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Flexural behaviour of concrete-filled aluminium alloy thin-walled SHS and RHS tubes

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ABSTRACT

This paper presents an experimental study on flexural behaviour of concrete-filled aluminium alloy thin-walled square and rectangular hollow section (SHS and RHS) tubes subjected to in-plane bending. A total of 30 specimens including 20 concrete-filled aluminium alloy tubes (CFAT) and 10 bare aluminium alloy tubes (BAT) were tested. The ultimate strengths, failure modes, flexural stiffness, ductility, bending moment-midspan deflection curves, overall deflection curves, bending moment-longitudinal strain curves and longitudinal strain distribution curves of test specimens are reported. It is demonstrated that the ultimate strength, flexural stiffness and ductility of the BAT specimens are significantly enhanced by filling the concrete in the specimen along its full length. Furthermore, the enhancement is increased with the increase of the concrete strength, but the increase of enhancement is insignificant. The measured flexural stiffness including both initial flexural stiffness and post-yield flexural stiffness were compared with the design flexural stiffness calculated using the current AIJ standard, BS 5400, Eurocode 4 and AISC specification. It is shown from the comparison that the current design rules for the bare steel tube (BST) and concrete-filled steel tube (CFST) are generally inappropriate for the flexural stiffness of the BAT and CFAT under pure in-plane bending with high scatter of predictions. Furthermore, the design equations were proposed for the ultimate strengths of CFAT under in-plane bending, which were verified to be applicable.

1. Introduction

Aluminium alloy tubular members are increasingly used in space structures, claddings, curtain walls and many other structural applications owing to their high strength-to-weight ratio, excellent corrosion resistance, ease of fabrication, transportation and assembly. However, the elastic modulus of aluminium alloy is roughly one third of that of carbon steel, which causes aluminium alloy members easily failed by buckling. Therefore, the concrete-filled aluminium alloy tube (CFAT) was introduced by filling the concrete or grout in the bare aluminium alloy tube (BAT). The concrete infill could delay or prevent the inward local buckling of BAT and provide superior fire resistance. This commonly used method of reinforcement is expected to significantly improve the structural performance of BAT as the concrete-filled steel tube (CFST) behaved.

Concrete-filled aluminium alloy tubular columns can effectively take advantages of these two materials to provide both high strength and high stiffness. There are many advantages in using aluminium alloy as a structural material, such as appearance, lightness, corrosion resistance and ease of production. Furthermore, the aluminium alloy tubes surrounding the concrete eliminate permanent formwork, and therefore the construction time can be reduced. Furthermore, in concrete-filled aluminium alloy tube, an aluminium alloy beam may be partly tensioned, while Young's modulus of aluminium alloy is more similar to that of concrete compared to steel. For this reason, the cooperation between aluminium alloy and concrete may be better than cooperation between steel and concrete. Aluminium alloy structural elements may be manufactured by rolling, extrusion, casting and drawing, which make it possible to obtain any shape. Corrosion resistance is one of the most important properties of aluminium alloy. For this reason, aluminium alloy may be used in structures located in corrosive or humid environments. Up to the authors' knowledge, however, little research has been carried out on the flexural behaviour of CFAT.

Extensive researches have been reported in the previous literatures on the flexural behaviour of CFST. The CFST beams were tested by Furlong [1] to investigate the flexural behaviour of

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Nomenclature

A_a	cross-section area of aluminium alloy tube
A_c	cross-section area of concrete
A_s	cross-section area of steel tube
A_{sc}	cross-section area of CFST
b	outer width of aluminium alloy tube
b_c	width of concrete
E_a	elastic modulus of aluminium alloy
E_c	elastic modulus of concrete
E_s	elastic modulus of steel
f_c'	concrete cylinder strength
f_{cc}'	confined concrete strength
f_{cu}	concrete cube strength
f_u	ultimate tensile stress of aluminium alloy
f_y	tensile yield stress of aluminium alloy
h	outer depth of aluminium alloy tube
h_c	height of concrete
I_c	moment of inertia of concrete infill
I_s	moment of inertia of steel tube
I_a	moment of inertia of aluminiun alloy thin-walled SHS and RHS tube
K	flexural stiffness
$K_{i\text{-}AIJ}$	initial flexural stiffness calculated using AIJ standard
$K_{i\text{-}AS}$	initial flexural stiffness calculated using AISC specification
$K_{i\text{-}BS}$	initial flexural stiffness calculated using BS 5400
$K_{i\text{-}EC}$	initial flexural stiffness calculated using Eurocode 4
K_{is}	initial flexural stiffness obtained from tests
K_{is0}	initial flexural stiffness of BAT
K_{is30}	initial flexural stiffness of CFAT with nominal concrete cube strength of 30 MPa
K_{is50}	initial flexural stiffness of CFAT with nominal concrete cube strength of 50 MPa
$K_{py\text{-}AIJ}$	post-yield flexural stiffness calculated using AIJ standard
$K_{py\text{-}AS}$	post-yield flexural stiffness calculated using AISC specification
$K_{py\text{-}BS}$	post-yield flexural stiffness calculated using BS 5400
$K_{py\text{-}EC}$	post-yield flexural stiffness calculated using Eurocode 4
K_{pys}	post-yield flexural stiffness obtained from tests
K_{pys0}	post-yield flexural stiffness of BAT
K_{pys30}	post-yield flexural stiffness of CFAT with nominal concrete cube strength of 30 MPa
K_{pys50}	post-yield flexural stiffness of CFAT with nominal concrete cube strength of 50 MPa
L	overall length of aluminium alloy tube
L_e	effective span of aluminium alloy tube
M	bending moment
M_u	ultimate bending moment of CFAT
M_{ua}	ultimate bending moment taken by aluminium alloy tube
M_{uc}	ultimate bending moment taken by concrete
M_{uc1}	ultimate bending moment of CFAT calculated using design Eq. (17)
M_{uc2}	ultimate bending moment of CFAT calculated using design Eq. (19)
M_{ut}	ultimate bending moment of CFAT obtained from tests
M_{u0}	ultimate bending moment of BAT
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
N_u	ultimate axial force of CFAT
N_{ua}	ultimate axial force taken by aluminium alloy tube
N_{uc}	ultimate axial force taken by concrete
P	axial compression force
SD	standard deviation
t	wall thickness of aluminium alloy tube
u	ductility (δ_u/δ_y)
u_0	ductility of BAT
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
x	height of rectangular stress distribution
x_c	height of compression zone
α	reduction factor
β	ratio of height of rectangular stress distribution to height of compression zone (x/x_c)
δ	vertical deflection
δ_m	midspan vertical deflection
δ_u	midspan vertical deflection at ultimate load
δ_y	midspan vertical deflection at yield load
ε	longitudinal strain
ε_{cc}'	ultimate compressive strain of concrete
ξ_a	confinement coefficient of aluminium alloy tube to core concrete ($f_yA_a/f_{ck}A_c$)
ξ_c	relative height of compression zone (x_c/h_c)
σ_{1s}	compressive stress of aluminium alloy SHS tube in longitudinal direction
σ_{2s}	tensile stress of aluminium alloy SHS tube in circumferential direction
σ_{3s}	stress of aluminium alloy SHS tube in radial direction

concrete-filled circular hollow sections (CHS). It was found that the ultimate strength of the CFST under in-plane bending is roughly 49% higher than its bare counterpart. A series of four flexural tests on rectangular and square cold-formed hollow structural steel sections and twelve on concrete-filled sections were undertaken to assess the general behaviour of these composite sections by Lu and Kennedy [2]. A series of four flexural tests on rectangular and square cold-formed hollow structural steel sections and twelve on concrete-filled sections were undertaken to assess the general behaviour of these composite sections. A post-local buckling model based on the effective width principle was established which can be used to determine the strength of a concrete filled box section by Uy [3]. The flexural response of polymer CFST beams under uniform bending was studied by Oyawa et al. [4]. The more durable polymer-based materials showed immense potential as the complementary materials of the concrete infill for the stiffness enhancement. Finite element analyses were performed by Queiroz et al. [5] on composite beams with full and partial shear connection subjected to either concentrated loads or uniformly distributed loads. It was found that the continuation of the shear connection beyond the supports of simply supported beams affected the overall structural response, the slip and the stud force distributions along the beams. An experimental investigation was conducted by Lu et al. [6] on concrete-filled non-uni-thickness walled rectangular steel tube under pure bending. The optimum thickness ratio of the cross section was recommended for the flexural behaviour of rectangular CFST beams. A series of tests were conducted by Han et al. [7] on the CFST beams under transverse impact loading. It was shown that the CFST beams under impact loading generated comparatively large plastic deformations and excellent flexural behaviour due to the strain rate effect of the materials and the influence of the inertia force. The flexural behaviour of the CFST