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Flexural behavior of concrete-filled aluminum alloy circular hollow section tubes

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HIGHLIGHTS

- Flexural behavior of concrete-filled aluminum alloy CHS tubes was investigated.
- Large wall thickness enhanced the bearing capacity and ductility of beam.
- Concrete strength has insignificant influence on the flexural strength.
- Neutral axes generally move upward of the centroid towards the top flange of the specimens.
- Current design rules are inappropriate for concrete-filled aluminium alloy CHS tubes.

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ABSTRACT

This paper presents an experimental investigation on flexural behavior of concrete-filled aluminum alloy circular hollow section (CHS) tubes under pure in-plane bending. A total of 28 circular concrete-filled aluminum alloy tubes (CFAT) with nominal concrete cube strengths of 30 MPa and 50 MPa were tested. The flexural strengths, failure modes, flexural stiffness, ductility, bending moment versus mid-span deflection curves, overall vertical deflection curves, bending moment versus longitudinal strain curves and longitudinal strain distribution curves of circular CFAT beams are reported. It is demonstrated that the comparatively large wall thickness of aluminum alloy CHS tube enhanced the bearing capacity, the bending deformation capacity and the ductility of circular CFAT beams. Whereas, the concrete strength generally has insignificant influence on the flexural strength, flexural stiffness and ductility of circular CFAT beams. The current design specifications for the CFST are generally inappropriate for circular CFAT beams under pure in-plane bending with high scatter of predictions. Further research is still required to propose accurate design rules for circular CFAT beams.

1. Introduction

Concrete-filled steel tubes (CFST) on the other way resulted in the significant increase of the self-weight, which may greatly amplify the seismic action on the composite structures. Therefore, concrete-filled aluminum alloy tube (CFAT) was developed by replacing the outer steel tube with the light-weight aluminum alloy tube. However, the Young's modulus of aluminum alloy is roughly one third of that of steel that may cause aluminum alloy members easily failed by buckling. The use of CFAT could solve this problem by filling the concrete or grout in the aluminum alloy tube, which greatly enhanced the stiffness and strength.

The concrete infill could delay or prevent the inward local buckling of bare aluminum tube (BAT) and provide superior fire resistance. Fire performance of CFAT is superior to that of CFST because thermal conductivity of aluminum alloy is low. The strength of CFAT is larger than that of CFST under in-plane bending per unit weight.

A considerable number of researches were conducted in the literature on the flexural behavior of CFST. The CFST beams were experimentally investigated by Furlong [1]. It was found that the flexural strength of CFST was increased by 49% in comparison with the bare counterpart. A series of tests were conducted by Han et al. [2] on CFST beams by using a drop hammer rig. It was shown from

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Nomenclature

A_s	cross-section area of steel tube
A_{sc}	cross-section area of CFST
D	outer diameter of aluminum alloy CHS tube
E_a	elastic modulus of aluminum alloy
E_c	elastic modulus of concrete
E_s	elastic modulus of steel
f_c'	concrete cylinder strength
f_{cu}	concrete cube strength
f_u	ultimate tensile stress of aluminum alloy
f_y	tensile yield stress of aluminum alloy
I_c	moment of inertia of concrete
I_s	moment of inertia of steel tube
K	flexural stiffness
K_{AIJ}	flexural stiffness calculated using AIJ standard
K_{AS}	flexural stiffness calculated using AISC specification
K_{BS}	flexural stiffness calculated using BS5400
K_{EC}	flexural stiffness calculated using Eurocode 4
K_{ie}	initial flexural stiffness obtained from tests
K_{ie30}	initial flexural stiffness of CFAT with nominal concrete cube strength of 30 MPa
K_{ie50}	initial flexural stiffness of CFAT with nominal concrete cube strength of 50 MPa
K_{pye}	post-yield flexural stiffness obtained from tests
K_{pye30}	post-yield flexural stiffness of CFAT with nominal concrete cube strength of 30 MPa
K_{pye50}	post-yield flexural stiffness of CFAT with nominal concrete cube strength of 50 MPa
L	overall length of circular CFAT beam
L_0	effective span of circular CFAT beam
M	bending moment
M_u	ultimate bending moment
M_{u30}	ultimate bending moment of CFAT with nominal concrete cube strength of 30 MPa
M_{u50}	ultimate bending moment of CFAT with nominal concrete cube strength of 50 MPa
P	axial compression force
r_c	enhancement of flexural strength of CFAT from increase of concrete strength
r_{t30}	enhancement of flexural strength of CFAT with nominal concrete cube strength of 30 MPa from increase of thickness of aluminum alloy tube
r_{t50}	enhancement of flexural strength of CFAT with nominal concrete cube strength of 50 MPa from increase of thickness of aluminum alloy tube
t	wall thickness of aluminum alloy tube
u	ductility ($u = \delta_u/\delta_y$)
u_{30}	ductility of CFAT with nominal concrete cube strength of 30 MPa
u_{50}	ductility of CFAT with nominal concrete cube strength of 50 MPa
δ	vertical deflection
δ_m	mid-span vertical deflection
δ_u	mid-span vertical deflection at ultimate load
δ_y	mid-span vertical deflection at yield load
ε	longitudinal strain

the test results that the CFST specimens deformed in a ductile manner, which means the specimens have good resistance under impact loading. The flexural response of polymer CFST under uniform bending was studied by Oyawa et al. [3]. Immense potential of more durable polymer-based filled materials as complementary to cement concrete enhanced stiffness. Experimental study was also performed by Lu et al. [4] on concrete-filled non-uni-thickness walled rectangular steel tube subjected to pure bending. The ratio of different thickness within the range from 1.5 to 2.0 was recommended. Finite element analyses were performed by Queiroz et al. [5] on composite beams with full and partial shear connection. The evaluation of the ultimate behavior of CFST members subjected to bending moment was performed by Montuori and Piluso [6]. A fiber model was put forwarded to predict the ultimate response of CFST members.

Extensive researches were also performed on the flexural behavior of aluminum alloy tubes. Landolfo and Mazzolani [7] compared different approaches in the design of aluminum alloy slender sections. A closed-form solution was presented by Mirzaeifar et al. [8] for bending analysis of shape memory alloy. The tensile response of micropillars was also found by using the responses in compression and bending. An experimental investigation was also performed by Zhu and Young [9] on aluminum alloy circular hollow sections (CHSs) subjected to combined axial compression and bending. Furthermore, Mazzolani [10] and Galambos [11] summarized the previous researches on aluminum alloy beam-columns. Mechanical behavior of CFAT beams may be enhanced by filling the concrete in the aluminum alloy tubes since the specimens usually failed in a ductile way. However, little research has been reported on the flexural behavior of CFAT. Design guidelines should be prepared for flexural capacity and stiffness of CFAT to facilitate the use of this type of composite structures.

This paper mainly focuses on the flexural behavior, failure modes, flexural stiffness and development of plastic properties of concrete-filled aluminum alloy CHS tubes by conducting the experimental investigation on circular CFAT beams. Some design recommendations are provided for the proper design of circular CFAT beams.

2. Experimental program

2.1. Test specimens

A total of 28 specimens were tested under in-plane bending, which were fabricated by filling the concrete with nominal cube strengths of 30 MPa and 50 MPa in the specimen along its full length. All specimens were manufactured from the same batch of aluminum alloy CHS tubes supplied in un-cut length of 6000 mm. The CHS tubes consist of a large range of section sizes, which have nominal outer diameter (D) range from 61 to 140 mm, and nominal thickness (t) ranged from 3.3 to 8.4 mm. The overall length (L) of all specimens was taken to be a constant value of 1000 mm for comparison, with the effective span (L_0) between the end supports of 900 mm. The nominal cross-section dimensions of all specimens are summarized in Table 1, using the nomenclature defined in Fig. 1 for concrete-filled aluminum alloy CHS tube. The measured cross-section dimensions of all specimens are summarized in Table 2.

The material properties of aluminum alloy are summarized in Table 3 according to GB/T 228.1-2010 [12]. The material properties of concrete are summarized in Table 4 according to GB/T 50081-2002 [13].

2.2. Specimen labelling

The test specimens are labelled according to their cross-section geometry, cross-section dimensions and strength of concrete infill. For instance, the label ‘C140 × 5.8C30’ defines the following specimen: