 [1]. According to the specification, the fineness modulus of super fine sand was defined as less than 1.5 or the average particle size was less than 0.25 mm. The average grain size ranged from 0.25 to 0.5 mm was defined as the fine sand, and it was classified as the coarse sand when the average particle size was larger than 0.5 mm. The diameter of dune sand ranges from 0.08 to 0.63 mm, and the fineness modulus is usually 0.45-0.88 [2,3]. The low fineness modulus and the poor gradation are the critical problems when using the dune sand for making concrete. The fresh concrete mixture using the dune sand as the fine aggregate has several special characteristics, such as high cohesiveness, small slump, poor fluidity and easy of segregation and low workability. In addition, the compressive strength of the dune sand concrete is usually low too [2,4].

Some research has been conducted on the workability and the mechanical behavior of cement pastes or mortars with dune sand powder [2–5]. Zhang et al. [5] carried out experimental research on the performance of mortar and concrete made of Tengri dune sand and Mu Us dune sand (both in China). Chemical composition and physical properties of dune sand were presented, after the

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Nomenclature

A_c	cross-sectional area of concrete
A_s	cross-sectional area of steel
A_{sc}	cross-sectional area of composite member, given by $A_s + A_c$
b	width of composite beams sections
B	width of square stub column sections
D	outside diameter of circular CFST sections
E_c	modulus of elasticity of concrete
f_c	characteristic cylinder strength of concrete
f_{ck}	characteristic compressive strength of concrete ($f_{ck} = 0.67\ f_{cu}$ for normal strength concrete)
f_{cu}	compressive strength concrete cube
f_y	yield strength of steel
f_{scy}	nominal yielding strength of composite sections
f_u	ultimate strength of steel
h	depth of composite beam sections
$K_{0.2}$	initial flexural stiffness
$K_{0.6}$	working stage flexural stiffness
L	axial length of stub columns or beams
M	bending moment
M_u	ultimate flexural strength
N	axial load
N_u	ultimate compressive strength
t	wall thickness of steel tubes
u_m	mid-span deflection of composite beams
W_{sc}	modulus of composite beam sections
α	steel ratio (=A_s/A_c)
Δ	axial shortening of stub columns
ξ	confinement factor of composite section $\left(= \alpha \cdot \frac{f_y}{f_{ck}}\right)$
ε	strain
ε_p	peak strain related to maximum axial load
ε_y	yield strain
ϕ	curvature at mid-span of beams
γ_m	flexural strength index

additives were added to the fresh concrete mixture, the maximum cube concrete strength at 28 days was 51.4 MPa with a slump of 45 mm. Al-Harthy et al. [3] presented the properties of concrete using different concrete mixtures, the workability ranged from 16 mm to 122 mm and the percentages of dune sand replacement was from 10% to 100%. Compared to the fully replacement, when the fine aggregate were partially replaced, the workability improved and the strength of concrete decreased with the increase in dune sand replacement. Alhozaimy et al. [6] reported the properties of the high strength concrete under normal and autoclaved curing using the white sand or the dune sand. Results showed that it was possible to use the dune sand or the white sand as 30% partial cement replacement under autoclaved curing. One of the benefits of using dune sand as the fine aggregate is that the construction cost will be reduced in some desert area. Although the workability and the strength of the dune sand concrete may not be as good as the normal concrete, the dune sand could still be an available alternative material as the fine aggregate in concrete mixture if proper curing methods are taken. Filling the concrete consisting of dune sand into steel tubes may be a possible way to use this kind of materials.

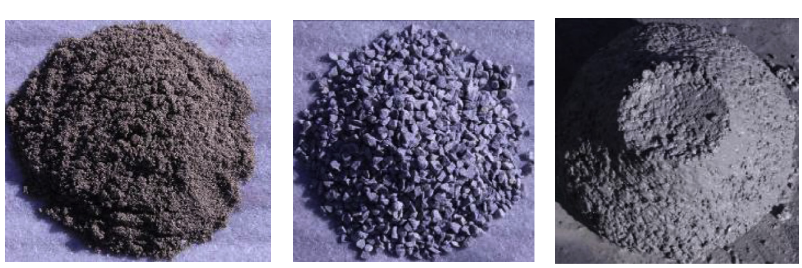
Concrete-filled steel tubular (CFST) structures have been widely used in high-rise buildings or bridges, and the blooming research on the mechanical behavior of CFST structures have been carried out in the past decades [7–11]. The mechanical behavior on the normal CFST members under axial compression and bending were sufficiently studied [12–15]. Recently, studies were also conducted on the CFST stub columns with special concrete infilling, such as the high performance plain concrete, the lightweight concrete and the recycled aggregate concrete [16–18]. Due to the confinement of the outer steel tube, CFST structures using the dune sand concrete (using dune sand as part of the fine aggregate) are expected to have favorable performance under static or dynamic loading.

To date, the mechanical performance of CFST members using the concrete consisting of dune sand as part of the fine aggregate (dune sand CFST) has not been studied yet. There's no test data found in literature for such kind of CFST members. Hence, the objectives of this research are as follows: (1) to study the compressive and flexural behavior of dune sand CFST members by tests. (2) to check the feasibility of current codes in the prediction of the stiffness and strength of dune sand CFST members. A 10% fine aggregate replacement ratio of the dune sand is used for the practical reason in this investigation, i.e. the mass of the dune sand is 10% of the total mass of fine aggregate, and the normal curing method can be applied in the experiments.

2. Experimental program

2.1. Specimen preparation

There are 26 stub column and beam specimens in total, including 10 dune sand CFST stub columns, 4 stub columns with hollow steel section, 6 dune sand reinforcement concrete (RC) stub columns and 6 dune sand CFST beams with rectangular cross section. The components of concrete mixture were shown in Fig. 1. The test parameters for composite column specimens were the confinement factor, the compressive strength of the concrete, and the cross-sectional type. Each specimen had a duplicated one with same parameters and loading conditions. The summary of the dune sand CFST columns is listed in Table 1, where the confinement factor $\xi = \frac{A_s f_y}{A_c f_{ck}} = \alpha \frac{f_y}{f_{ck}}$, A_s and A_c are areas of steel tubes and core concrete, respectively; α



(a) Dune sand fine aggregate (b) Coarse aggregate (c) Concrete mixture

Fig. 1. Components of concrete mixture.