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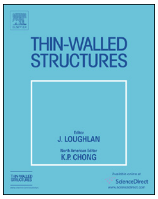

Experimental investigation on the stability of aluminium alloy 6082 circular tubes in axial compression

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ABSTRACT

6082 is a relatively new alloy that currently provides the best combination of properties in 6xxx series alloys. A series of tests was conducted on the stability of heat-treated aluminium alloy 6082-T6 circular tube columns to check the reliability of buckling strength predictions of 6082-T6 alloy circular tube columns using current design rules. First, nine stub columns were tested to obtain stress–strain curves and three parameters of the Ramberg–Osgood expression (E, $\sigma_{0.2}$ and n). The experimental stress–strain curves were in good agreement with the Ramberg–Osgood expression, and the mean value of $\sigma_{0.2}/n$ obtained from the tests was close to the Steinhardt assumption. Second, prior to column tests, the initial out-of-straightness of 15 circular tubes was accurately measured. Third, these 15 tubes, with five nominal slenderness ratios varying from 20.4 to 69.6, were tested between two pinned ends under axial compression to obtain failing modes and buckling strengths. Finally, the experimental buckling strengths were compared with the buckling strengths predicted by several current aluminium structure design codes, including the American Aluminium Design Manual (AA), Australian/New Zealand Standard 1664 (AS/NZS), and Eurocode 9 (EC9), as well as the general column curve formulation proposed by Rasmussen and Rondal [13]. These comparisons shows that the AA predictions are too conservative at small slenderness ratios, the AS/NZS predictions are unsafe at large slenderness ratios, the EC9 predictions are conservative, and the Rasmussen–Rondal formulation provides the closest and generally conservative strength predictions.

1. Introduction

Aluminium alloy has become an established primary structural material for transportation applications in the aeronautical, rail, automotive and shipping industries. Over the past few decades, it has also become an important alternative to conventional carbon steel, particularly for weight-sensitive structures such as large-span roofing systems, bridges, and topsides of offshore structures [1]. The increasing growth in the structural application of aluminium alloy is due to its several particular advantages over conventional carbon steel, including satisfactory corrosion resistance, high strength-to-weight ratio and good formability; it also offers comparable ease of manufacture, low maintenance costs, and superior aesthetics.

In structural applications, 6000 series alloys are commonly used because of their favourable combination of properties. Among the 6000 series alloys, 6082 alloy is a relatively new aluminium alloy, one popular in Europe and experiencing much in use in America as well [2]. 6082 alloy provides a superior combination of properties such as high strength after heat treatment, satisfactory corrosion resistance, good machining properties, and good weldability [3]. Compared with the classic and widely-used 6061 alloy, 6082 alloy has higher strength (0–8% higher for characteristic values of 0.2% proof strength, and 12–19% higher for characteristic values of ultimate tensile strength, depending on product form and alloy temper, provided by European Code 9 [12]), better general corrosion resistance, and is approximately equivalent in terms of other properties such as density, extrudability, and anodising response [2].

Circular tubes are widely used in curtain walls, space structures, and other structural applications, and an important failure mode of such tubes is flexural buckling under axial compression. One of the main concerns about aluminium alloy members is their lower stability compared with carbon steel members, because aluminium alloy has Young's modulus values about one-third those of steel [3]. Significant advances in estimating such stability have been made through persistent experimental and analytical studies, as summarised in Mazzolani [3] and Sharp [4]. Recently, experimental investigation on circular tube columns made of 6063-T5 and 6061-T6 aluminium alloys was conducted by Zhu and Young [5]. Compared with the extensive studies on widely-used 6061 alloy

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Nomenclature

A	gross cross-section area
COV	coefficients of variation
D	outside diameter
D_m	mid-thickness diameter
E	initial Young's modulus
e_0	initial loading eccentricities at specimen ends
e_{0_mid}	initial loading eccentricities at specimen mid-length
F_d	design buckling strength
h_i	vertical distance from sensor's zero position to measuring point i
i	imperfection measurement point number starting from zero to m
I	inertia moment of the cross-section
k_c	coefficient for compression members in the AS/NZS Standard
L	specimen length
L_e	column effective length
LVDT	linear variable differential transformer
m	largest number of measuring points on the longitudinal line
n	exponent in Ramberg–Osgood expression
N	axial load
N_u	experimental ultimate load
$N_{0.2}$	cross-sectional yield load defined by $N_{0.2} = \sigma_{0.2} A$
r	radius of gyration
t	wall thickness of aluminium tube
ν_0	maximum initial out-of-straightness at mid-length of aluminium tube
α	parameter used to define the imperfection parameter (η)
β	parameter used to define the imperfection parameter (η)
χ	normalised column strength
χ_t	normalised column strength obtained from test
χ_p	prediction of normalised column strength
χ_{AA}	prediction of normalised column strength using Aluminium Design Manual
$\chi_{AS/NZS}$	prediction of normalised column strength using Australian/New Zealand Standard
χ_{EC9}	prediction of normalised column strength using Eurocode9
ε	strain
ϕ	resistance factor
η	imperfection parameter
λ	column slenderness ratio defined by$\lambda = L/r = L\sqrt{A/I}$
$\overline{\lambda}$	column regularised slenderness ratio, calculated by $\overline{\lambda} = \lambda/\pi\sqrt{\sigma_{0.2}/E}$
$\overline{\lambda}_0$	limit of the horizontal plateau of Perry-formed column curve
$\overline{\lambda}_1$	parameter used to define the imperfection parameter (η)
θ	angle between the connecting line of specimen ends and standard platform
σ	stress
$\sigma_{0.1}$	static 0.1% compressive proof stress
$\sigma_{0.2}$	static 0.2% compressive proof stress
Δ_i	initial out-of-straightness at measuring point i
Δ_{Mid}	maximum absolute value of initial out-of-straightness at mid-length of eight longitudinal lines
Δ_{Amp}	maximum absolute value of initial out-of-straightness amplitudes of eight longitudinal lines
Φ	parameter used to define the normalised column strength (χ)

members, research results regarding the stability of 6082 alloy column members are rarely found in the literature, except for a few 1970-era experiments conducted under the auspices of the European Convention for Constructional Steelwork (ECCS) [6–9] on 6082 alloy columns with circular hollow sections and H-shaped sections. Stability design criteria for aluminium alloy members in axial compression have been provided in current specifications such as the American Aluminium Design Manual (AA 2010) [10], Australian/New Zealand Standard (AS/NZS 1997) [11], and European Code (EC9 2007) [12]. In 1997 Rasmussen and Rondal [13] proposed a general column curve formulation using a simple extension of the Perry curve to predict the column strength of metallic materials, especially aluminium and stainless steel.

Material properties and initial geometric imperfections are the two predominant factors underlying the stability of aluminium alloy columns. Material properties may be determined through stub column tests [13–15]. Initial geometric imperfections of aluminium extrusions introduced by heat treatment and transportation include deviations in size and initial out-of-straightness. In the past, initial out-of-straightness in circular tubes has been measured using methods such as feeler gauges, theodolites [16], and relative rotation of laser sensors, LVDTs, or infrared detectors [17–21]. The method using ffeeler gauges is convenient but insufficiently accurate, and the relative-rotation method requires a complex device to fix and rotate the circular tubes accurately.

The purposes of this paper are first to present a simple but accurate approach for obtaining initial out-of-straightness of circular tubes employing a laser sensor and a standard platform; second, to present a series of tests on aluminium alloy 6082-T6 circular tube columns with various slenderness ratios; and third, to compare the experimental column strengths with the column strengths predicted using the specifications [10–12] and the general column curve formulation by Rasmussen and Rondal [13].

2. Stub column tests

The material properties of the aluminium tube specimens for column tests were determined by stub column tests. A stub column is a member sufficiently short to prevent buckling under compression but sufficiently long to contain the same initial residual stress pattern as a much longer member cut from the same stock [14].

2.1. Stub column specimens

The tests were performed on circular tubes with two cross-sectional geometries, $\varnothing 89 \times 6.5$ and $\varnothing 76 \times 3.0$ ($D \times t$, mm), as shown

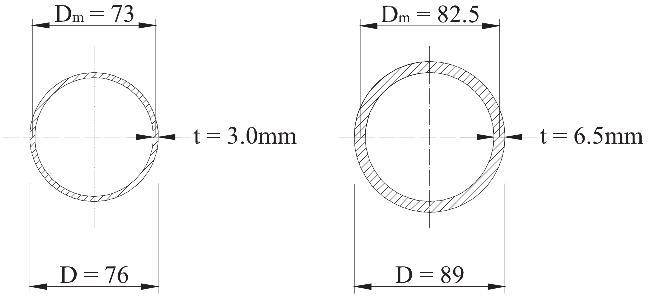

Fig. 1. Nominal cross-section dimensions.