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

Ran Feng a, Yu Chen b,⇑, Wenzhi Gong c

a School of Civil and Environmental Engineering, Harbin Institute of Technology, Shenzhen 518055, China
b School of Urban Construction, Yangtze University, Jingzhou 434023, China
c College of Civil Engineering, Huaqiao University, Xiamen 361021, China

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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 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 tube 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
under uniform bending was studied by Oyawa et al.\cite{4}. The more box section by Uy\cite{3}. The flexural response of polymer CFST beams which can be used to determine the strength of a concrete filled ling model based on the effective width principle was established twelve on concrete-filled sections were undertaken to assess the and square cold-formed hollow structural steel sections and durable polymer-based materials showed immense potential as ptions and twelve on concrete-filled sections were undertaken to assess the ultimate strength of the CFST under in-plane bending is roughly concrete-filled circular hollow sections (CHS). It was found that the concrete cube strength of 50 MPa ultimate bending moment of CFAT with nominal concrete cube strength of 50 MPa

\[ M_{u} \] ultimate bending moment of CFAT

\[ M_{u} \text{a} \] 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

\[ N_{u0} \] ultimate axial force taken by aluminium alloy tube

\[ N_{uc} \] ultimate axial force taken by concrete

\[ P \] axial compression force

\[ SD \] standard deviation

\[ w \] wall thickness of aluminium alloy tube

\[ u \] ductility \((\Delta_u/\Delta_0)\)

\[ u_a \] ductility of BAT

\[ u_{50} \] ductility of CFAT with nominal concrete cube strength of 50 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

\[ \gamma \] reduction factor

\[ \beta \] ratio of height of rectangular stress distribution to height of compression zone \((x/x_c)\)

\[ \delta \] vertical deflection

\[ \delta_{V} \] midspan vertical deflection

\[ \delta_{u} \] midspan vertical deflection at ultimate load

\[ \delta_{yy} \] midspan vertical deflection at yield load

\[ \varepsilon \] longitudinal strain

\[ \varepsilon_{c} \] ultimate compressive strain of concrete

\[ \varepsilon_{a} \] confinement coefficient of aluminium alloy tube to core concrete \((f_{c,As}/f_{c,Ac})\)

\[ \varepsilon_{x} \] relative height of compression zone \((x_c/h_c)\)

\[ \sigma_{15} \] compressive stress of aluminium alloy SHS tube in longitudinal direction

\[ \sigma_{25} \] tensile stress of aluminium alloy SHS tube in circumferential direction

\[ \sigma_{35} \] 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\cite{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 Uly\cite{3}. The flexural response of polymer CFST beams under uniform bending was studied by Oyawa et al.\cite{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.\cite{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.\cite{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.\cite{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