EXPERIMENTAL INVESTIGATION OF ALUMINUM-LIGHTWEIGHT CONCRETE COMPOSITE COLUMNS

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Abstract

An experimental and theoretical study of light weight concrete filled aluminum tubes having circular hollow section is presented in this paper. The structural performance of columns was investigated using different light weight concrete fashions and compressive strengths. The column specimens were subjected to uniform axial compression with two different loading styles, in the first one (composite action); aluminum tube is utilized to be axially loaded as well as its confining function, and in the second loading style (confinement action), aluminum tube is utilized to confine concrete core only. The aluminum circular hollow sections have nominal proof stress, $f_{0.2}$ = 170 MPa. A grade of light weight expansion clay aggregate (LECA) is used to fabricate light weight concrete. The strengths, axial load- shortening displacement relationship, axial and lateral strains, and failure modes of columns are presented. The unfactored strengths predicted are found to be in a good agreement with the experimental values using the general design guidelines specified in the American specifications and Euro code.

Key words: Aluminum tube, lightweight concrete, composite column, and strength rating.

دراسة عملية للأعمدة المركبة من الالمنيوم والخرسانة خفيفة الوزن

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الخلاصة

تم اجراء دراسة عملية و نظرية لخواص الاعمدة الدائرية المكونة من انابيب الالمنيوم المملوءة بالخرسانة خفيفة الوزن. ان الاداء الانشائي لهذه الاعمدة تم بيانه باستخدام انواع مختلفة من الخرسانة خفيفة الوزن و مقاومات انضغاط مختلفة. و اختبرت جميع النماذج تحت تأثير الحمل المحوري بنمطين مختلفتين في النمط الاول تم تحميل مقطع الالمنيوم و الخرسانة الخفيفة معا , اما في نمط التحميل الثاني فقد تم توظيف مقاطع الالمنيوم للتقييد الجانبي فقط. تم استخدام مقاطع المنيوم دائرية الشكل لها مقاومة خضوع ($f_{0.2}$ =170 MPa) بينما الركام المستخدم في صناعة الخرسانة الخفيفة المالئة لأنابيب الالمنيوم هو الركام الخفيف المصنوع من الطين المحروق المنتفخ المعروف باسم (LECA). و تم تعيين مقاومة الأعمدة العلاقة بين الحمل و التقلص في الطول ألمحوري الانفعالات المحورية و ألجانبية و نوع نمط الفشل للأعمدة. و تم بالاعتماد على اساليب التصميم العامة المحددة بالمواصفات الامريكية و الاوربية التنبؤ بقيم التحمل للأعمدة و وجدت انها في توافق جيد مع النتائج العملية.

1. Introduction

It is well known that concrete-filled steel composite columns have the advantages of high-bearing capacity and ductility, easy construction and cost saving [1]. Similarly, aluminum tube columns filled with concrete can effectively take advantages of these two materials to provide both high strength and high stiffness. Furthermore, aluminum alloys are used in a variety of structural engineering applications due to their high strength-to-weight ratio and durability [2]. Light weight concrete is a type of concrete commonly made of light weight coarse aggregate, normal or light weight fine aggregate, hydraulic cement and water. The proper properties of light weight concrete and aluminum in additional to composite action benefits have encouraged the author to propose, fabricate and study the composite columns which consists of light weight concrete and aluminum components. The main purpose of the study is to generate data and provide information about the structural behavior of such columns as aluminum and lightweight concrete respective advantage can be utilized to the fullest extent. However, Such columns are not yet used owing to lack of underpinning research but the advanced technology aims to utilize everything available to introduce efficient structural elements. Two categories of previous studies related to current investigation may be distinguished. The first one relates to steel tubes filled with light weight concrete, while the second relates to aluminum tubes filled with normal weight concrete. In 2002, Hunaiti et al. [3] investigated hollow steel tubes of square, rectangular and circular section filled with foamed and light weight concrete. The test results showed that the light weight concrete filled specimens were capable of reaching the ultimate predicted loads in accordance with BS 5400 and EC4. In 2011, Ghannam et al.[4], carried out tests on steel tubular columns of rectangular and circular sections filled with normal and lightweight concrete to investigate the behavior of such columns under axial loadings. Comparison between normal and lightweight concrete filled steel columns for different column cross-sections using Euro Code 4 and BS 5400 codes was also conducted. In 2009, Zhou and Young [5] carry out an experimental investigation on concrete filled aluminum circular hollow section stud columns. The results showed that the design strengths were generally conservative. In 2012, Nasser [6] performed an experimental and theoretical study on the behavior of circular concrete filled aluminum tubular columns. The effect of slenderness ratio of aluminum tube on the load carrying capacity of the concrete filled tubular columns was investigated. The empirical equations proposed were capable of predicting the values of ultimate loads of aluminum - concrete composite columns and were in good agreement with the experimental values.

2. Material Properties

The same materials (aluminum, cement, normal and light weight fine aggregate, normal and light weight coarse aggregate, and water) were used for all specimens throughout this investigation.

2.1 Aluminium Circular Hollow Section

Structural aluminum alloy circular hollow section produced by Turkish aluminum industry has been used in this investigation. Plate (1) shows the structural section used in this study while the geometrical details are shown in Table (1).

Plate (1) Used aluminum section

Aluminum standards quote two levels of stress, both of which must be attained for a batch of material to be accepted:

$f_{0.2}$ minimum value of the 0.2% proof stress (or ‘0.2% offset’) and;

f_u minimum tensile strength (or ‘ultimate stress’).

So the mechanical properties of the used aluminum were determined by tensile coupon tests. The tensile coupons were taken from wall shell in the longitudinal direction of the specimens. The tensile coupons were prepared and tested according to the American Society for Testing and Materials standard (B557M - ASTM 2003) [7] for the tensile testing of metals using 12.5 mm wide coupons of 50 mm gauge length. Plates (2) and (3) show aluminum tensile coupons and their setup. The material properties obtained from the tensile coupon tests are summarized in Table (2). The Reported results are the average.

Plate (2) Aluminum tensile coupons

Plate (3) Test setup of aluminum tensile coupons

Table (1) Details of aluminum section

Configra-tion	**Height H, (mm)**	**Outer diameter D, (mm)**	**Wall thickness t, (mm)**	**(D/t)**	**Mass (kg/m)**
Thin wall, hollow section	340	80	2	40	1.5

Table (2) Aluminum tensile coupons results

No.	**Yield stress, $f_{0.2}$ (MPa)**	**Ultimate, f_u stress (MPa)**	**E (GPa)**	**Fracture elongation (٪)**
1	172.9	194.5	70.4	7.6
2	168.2	193.42	69.6	6.9
3	167.3	189.58	70.5	7.1

Table (2) includes the measured initial Young’s modulus (E), the static 0.2% tensile proof stress $f_{0.2}$, the static tensile strength f_u [7], and the elongation after fracture which is typically measured on a gauge-length of 50 mm and gives a crude indication of ductility. Figure (1) shows the stress-strain curve for one of tested specimens. The compressive proof stress is assumed to be the same as in tension [8].

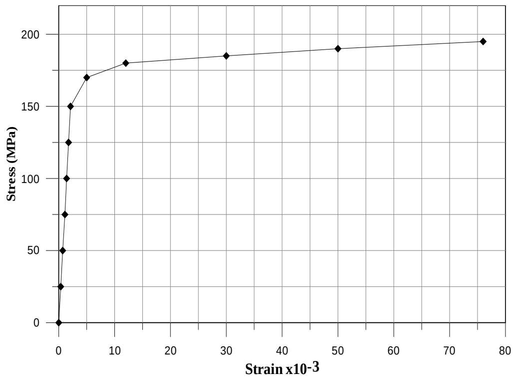


Figure (1) Stress – strain relationship for aluminum alloy, 1

2.2 Aggregate Characteristics (LECA)

Light Expanded Clay Aggregate (LECA) was used which consists of small, lightweight, bloated particles of burnt clay. The thousands of small, air-filled cavities give Leca its strength, lightness, and thermal insulation properties. The base material is plastic clay which is extensively retreated and then heated and expanded in a rotary kiln. Finally, the product is burned at 1100 °C to form the finished LECA product. The sieve analysis and water absorption of the aggregate with different fashions are given in Table (3).The results show that the grading is within specification limits determined by ASTM [9,10]. The size of LECA aggregates were between 4.75 to 19.5mm. The water absorption of the coarse LECA aggregate was 17%. Plate (4) illustrate the topography of the LECA aggregate specimens while Plates (5) and (6) show fine and coarse LECA aggregate, respectively. The grading and physical properties of LECA and normal aggregate are summarized in Table (3).

Table (3) Grading and physical properties of normal aggregate and LECA aggregate

Sieve Size (mm)	**Normal weight aggregate (% passing mass)**				**Light weight aggregate, LECA (% passing mass)**			
	Fine		**Coarse**		**Fine**		**Coarse**	
	Test results	**ASTM C330 [9]**	**Test results**	**ASTM C330[9]**	**Test results**	**ASTM C330[10]**	**Test results**	**ASTM C330[10]**
25	_	_	100	100		_	100	100
19	_	_	93	90_100		_	91	90-100
12.5	_	_	62	20_55		_		
9.5	100	100	5	0_10	100	100	14	10_50
4.75	100	95_100	_	0_5	97	85_100	0	0-15
2.36	93	80_100	_	_		_	_	_
1.18	67	50_85	_	_	75	40-80	_	_
600μm	48	25_60	_	_	12	_	_	_
300μm	48	5_30	_	_	12	10_35	_	_
150 μm	22	0_10	_	_	6	5_25	_	_
water absorption (%)	1.08	_	0.6	_	13.5	_	17	_
Bulk density (kg/m3)	1720	<1120	1490	<880	1050	<1120	790	<880

Plate (4) Topography of the LECA aggregate

Plate (5) Fine LECA aggregate

Plate (6) Coarse LECA aggregate

3. Test Specimens

The test program consisted of four test groups of columns categorized according to light weight concrete types, and loading styles, Table (4). The concrete core and aluminum circular hollow section (CHS) columns without concrete infill were also tested. The column lengths (L=340 mm) were chosen so that the length-to-diameter (D=80mm) ratio (L/D) generally remained at a constant value of 4.25 to prevent overall column buckling. The column specimens were tested using different nominal concrete cylinder strengths. The configurations of tested columns are shown in Fig. (2). A set of specimens from group 1 (with lightweight concrete type 1) is shown in Plate (7). The details of specimens are shown in Table (4).

Designations; ACi # (f'_c)

A: Aluminum tube.
C: Concrete filled aluminum tube.
i : Concrete type reference.
#:Aluminum tube utilized for confinement only
(f'_c): Concrete compressive strength (MPa).

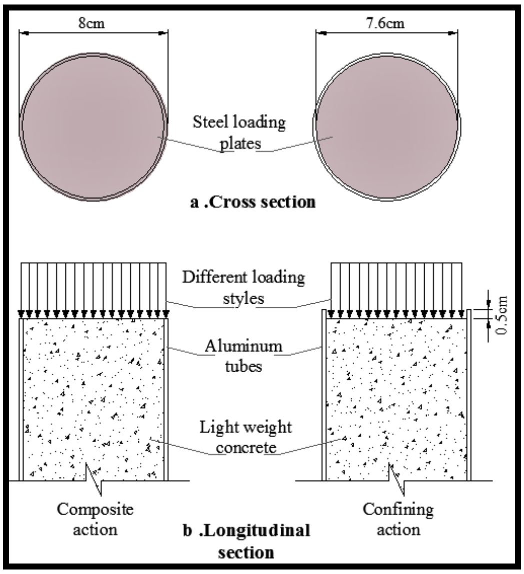


Figure (2) the configuration of tested columns

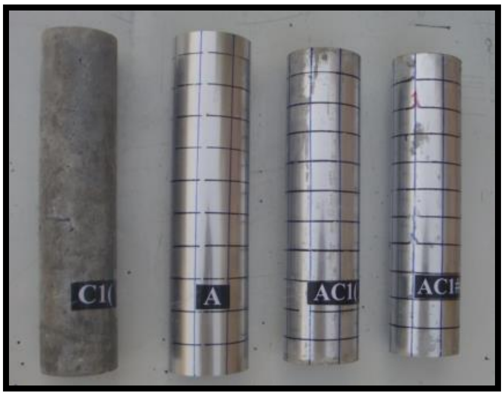


Plate (7) Specimens set (group 1)

3.1 Fabrication of the Specimens

The crushed lightweight aggregate (LECA) was used to develop different types of light weight concrete, Table (4). The concrete was filled into aluminum tube gradually and carefully compacted. All specimens were curried in same conditions by immersing the specimens in water basin for seven days. The mix proportions used were given in Table (4).

The volumetric method which is recommended by ACI was adopted to specify mix proportions of light weight concrete [11]. It consists of making a trial mixture using estimated volumes of cementitous materials, coarse and fine aggregates, and sufficient added water to produce the required slump (125 -75 mm) [11]. The resultant mixture was examined for workability and finishing ability characteristics.

Table (4) Details of tested specimens

Type	No.	Specimens Designation	Concrete type description	Concrete mix Proportions (cement:fine: coarse aggregate - w/c)	Concrete compres-sive strength, f'_c (Mpa)	Fresh concrete slump (mm)	Concrete Density (kN/m^3)
1	1	C1(16.2)	**Light weight concrete with light weight coarse aggregate (LECA) and normal fine aggregate**	1:1.58:0.86 - w/c 0.4	16.2	104	16.4
	2	AC1(16.2)					
	3	AC1#(16.2)					
	4	C1(20.1)		1:1.50:0.80 - w/c 0.41	20.1	93	17.8
	5	AC1(20.1)					
	6	C1(23.7)		1:1.40:0.75 - w/c 0.43	23.7	82	18.5
	7	AC1(23.7)					
2	8	C2(11.8)	**Light weight concrete with light weight coarse aggregate (LECA) and without fine aggregate**	1:0.00:1.85 - w/c 0.46	11.8	110	14.5
	9	AC2(11.8)					
	10	AC2#(11.8)					
3	11	C3(18.9)	**Light weight concrete with light weight coarse aggregate (LECA) and light weight fine aggregate (LECA)**	1:0.93:0.87 - w/c 0.43	18.9	85	16
	12	AC3(18.9)					
	13	AC3#(18.9)					
4	14	C4(24)	**Normal weight concrete with normal coarse aggregate and normal fine aggregate**	1:1.50:3.00 - w/c 0.4	24	120	24.5
	15	AC4(24)					
	16	AC4#(24)					

3.2 Testing Procedure

A hydraulic compression testing machine (MATEST) was used to apply compressive axial load to the column specimens, Plate (6). Prior to testing, both ends of the columns were milled flat, and then strengthened with steel. Hence, the column failure would not occur at its ends. Strengthening the ends of the columns has been used by Zhou and Young [5] for normal concrete-filled aluminum square hollow section (SHS), rectangular hollow section (RHS) and circular hollow section(CHS) columns.

The load on columns was applied monotonically in increments (rate of loading = 10 kg/sec). These increments were reduced in magnitude as the load reaches the ultimate load. The load was applied on the columns by uniform axial compression in two styles, in the first one, the load was applied over the concrete and aluminum tube together (composite action) and in the second loading style, the load was applied over the concrete core only while the aluminum tube was utilized to provide confinement only (confinement action).

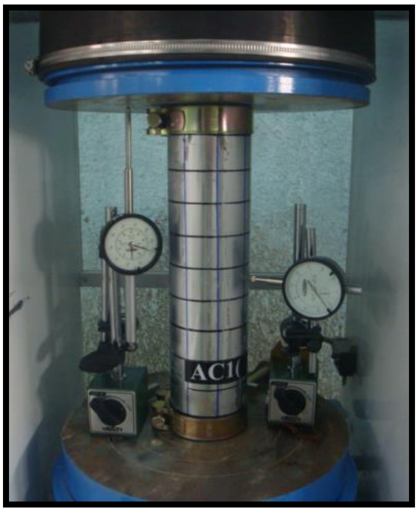


Plate (6) Testing arrangement

4. Test Results

The test strengths, load–axial shortening relationships and longitudinal and lateral strains were measured for each column specimens. The results of tests are summarized in Table (5). From this table, it can be seen that the use of infill lightweight concrete enhances the load carrying capacity of aluminum columns. For all specimens, the ratio P_{co}/P_{al} is always larger than one, ranging between 1.5 and 2.14 for columns under loading style 1 (composite action) and the average increase in strength is of the order of 1.85 while these ratios ranging between 1.31 and 2.15 for columns under loading style 2 (confinement action) and the average increase in strength is of the order 1.56.

From Table (5), it can be seen that the use of aluminum tubes increases the approximate axial strain at ultimate strength of tested columns. For all specimens, the ratio $\varepsilon_{co}/\varepsilon_{\mathrm{c}}$ is always larger than one. Also the lateral strain at failure increases up to 3-4 times concrete core. Although the midheight lateral strain of columns under loading style 2 are small (2.7×10^{-3} – 6.0×10^{-3}), it is found that the columns suffered from excessive lateral expansion at failure region.

Table (5) Specimens test results

No.	**Specimen designation**	**P_{al} (kN)**	**P_c (kN)**	**P_{co} *(kN)**	**P_{co}/P_{al}**	**P_{co}/P_c**	**S.R+**	**ε_{al}**	**ε_c**	**ε_{co}****	**$\varepsilon_{co}/\varepsilon_c$**	**ε'++**
1	A	103.2						0.009				0.0110
2	C1(16.2)		62.4						0.0036			0.002
3	C1(20.1)		77.5						0.0040			0.0015
4	C1(23.7)		89						0.0043			0.0019
5	AC1(16.2)			178.6	1.73	2.86	10.90			0.006	1.56	0.0108
6	AC1#(16.2)			165.1	1.60	2.65	10.07			0.011	3.06	0.0048
7	AC1(20.1)			208	2.02	2.69	11.70			0.009	2.13	0.0120

No.	Specimen designation	P_{al} (kN)	P_c (kN)	P_{co} *(kN)	P_{co}/P_{al}	P_{co}/P_c	S.R+	ε_{al}	ε_c	ε_{co}**	$\varepsilon_{co}/\varepsilon_c$	ε'++
8	AC1(23.7)			221	2.14	2.48	11.94			0.011	2.56	0.0100
9	C2(11.8)		45.5						0.0025			0.0009
10	AC2(11.8)			155	1.5	3.19	10.69			0.014	5.60	0.0130
11	AC2#(11.8)			135	1.31	2.86	8.96			0.036	14.40	0.0060
12	C3(18.9)		72.8						0.0029			0.0013
13	AC3(18.9)			202.3	1.96	2.78	12.64			0.009	3.10	0.0110
14	AC3#(18.9)			188.3	1.82	2.59	11.77			0.034	11.72	0.0037
15	C4(24)		90						0.0042			0.0018
16	AC4(24)			234	2.27	2.60	9.50			0.013	3.10	0.0081
17	AC4#(24)			222	2.15	2.47	9.06			0.036	8.57	0.0027

* P_{al}, P_c, and P_{co} are aluminum tube, concrete core and columns ultimate strengths, respectively.

**ε_{al}, ε_c, and ε_{co} are aluminum tube, concrete core and columns axial ultimate strains, respectively.

+S.R (Strength rating) is ultimate strength of composite columns to infill concrete unit weight ratio

++ε' lateral ultimate strain of different specimens

The effect of light weight concrete type is clearly reflected by strength rating, Table (5). For composite columns with different lightweight concrete type (1, 2, and 3) the strength ratings were (11.5 "average", 10.7, and 12.64), respectively; however, for columns in which aluminum was utilized for confining only, the strength ratings were (10.07, 8.96, and 11.77), respectively. This confirms the suitability of composite columns filled with concrete type (3) (Light weight concrete with light weight coarse aggregate (LECA) and light weight fine aggregate (LECA)) as they provide large strength rating compared with types 1 and 2. Columns filled with lightweight concrete type 2 (Light weight concrete with light weight coarse aggregate (LECA) and without fine aggregate) exhibited less loading capacity as this concrete does not develop acceptable strength (11.8 MPa).

An efficient comparison can be made if the ratio P_{co}/γ (termed the strength rating, which is the ratio between ultimate failure load of tested specimens and specific weight γ of light weight concrete).

Figure (3) shows the suitability of column with lightweight concrete type 1 (AC1) as compared with normal concrete, type 4 (AC4). It is found that as the ratio of concrete compressive strength of lightweight concrete to that of normal weight concrete approximately equal to 1, the strength rating of composite column consists of aluminum with lightweight concrete and concrete compressive strength (23.7 MPa) is (12.64) while the ratio is (9.5) for composite column with normal weight concrete and concrete compressive strength (24 MPa). The same finding is for columns with confinement action (strength rating, 11.77 verse 9.06).

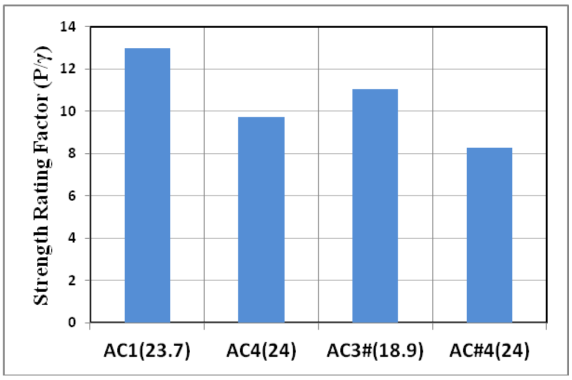


Figure (3) Variation of strength ratings for tested specimens within different groups (different concrete type)

Figure (4) clearly depicts the effect of confinement ratio (f_r/f'_c,) upon columns strength capacity, where f'_c is the concrete compressive strength and f_r is the confining stress (or burst stress or hoop stress) of the tube. Aluminum design manual[12] specifies the radial compressive stress or bursting pressure of aluminum tubes as :

$$f_r = (2\,t\,f_{tu}\,k) / D - 0.8t \ldots\ldots(1)$$

where:

f_r radial compressive stress MPa
t aluminum pipe wall thickness mm..
f_{tu} tensile ultimate strength MPa.
$k = 0.73+0.33 f_{ry}/f_{tu}$
D= outside diameter of aluminum tube mm.
f_{ry} tensile yield strength MPa.

Axial strength ratios (P_{co}/P_c) are 2.78 and 2.59 for loading styles 1 and 2, respectively, when the lateral compressive stress is 17% of concrete compressive stress (lightweight concrete type 3), and they are 3.19 and 2.86 for loading styles 1 and 2, respectively, when the lateral compressive stress is 22% of concrete compressive stress (light weight concrete type 2 which does not develop acceptable strength). Thus, if f'_c increases this would decrease the confinement ratio and consequently would decrease the ultimate strength increase ratio of the column.

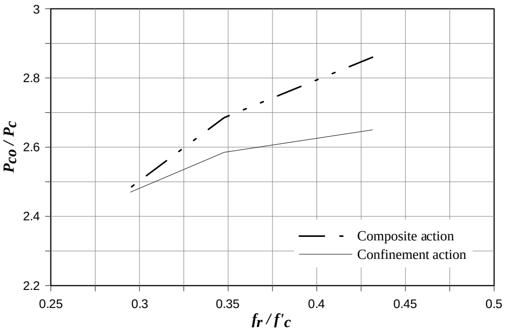


Figure (4) Effect of Confinement ratio upon columns strength capacity increment

Figure (5) illustrates the effect of concrete compressive strength on shortening displacement of composite specimens of group 1(concrete type 1). It is found that with increasing concrete compressive strength from 16.2 to 23.7 MPa , the ultimate load (P_{co}) increases from 178.6 to 221 MPa as the axial strength ratios (P_{co}/P_c) increase from 1.73 to 2.14, while the axial strain increases from (0.006 to 0.011).

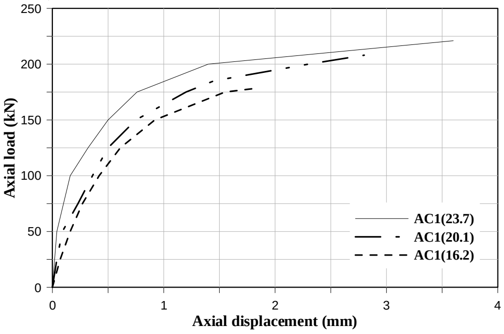


Figure (5) Load-displacement relationships of composite specimens of group 1 with different concrete compressive strength

Figures (6) to (9) denoted the measured load-axial displacement behavior of different specimens. On the same figures, the behavior is also compared with the response of the aluminum column without infill concrete. The figures clearly indicate that the load capacity of the composite columns under first loading style significantly exceed the direct summation of the load capacity of the two individual components (aluminum tube and concrete core), the same finding is indicated for columns under second loading style except for specimens AC2#(11.8) as the compressive strength of lightweight concrete is extremely low (11.8 MPa) therefore the failure is dominated by light weight concrete failure without significant effect for the confinement of aluminum tube. For all tested composite columns, the loading capacity exceed the capacity of the light weight concrete core where P_{co}/P_c increase ratios vary between (2.48 and 3.19) with average ratio of (2.8) while the increase ratios vary between (2.65 and 2.86) with average ratio of (2.64) for loading styles 1 and 2, respectively.

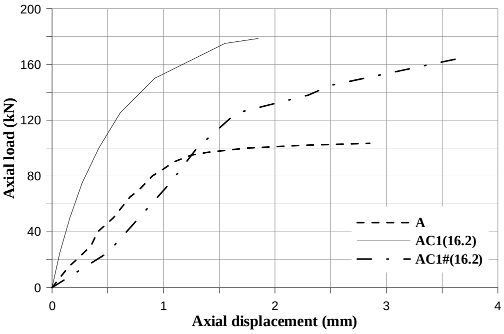


Figure (6) Load-axial displacement relationships of different specimens within group 1

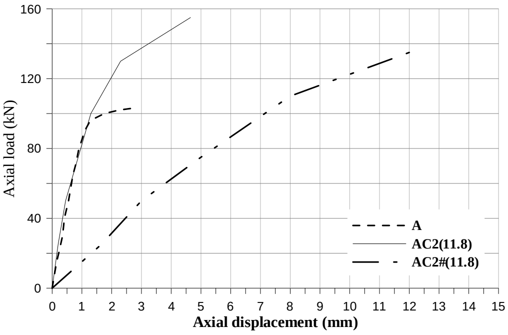


Figure (7) Load-axial displacement relationships of different specimens within group 2

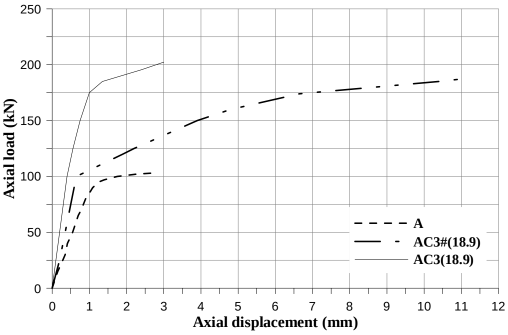


Figure (8) Load- axial displacement relationships of different specimens within group 3

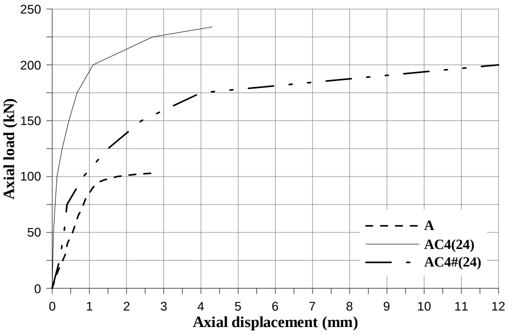
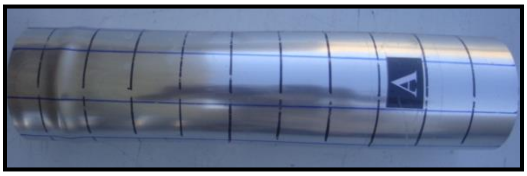


Figure (9) Load- axial displacement relationships of different specimens within group 4

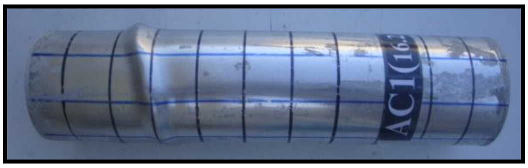
5. Failure Modes

The light weight concrete cores suffer from excessive lateral expansion due to unstable propagation of the internal micro-cracks, which causes the strain softening behavior and eventually the concrete mass loses its integrity and fails in splitting manner. The complete collapse usually occurred suddenly at strains between 0.0025 and 0.0043. The hollow aluminum tube, as shown in Plate (7-a), fails prematurely by local buckling.

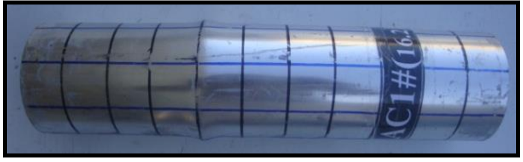
The failure modes of all tested composite columns are shown in Plate (7). For the aluminum - lightweight concrete composite columns, the typical failure is a classical shear mode failure. The concrete core typically failed in a classical shear mode failure. It was observed, when the aluminum tube is cut, that a smooth interface between the aluminum tube and concrete exists as shown in plate (8). This led to the conclusion that no bond is developed between concrete and aluminum tube. It seems that the confinement exerted by the aluminum tube could not fully prevent the concrete core from shear failure, although the aluminum tube did provide good confinement on the concrete core. Failure usually occurred quietly.



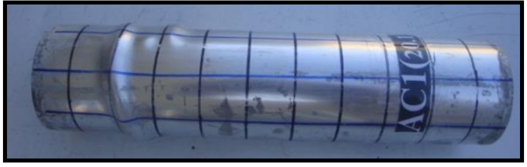
a. A



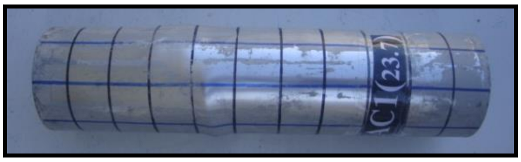
b. AC1(16.2)



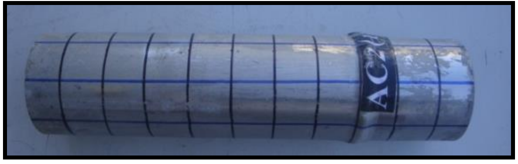
c. AC1#(16.2)



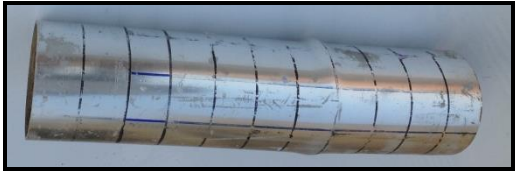
d. AC1(20.1)



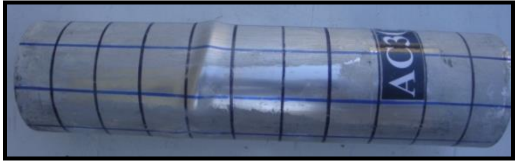
e. AC1(23.7)



f. AC2(11.8)

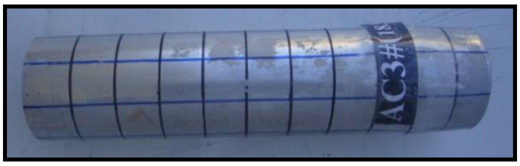


g. AC2#(11.8)

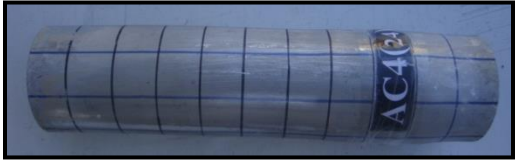


h. AC3(18.9)

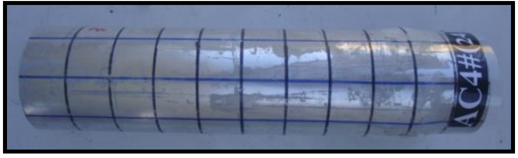
Plate (7) Failure modes of tested specimens



i. AC3#(18.9)



j. AC4(24)



k. AC4# (24)

Plate (7) Continued

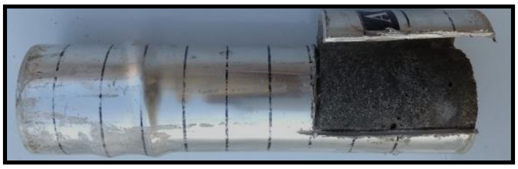


Plate (8) The smooth interface between aluminum tube and concrete

6. Theoretical Analysis

The unfactored strengths are predicted using the general design guidelines specified in the American specifications [12] and Euro code [13].

For composite action, the axial strengths P_{co} were obtained by determining the strength of the aluminum tube ($A_a f_a$) using the specifications for aluminum structures [14] as well as the strength of concrete infill ($0.85 f_{c'} A_c$), as shown in Eq. (2).

$$P_{co} = A_a f_a + 0.85 A_c f_{c'} \qquad \text{.......................(2)}$$

where:

A_a is the net cross-section area of aluminum tube, mm.

f_a is the limit state stress calculated using the Eurocode specification [14].

A_c is the area of concrete mm.

$f_{c'}$ is the concrete cylinder strength MPa.

Materials properties obtained from the tensile coupon tests for aluminum tubes are used in the calculation of the first term $A_a f_a$ in Eq. (2). The measured material properties obtained from the tensile coupon tests are shown in Table 2. The calculation of the strength of the concrete infill for the term $0.85Ac\ fc'$ in Eq. (2) is carried out using the measured concrete cylinder strengths, as shown in Table 5.

For columns in which aluminum tubes are used to confine lightweight concrete cores, a uniform radial compressive stresses (f_r) is utilized as a result of confinement The axial strength P_{cc} is specified in Eurocode [13], as shown in Eq. (3):

$$P_{cc} = P_c\,[1+5{,}000\,(f_r/P_c)]$$
$$\text{for } f_r \le 0{,}05\,P_c \qquad \text{.....................(3.a)}$$
$$P_{cc} = P_c\,[1{,}125 + 2{,}5\,(f_r/P_c)]$$
$$\text{for } f_r > 0{,}05\,P_c \qquad \text{.....................(3.b)}$$

where:

P_{cc} axial strength of confined column MPa.

P_c axial strength of concrete core.

f_r radial compressive stress MPa.

Table (8) shows the comparison of theoretical analysis results with experimental results. The analysis is found to give ultimate loads closer to the experimental values and so it could be used for designing such columns.

The ratios of experimental to predicted plastic ultimate strengths are 1.22 to 1.33 with an average value of 1.26 for loading style 1 (composite action) and 0.92 to 1.03 with an average value of 0.94 for aluminum tubes confined lightweight concrete cores.

The theoretical analysis results depict that the ultimate strength capacity of aluminum – lightweight concrete columns can be efficiently estimated by using conventional design procedures and the constitutive laws prescribed by specifications and standard tests for the materials.

Table (8) Comparison of theoretical with experimental results for tested columns

Column designation	P_{exp} (kN)*	P_{th} (kN)**	P_{exp}/P_{th}
Composite action			
AC1(16.2)	178.60	145.84	1.22
AC1(20.1)	208.00	160.89	1.29
AC1(23.7)	221.00	174.77	1.26
AC2(11.8)	155.00	128.87	1.20
AC3(18.9)	202.30	156.26	1.29
AC4(24)	234.00	175.93	1.33
Confinement action			
AC1#(16.2)	165.10	171.20	0.96
AC2#(11.8)	135.00	146.24	0.92
AC3#(18.9)	188.30	186.52	1.01
AC4#(24)	222.00	215.45	1.03

* P_{exp} is experimental ultimate load.
**P_{th} is theoretical ultimate load.

7. Conclusions

Aluminum – lightweight concrete columns exhibited high capacity increments as compared with aluminum columns. Although the used aluminum tube adds (0.5 kg/m) for the aluminum – lightweight concrete composite column, the overall stiffness and strength increase with high ratio. The ratios of increase in strength (P_{co}/P_{al}) range between (1.5) and (2.14) for composite action and between (1.3) and (1.86) for confinement action, this prove that the aluminum tube provided sufficient lateral support to the light weight core and increased the ultimate strength of the column.

The efficiently concise comparison in term of the ratio P_{co}/γ shows that the comparison is extremely positive for columns filled with lightweight concrete when compare them with those filled with normal weight concrete.

The effect of confinement ratio (f_r/f'_c,) upon columns strength capacity clearly assigned. Thus, if f'_c increases this would decrease the confinement ratio and consequently would decrease the ultimate strength increase ratio of the column.

From theoretical analysis, I was observed that the general design guidelines specified in the American specifications and Euro code are capable of predicting the values of ultimate strengths of aluminum - lightweight concrete columns with a good agreement with the experimental values.

The highlight tip which the research focuses upon it is the possibility of utilizing powerful properties of aluminum and lightweight concrete (both materials have high strength to weight ratio) in specific composite column of high strength to weight ratio.

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