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Effects of transverse welds on aluminum alloy columns

Ji-Hua Zhu[a,1], Ben Young[b,*]

[a]College of Civil Engineering, Shenzhen University, Shenzhen 518060, PR China
[b]Department of Civil Engineering, The University of Hong Kong, Pokfulam Road, Hong Kong

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Abstract

This paper investigates the effects of transverse welds on aluminum alloy columns. The materials of the specimens were 6063-T5 and 6061-T6 heat-treated aluminum alloys. Various coupon tests were performed to obtain the non-welded and welded material properties of aluminum alloys. An accurate and reliable finite element model (FEM) was used for the simulation of aluminum alloy stub columns of square and circular hollow sections (SHS, CHS) in this study. The stress–strain relationships obtained from the coupon tests were incorporated in the FEM. A parametric study was conducted that included 48 columns of different section shapes with and without transverse welds at the ends of the columns. This study focused on the effects of transverse welds on column strengths with respect to the section slenderness. Hence, the parametric study was performed on stub columns of SHS and CHS in constant column length. The European Code for aluminum structures uses the heat-affected zone (HAZ) softening factor to consider the weakening effects of transverse welds on column strength. The HAZ softening factors obtained from the parametric study were compared with the corresponding values specified in the European Code. HAZ softening factors were proposed in this study.

Keywords: Aluminum alloy; Columns; Experimental investigation; Finite element analysis; Heat-affected zone; Parametric study; Structural design; Transverse welds

1. Introduction

Aluminum tubular members are used in curtain walls, space structures and other structural applications, and these members can be joined by welding. The aluminum tubular members are normally manufactured by heat-treated aluminum alloys. This is because the heat-treated alloys have notably higher yield stress than the non-heat-treated alloys. The advantages of using aluminum alloys as a structural material are the high strength-to-weight ratio, lightness, corrosion resistance and ease of production. However, when heat-treated aluminum alloys are welded, the heat generated from the welding reduces the material strength significantly in a localized region, and this is known as the heat-affected zone (HAZ) softening. It is assumed that the HAZ extends 1 in (25.4 mm) to each side of the center of a weld [1]. In the case of the 6000 Series aluminum alloys, the heat generated from the welding can locally reduce the parent metal strength by nearly half [2]. The effects of welding on the strength and behavior of aluminum structural members depend on the direction, location and number of welds, as described in the American Specification for aluminum structures [1] as well as Lai and Nethercot [3]. In aluminum structures, welds are mainly divided into two types, namely (1) transverse welds; and (2) longitudinal welds. Generally, transverse welds are often used in connections, whereas longitudinal welds are used for the fabrication of built-up members [4]. Structural members such as columns may easily connect to other structural members or parts by welding at the ends of the columns. Hence, it is important to investigate the behavior of aluminum columns with transverse welds at the ends of the columns. Research have been reported on aluminum columns containing transverse welds, as summarized by Mazzolani [2] and Sharp [5]. However, previous research

*Corresponding author. Tel.: +852 2859 2674; fax: +852 2559 5337.
E-mail address: young@hku.hk (B. Young).
[1]Formerly, PhD student, Department of Civil Engineering, The University of Hong Kong, Pokfulam Road, Hong Kong.

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Nomenclature

A	gross cross-section area
B	overall width of SHS and RHS
COV	coefficient of variation
D	overall diameter of CHS
DL	dead load
E_0	initial Young's modulus
e	axial shortening
FEA	finite element analysis
FEM	finite element model
H	overall depth of SHS and RHS
L	length of specimen
n	exponent in Ramberg–Osgood expression
P_{NW}	non-welded column strength
P_{W}	welded column strength
t	thickness of section
ε	strain
ε_f	elongation (tensile strain) at fracture;
ρ_{haz}	heat-affected zone (HAZ) softening factor ($P_{\mathrm{W}}/P_{\mathrm{NW}}$)
$\rho_{haz\text{-EC9}}$	heat-affected zone (HAZ) softening factor specified in the Eurocode 9
$\rho_{haz\text{-FEA}}$	heat-affected zone (HAZ) softening factor obtained from the FEA
$\rho_{haz\text{-P1}}$	proposed heat-affected zone (HAZ) softening factor for square hollow section
$\rho_{haz\text{-P2}}$	proposed heat-affected zone (HAZ) softening factor for circular hollow section
σ	stress
$\sigma_{0.01}$	static 0.01% tensile stress
$\sigma_{0.1}$	static 0.1% tensile stress
$\sigma_{0.2}$	static 0.2% proof stress
$\sigma_{0.2\text{-NW}}$	static 0.2% proof stress obtained from non-welded tensile coupon test
$\sigma_{0.2\text{-W25}}$	static 0.2% proof stress obtained from welded tensile coupon test of 25 mm gauge length
$\sigma_{0.2\text{-W250}}$	static 0.2% proof stress obtained from welded tensile coupon test of 250 mm gauge length
σ_u	static ultimate tensile strength

were mainly focused on the effects of transverse welds with respect to different column lengths.

Recently, a series of tests on aluminum columns with and without transverse welds has been conducted by Zhu and Young [6,7]. Aluminum columns of square hollow section (SHS), rectangular hollow section (RHS) and circular hollow section (CHS) with and without transverse welds at the ends of the columns were investigated. As a result, one concern is that the effects of transverse welds on column strength could be varied with the section slenderness. Following these research, a numerical investigation was performed and presented in this paper that focused on the effects of transverse welds on aluminum alloy columns with respect to section slenderness.

The current European Code (EC9) [8] for aluminum structures provides design rules for column containing transverse welds. In calculating the strength of aluminum column with transverse welds at both ends of the column, the EC9 uses a HAZ softening factor (ρ_{haz}) to consider the weakening effects of welding on column strength. The ρ_{haz} are constant values and equal to 0.6 and 0.5 for aluminum alloy 6063-T5 and 6061-T6, respectively. The values of the HAZ softening factors obtained from this study were compared with the corresponding values specified in the European Code.

The purpose of this paper is firstly to present a series of coupon tests on heat-treated aluminum alloy 6063-T5 and 6061-T6; both the non-welded and welded material properties were investigated; secondly, a numerical investigation using finite element analysis (FEA) is presented to examine the effects of transverse welds on aluminum stub columns of SHS and CHS with different section slenderness; the stress–strain relationships obtained from the non-welded and welded coupon tests were incorporated in the finite element model (FEM); thirdly, the HAZ softening factors obtained from the parametric study were compared with the factors specified in the Eurocode for aluminum structures [8]; and lastly, HAZ softening factors were proposed.

2. Material properties

2.1. Labeling

Non-welded and welded material properties were measured on SHS, RHS and CHS of heat-treated aluminum alloy 6063-T5 and 6061-T6. In this paper, the term of "non-welded material" refers to the material without being heat affected by welding, whereas the term of "welded material" refers to the material in the HAZ that being heat affected by welding. The nominal cross-section dimension geometry and aluminum alloy for the SHS, RHS and CHS are shown in Tables 1 and 2 using the symbols illustrated in Fig. 1. The SHS, RHS and CHS were labeled such that the type of material and cross-section shapes could be

Table 1
SHS and RHS sections for coupon tests

Section	Type of material	Dimension $H \times B \times t$ (mm)
N-S1	6063-T5	$44 \times 44 \times 1.1$
N-R1	6063-T5	$100 \times 44 \times 1.2$
N-R2	6063-T5	$100 \times 44 \times 3.0$
H-R1	6061-T6	$100 \times 44 \times 1.2$
H-R2	6061-T6	$100 \times 44 \times 3.0$

Note: 1 in. = 25.4 mm.