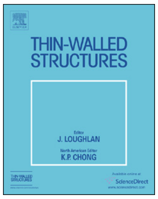
Thin-Walled Structures 130 (2018) 194–212

Contents lists available at ScienceDirect

Thin-Walled Structures

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



Full length article

Tests of perforated aluminium alloy SHSs and RHSs under axial compression

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ARTICLE INFO

Keywords:
Aluminium alloy
Circular opening
Flexural buckling
Heat-affected zone (HAZ)
Local buckling
Rectangular hollow section (RHS)
Square hollow section (SHS)

ABSTRACT

This paper presents an experimental investigation on a wide range of aluminium alloy stub, intermediate and slender columns containing multiple circular openings. Three series of compression tests including six different cross-section dimensions of columns with different lengths were conducted by applying uniform axial load to the pin-ended specimens, which were fabricated by extrusion of square and rectangular hollow sections (SHS and RHS) using 6061-T6 and 6063-T5 heat-treated aluminium alloys. In test series I, the specimens were fabricated by welding aluminium alloy plates at both ends of the columns for pin-ended compression tests. In test series II, the specimens were further reinforced by carbon fiber-reinforced polymer (CFRP) at the heat-affected zone resulted from the welding. In test series III, the special aluminium alloy sleeves were designed instead of welding at both ends of the columns to preclude the form of the heat-affected zone. The column strengths, failure modes, load versus axial shortening curves, and strain distributions along the circular openings of test specimens were all obtained from the experimental investigation. In addition, the test strengths of aluminium alloy SHS and RHS columns with or without openings were compared with the design strengths calculated using the design rules given in the current design guidelines. It is shown from the comparison that the first design method proposed by Zhu and Young for aluminium alloy SHS and RHS welded columns is comparatively appropriate for the design of aluminium alloy SHSs and RHSs under axial compression. Whereas, the current design rules for cold-formed steel structural members with openings may be inapplicable to the design of perforated aluminium alloy SHSs and RHSs under axial compression.

1. Introduction

Aluminium alloy members are increasingly used for structural applications, especially in space structures, bridges and curtain walls owing to their attractive appearance, high strength-to-weight ratio and excellent corrosion resistance. Furthermore, aluminium alloy members are ease of extrusion, transportation and assembly. Nowadays, structural members are often perforated to facilitate the building services and inspection. These pre-punched openings could result in the redistribution of membrane forces in the members that may change the elastic stiffness and ultimate strengths of structural members. The behaviour of perforated structural members is significantly influenced by the shape, size, location and number of openings.

A large number of investigations have been conducted on the behaviour and design of aluminium alloy columns. In 1999, Hopperstad et al. [1] studied the overall stability of 6082-T4 and 6082-T6 aluminium alloy axial compression members with ten different cross sections by using the experimental investigation. The test results were compared with the design strengths. In 2000, an extensive experimental investigation was conducted by Faella et al. [2] on 6060, 6061 and 6082 aluminium alloy columns with square and rectangular hollow sections (SHS and RHS) under uniform axial compression. A new classification criterion for aluminium alloy sections was established. In 2006, Zhu and Young [3–5] experimentally investigated five series of specimens on 6063-T5 and 6061-T6 aluminium alloy SHSs and RHSs that were compressed between fixed ends. The design formulae were proposed for aluminium alloy columns based on direct strength method by carrying out further numerical investigation and parametric study. In 2015, tests were conducted by Yuan et al. [6] on I-section stub column specimens under axial compression between two fixed end supports, which were made of 6061-T6 and 6063-T5 aluminium alloy materials. The corresponding local buckling and post-buckling strengths were studied. Liu et al. [7] carried out experiments on 6063-T5 aluminium alloy columns with four stiffened closed-section types under axial compression. Local

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https://doi.org/10.1016/j.tws.2018.03.017
Received 20 April 2017; Received in revised form 16 October 2017; Accepted 21 March 2018

Notation

A	Gross cross-section area
A_{eff}	Effective area
B	Outer width of square and rectangular hollow section
B_c, C_c, D_c	Buckling constant
COV	Coefficient of variation
D	Outer depth of square and rectangular hollow section
d	Diameter of circular opening
E	Young's modulus
F_c	Allowable compressive stress
f_{cyw}	Compressive yield stress across a butt weld
F_L	Limit state stress
F_n	Nominal buckling stress
f_L	Design strength in American Specification
f_y	Yield stress
k	Buckling factor
k_c	Coefficient for compression member
L	Overall length of aluminium alloy column
L_e	Effective length of aluminium alloy column
n	Number of hole
$P_{A/N-1}$	Design strength obtained from design formulae of AS/NZS 1664.1:1997
$P_{A/N-2}$	Design strength obtained from design formulae of AS/NZS 1664.2:1997
P_{AS}	Design strength obtained from design formulae of American Specification
P_{CC}	Design strength obtained from design formulae of GB 50429–2007
P_{cre}	Global buckling load
P_{crl}	Local buckling load
P_{DSM}	Design strength obtained from design formulae of Moen and Schafer
P_{EC}	Design strength obtained from design formulae of EN 1999–1-1:2007
P_{NAS}	Design strength obtained from design formulae of NAS
P_{ne}	Nominal axial strength for global buckling
P_{nl}	Nominal axial strength for local buckling
P_{ult}	Ultimate strength
P_y	Yield strength
P_{ynet}	Yield strength considering influence of holes
$P_{ZY\text{-}NW}$	Design strength obtained from design formulae of Zhu and Young for non-welded column
$P_{ZY\text{-}W1}$	Design strength obtained from the first design method of Zhu and Young for welded column
$P_{ZY\text{-}W2}$	Design strength obtained from the second design method of Zhu and Young for welded column
r	Radius of gyration of square and rectangular hollow section
s	Distance between center of adjacent openings
t	Thickness of square and rectangular hollow section
w	Flat width
γ_{M1}	Safety factor for ultimate limit state
δ	Overall geometric imperfection
ε_f	Elongation after fracture based on a gauge length of 50 mm
η_e	Correction factor
η_{haz}	Impact factor considering influence of welding
κ	Factor to allow for the weakening effect of welding
λ	Slenderness parameter
λ_c, λ_l	Slenderness factor
μ	Poisson's ratio
ρ_{haz}	Reduction factor of material strength at the heat-affected zone
σ_u	Static ultimate tensile stress
$\sigma_{0.2}$	Static 0.2% tensile proof stress
φ	Stability factor
χ	Reduction factor
ω_x	Factor of section with localized weld
ϕ	Resistance factor
ϕ_{cc}	Capacity factor

buckling failure occurred for all specimens. In 2016, the buckling behaviour of extruded columns with box-type and L-type sections made of 6068-T6 aluminium alloy was experimentally studied by Zhao et al. [8] under eccentric compression. The design formulae given in Chinese Code [9] were modified to accurately predict the ultimate strengths of 6082-T6 aluminium alloy columns.

On the other hand, perforated structural members have been widely studied on cold-formed steel compression members. Moen and Schafer [10,11] studied the relationship between elastic buckling and tested response of cold-formed steel columns with holes. Compression tests were conducted on stub and intermediate cold-formed steel columns with and without slotted web holes. Furthermore, design equations were derived that extended the direct strength method (DSM) given in North American Specification [12,13] to the design of cold-formed steel columns with holes. Finite element analysis was performed by Kulatunga and Macdonald [14] on cold-formed steel lipped channel sections subjected to compression. The effect of perforation position on the load carrying capacity of column members with lipped channel cross section was evaluated. In addition, both experimental work and finite element analysis were carried out by Kulatunga et al. [15] to investigate the influence of perforations with various shapes on the buckling behaviour of cold-formed column members with lipped channel cross section.

There is little research being carried out on the perforated aluminium alloy members. In 2010, Zhou and Young [16] studied the behaviour of 6061-T6 aluminium alloy SHSs with a circular hole in the webs subjected to web crippling. A total of 216 data including 84 test results and 132 numerical results were presented. A unified web crippling equation for the aluminium alloy SHSs with circular web holes was also proposed. In 2015, a series of tests were conducted by Feng and Young [17] on the aluminium alloy SHS stub columns with circular openings. The test results were compared with the design strengths calculated using the current design rules for perforated steel structural members. It was found that the current design rules for perforated steel structural members were inappropriate for the design of aluminium alloy SHS stub columns with circular openings. There is no design rules currently used for perforated aluminium alloy columns. However, the design rules for cold-formed steel columns with holes are available in North American Specification [12,13], which predict the ultimate strength of perforated steel structural members based on the effective width method (EWM). Furthermore, Moen and Schafer [11] extended the design rules given in North American Specification [12,13] for cold-formed steel columns based on the direct strength method (DSM) to the design of cold-formed steel columns with holes.

This paper presents a series of tests on pin-ended aluminium alloy square and rectangular hollow section (SHS and RHS) columns with circular openings. The effects of opening size and number of openings on the structural behaviour of perforated aluminium alloy SHSs and RHSs under axial compression were evaluated. The typical failure modes observed from the tests include local buckling, flexural buckling, interaction of local and flexural buckling, and material yielding at the heat-affected zone (HAZ). The column strengths obtained from the tests were compared with the design strengths calculated using the current design rules for cold-formed steel columns with holes by replacing the material properties of aluminium alloy tubes. Furthermore, the