Engineering Structures 95 (2015) 127–137

Contents lists available at ScienceDirect

Engineering Structures

journal homepage: www.elsevier.com/locate/engstruct

Buckling behaviors of section aluminum alloy columns under axial compression

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ARTICLE INFO

Article history:
Received 30 January 2015
Revised 27 March 2015
Accepted 28 March 2015
Available online 10 April 2015

Keywords:
Aluminum alloy column
Irregular shaped cross section
Buckling behavior
Thin-walled structures
Direct strength method

ABSTRACT

Thin-walled columns with section are used widely as columns in aluminum alloy framed structures, offering high strength-to-weight ratios and convenience in connection with maintaining walls. In this paper, thin-walled aluminum alloy columns with section were studied experimentally and numerically to investigate the buckling behavior and to assess the accuracy of current design methods. A finite element model (FEM) was developed and used to perform parametric studies after being verified by tests. Effects of plate thickness on elastic buckling stress was studied using finite strip method (FSM) and to find the potential buckling failure mode at a given length. Tested ultimate strengths were compared with those predicted by the current American, European and Chinese specifications on aluminum alloy structures and the Direct Strength Method (DSM) on thin-walled structures. Following reliability analysis, the design strength predicted by current design specifications were found to be generally conservative, whereas DSM offered more accurate results.

1. Introduction

For its high strength-to-weight ratio, better corrosion resistance and flexural manufacture procedure through extrusion, aluminum alloy members are being widely used in structural applications [1]. Summers et al. [2] performed a series of uniaxial tension tests on AA5083–H116 and AA6061–T651 after simulated fire exposure and developed empirical laws for residual yield strength. Fogle et al. [3] quantified the response and failure of 5083-H116 and 6082-T6 aluminum plates under compression load while being subjected to a fire. Rasmussen and Rondal [4] proposed a column curve to predict the strengths of the extruded aluminum alloy column failed at flexural buckling. Based on the FEM parametric studies on buckling behaviors of fire exposed aluminum alloy columns, Maljaars et al. [5] found that EN 1999-1-2 [6] did not give an accurate prediction for flexural buckling strength of fire exposed aluminum columns. A new design method was proposed for the fire resistance design of aluminum alloy columns design considering the stress–strain relationship of aluminum alloys at elevated temperatures. Manganiello et al. [7] evaluated the inelastic flexural behavior of aluminum alloy structures through numerical method and proposed a method for the ultimate strength of the rotational capacity of a cross-section in bending. Maljaars et al. [8] studied local buckling of compressed aluminum alloy at elevated temperatures through tests. Adeoti et al. [9] presented a column curve for extruded members made of 6082-T6 aluminum alloy. Yuan et al. [10] investigated the local buckling and postbuckling strengths of aluminum alloy I-section stub columns under axial compression. Their research results showed that current design codes were conservative to predict ultimate strength of aluminum alloy columns. Su et al. [11,12] carried out a series of stub-column tests on box sections and two series of experiments on aluminum alloy hollow section beams. The deformation based continuous method gave more accurate prediction for the ultimate strength. Wang et al. [13] carried out tests on the columns of 6082-T6 circular tubes. Zhu and Young [14] presented tests results of aluminum alloy circular hollow section columns with and without transverse welds and assessed the accuracy of the design rules in the current specifications. These researches greatly advanced the mechanism of buckling behaviors of extruded aluminum alloy columns.

Many countries have already published design codes for aluminum alloy structural members, such as EN1999-1-2 (EC9) [6], American Aluminum Design Manual (AA) [15], Australian/New Zealand Standard [16], and Chinese Design Specifications for Aluminum Structures (GB50429) [17]. To make full use of structural material, the cross-section of an aluminum alloy member is usually made up of thin-walled plates. These design codes follow the element approach to calculate the buckling strength of each thin-walled element considering effects of local bucking. In design of thin-walled steel structures, the effective section is usually determined through the effective width method [18]. While the

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http://dx.doi.org/10.1016/j.engstruct.2015.03.064
0141-0296/

aluminum alloy members usually have complex shape cross sections, the effective width method appears tedious because it needs iterations for the effective width dependent on stress distribution across the section. At this kind of circumstance, the effective thickness method [19] is more feasible.

Schafer and Peköz [20] developed DSM for predicting the ultimate strength of thin-walled steel structural members. The DSM had been adopted by AISI [21,22] now. The design equations of DSM was proposed by curve fitting the test data and FEA results on open section thin-walled structural members such as channel, lipped channel with web stiffeners, Z-section, hat section and rack upright section. Unlike the traditional design method uses the effective section, DSM uses whole section to calculate the ultimate strength, which provides rational analysis procedure for irregular shaped section and allows section optimization. Zhu and Young [23,24] found that the modified DSM could be used in the design of square hollow section (SHS) and rectangular hollow section (RHS) aluminum alloy columns. Aluminum alloy extruded members usually have complex sections to include as many functions as possible. However, the applicability of DSM in aluminum alloy member with irregular shaped section has not been investigated yet.

This paper presented experimental and numerical investigation on the buckling behaviors of aluminum alloy columns with shape cross-section under axial compression. The structural component with the studied cross section is usually used as columns in an aluminum alloy framed structure, as shown in Fig. 1(a). The Fiber Reinforced Plastic (FRP) wall can be easily fixed in the channel of the section, as shown in Fig. 1(b).The FSM software CUFSM [25] was used to illustrate effects of plate thickness on the buckling strength and the potential buckling mode at a given length. The FEA software ABAQUS [26] was used to obtain the ultimate strength of the member considering effects of initial geometric imperfection and the elastic–plastic properties of aluminum alloy. Current design codes were assessed through the comparison of FEA results with predictions by AA [15], EC9 [6], GB50429 [17] and DSM [21,22], as well as AISI by substituting the material properties of steel with those of aluminum alloy.

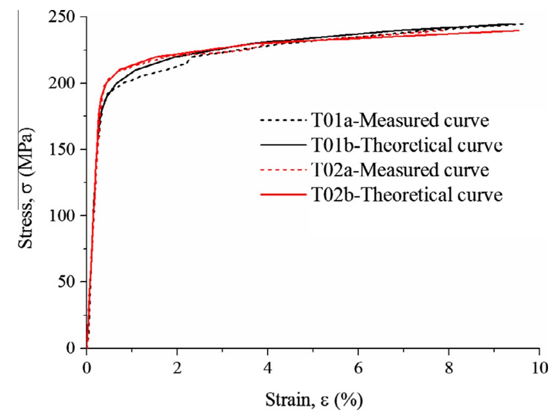

Fig. 2. Stress–strain relationships.

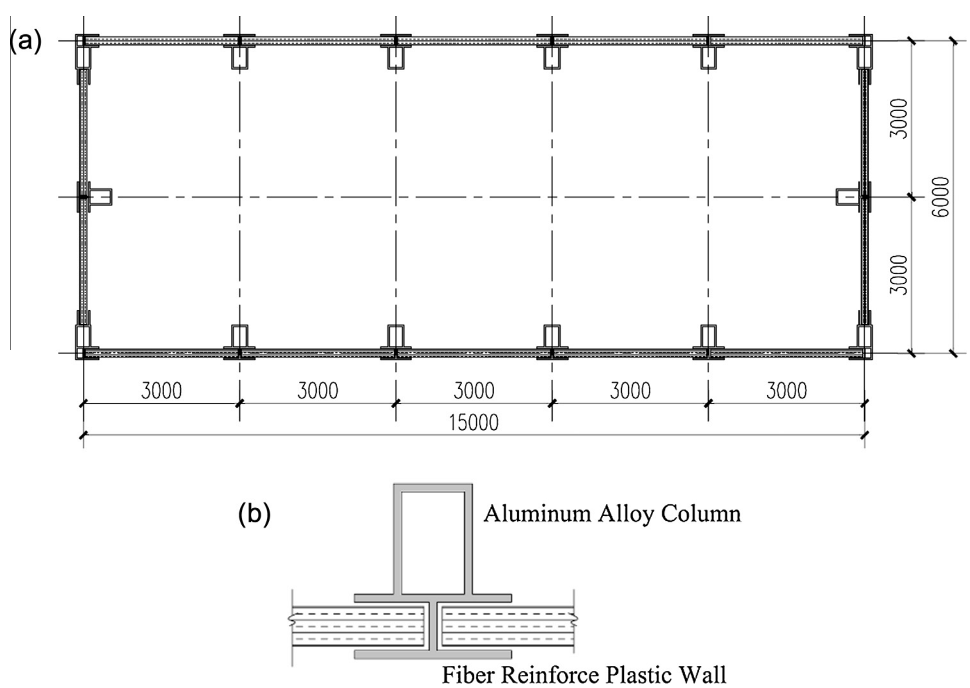

Fig. 1. Application of aluminum alloy column with section. (a) Layout of the aluminum alloy columns. (b) Connection of the aluminum alloy column with FRP.

Table 1
Material properties.

Specimens	Area A (mm^2)	Length L (mm)	Elastic modulus E (GPa)	0.1% proof stress $f_{0.1}$ (MPa)	0.2% proof stress $f_{0.2}$ (MPa)	Ultimate strength f_u (MPa)	Ultimate strain ε_u (%)	Parameter n
T01a	113.46	399.6	67.07	187.2	193.1	233.2	9.7	22.0
T01b	110.25	400.8	70.06	200.5	207.6	235.4	7.9	19.9
Mean value	111.86	400.2	68.57	193.9	200.4	234.3	8.8	20.9