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Concrete-filled double-skin aluminum circular hollow section stub columns

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ABSTRACT

This paper presents experimental and numerical investigations and design of concrete-filled double-skin aluminum stub columns with circular hollow sections (CHS) as both outer and inner skins. A series of tests was carried out to investigate the effects of the geometric dimension of the aluminum CHS and concrete strength on the behaviour and strength of the composite columns. The CHS tubes were fabricated by extrusion using 6061-T6 heat-treated aluminum alloy having nominal 0.2% proof stress of 240 MPa. The structural performance of the composite columns was investigated using different nominal concrete cylinder strengths of 40, 70 and 100 MPa. A non-linear finite element model is developed and verified against the experimental results.

The test results and the composite column strengths predicted from the finite element analysis (FEA) were compared with the design strengths to evaluate the reliability of the design rules in the current American specifications for aluminum and concrete structures. Furthermore, design equations were proposed to consider the benefits of the composite columns due to the composite action between the aluminum tubes and concrete. The proposed design equations accurately predicted the ultimate strengths of the concrete-filled double-skin aluminum CHS stub columns.

1. Introduction

The increasing demand and strong potential of using concrete-filled double-skin tube (CFDT) columns is highlighted through recent research, particularly in Japan [1]. CFDT section consists of two concentric tubes with the annulus between them filled with concrete. The advantages of CFDT over conventional single-skin concrete-filled tube (CFT) include higher earthquake resistant due to reduced own weight, good local stability due to the interaction of the three components, higher global stability due to the larger section modulus and good fire resistance. CFT columns have been well researched [2–4] and design rules for CFT columns are well established [5]. In recent years, many studies have also been carried out on CFDT columns, such as [6–11]; however, to the authors' knowledge, there are no design rules for CFDT columns. A detailed review of research on CFDT stub columns can be found in Huang et al. [12].

Aluminum alloys as structural members can be used due to its good corrosion resistance and appearance. Aluminum composite tube columns also hold the characteristics of steel composite tube columns. Aluminum tube columns filled with concrete can effectively take advantage of these two materials to provide both high strength and high stiffness. Experimental investigation of concrete-filled aluminum SHS and RHS composite columns was reported by Zhou and Young [13]. It was shown that the stiffness and the load carrying capacity of the composite columns improved considerably compared with the aluminum SHS and RHS tube columns without concrete infill. Experimental and numerical investigations of concrete-filled aluminum CHS tube columns were reported by Zhou and Young [14,15]. It was also shown that the stiffness and the load carrying capacity of the composite columns improved a lot compared with the aluminum CHS tube columns without concrete infill. These authors proposed composite column design equations which consider the benefits of concrete-filled aluminum CHS columns due to the composite action between the constituent elements. The proposed design equations accurately predicted the ultimate strengths of the concrete-filled single-skin aluminum CHS tube columns.

Concrete-filled double-skin aluminum tubular columns, combining the advantages of CFDT and the aluminum alloys, could be used in ocean platforms, high piers of bridges in valleys and other structures that durability is one of the major considerations. The purpose of this study was to investigate the structural behaviour and strength of concrete-filled double-skin aluminum stub columns with circular hollow sections (CHS) as both outer and inner skins. A series of tests was conducted on aluminum CHS tubes with concrete infill of different

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Nomenclature

A_{ai}	full cross-section area of aluminum inner tube;
A_{ao}	full cross-section area of aluminum outer tube;
A_c	area of concrete;
COV	coefficient of variation;
D_i	outer diameter of inner tube;
D_o	outer diameter of outer tube;
E_0	initial Young's modulus;
F_{Li}	limit state stress of aluminum inner tube;
F_{Lo}	limit state stress of aluminum outer tube;
F_m	mean value of fabrication factor;
f_c	measured concrete cylinder strength;
L	length of column specimen;
M_m	mean value of material factor;
P_{AA}	nominal axial strength calculated using the American specifications;
P_{Exp}	test ultimate load (test strength);
P_{FEA}	ultimate load obtained from finite element analysis;
P_m	mean value of load ratio;
P_n	design strength;
P_p	nominal axial strength calculated using the proposed design equations;
t_i	thickness of aluminum inner tube;
t_o	thickness of aluminum outer tube;
V_F	coefficient of variation of fabrication factor;
V_M	coefficient of variation of material factor;
V_p	coefficient of variation of load ratio;
ε_f	elongation (tensile strain) after fracture based on gauge length of 25 mm;
$\sigma_{0.2}$	static 0.2% proof stress;
σ_u	static ultimate stress;
β	reliability index;
ϕ	resistance (capacity) factor; and
Δ	axial shortening of specimens.

cylinder strengths. The stub composite columns were subjected to uniform axial compression. The finite element model (FEM) of concrete-filled double-skin aluminum CHS stub columns was developed and verified against the test results. An extensive parametric study was conducted to investigate the effects of cross-section geometries and material properties on the composite column strengths. The reliability of the design rules was evaluated using reliability analysis by comparing the composite column strengths obtained from the tests (P_{Exp}) and column strengths predicted from the finite element analysis (FEA) (P_{FEA}) with the design strengths (P_{AA}) calculated using the American specifications [16,17] for aluminum and concrete structures. The proposed composite column design equations were developed based on the results obtained from the experimental and numerical investigation in this study. The proposed design equations consider the benefits of concrete-filled double-skin aluminum CHS stub columns due to the composite action between the aluminum CHS tubes and the concrete infill. Hence, the proposed design equations accurately predict the composite column strengths.

2. Experimental investigation

2.1. Test specimens

A total of 24 tests was performed to study the structural performance of concrete-filled double-skin aluminum stub columns with circular hollow sections (CHS) as both outer and inner skins. Six different section size CHS tubes (C1 – C6) were chosen in this study, of which four large section sizes (C3 – C6) were used for the outer skin with measured diameter-to-thickness (D_o/t_o) ratio ranging from 29.2 to 60.3 and two small section sizes (C1 and C2) were used for the inner skin with measured D_i/t_i ratio ranging from 15.7 to 39.0, where D_o and t_o are the diameter and the thickness of the outer skin, and D_i and t_i are the diameter and the thickness of the inner skin as shown in Fig. 1. The CHS tubes were fabricated by extrusion using 6061-T6 heat-treated aluminum alloy, hence the residual stresses of the tubes were very small and could be ignored. The column lengths (L) were chosen so that the length-to-outer diameter ratio (L/D_o) for the concrete-filled double-skin aluminum columns generally remained at a constant value of 3 to prevent overall column buckling. The column specimens were tested using nominal concrete cylinder strengths of 40, 70 and 100 MPa. The measured dimensions of the concrete-filled double-skin aluminum CHS stub column test specimens are shown in Table 1.

In manufacturing the composite specimens, the aluminum CHS tubes were cut to size, and then they were capped by a thin steel plate to allow casting of the concrete. This plate was marked to obtain a concentric construction of the composite specimens. The specimen was cast using the outer and inner tubes as a mould for the concrete. The specimen was cast on a vibrating table to allow compacting of the concrete. The specimens were cured in the lab for 28 days. Prior to testing, the thin steel plate was removed and both ends of the columns were milled flat, and then strengthened with a fiber reinforced polymer (FRP). Hence, column failure would not occur at the ends of the columns. This method of strengthening the ends of the columns by FRP has been used by Zhou and Young [13,14] for concrete-filled single-skin aluminum tube columns. The ends of the columns were then cast in plaster to ensure the load was applied uniformly on the concrete and the aluminum tubes simultaneously.

2.2. Specimen labeling

In Table 1, the column test specimens are labelled such that the

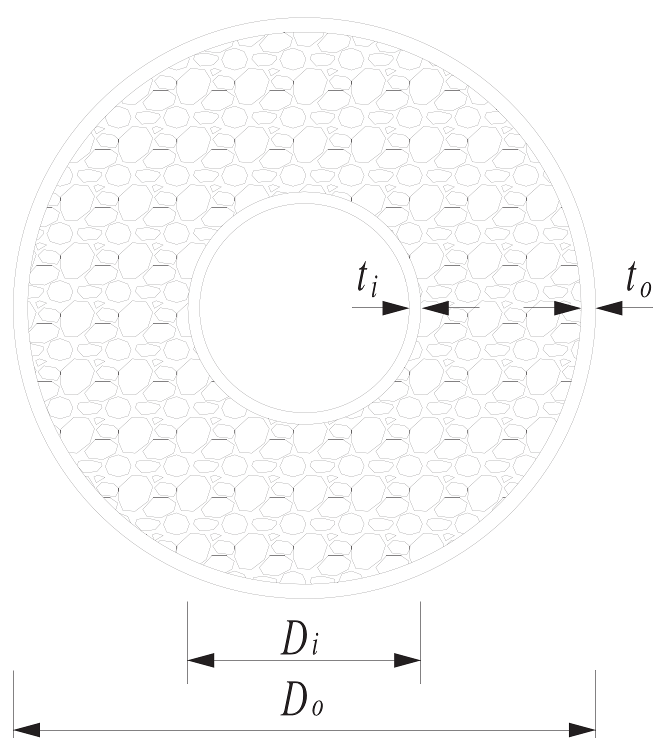

Fig. 1. Definition of symbols for concrete-filled double-skin aluminum CHS.