Structural Behavior of Confined Concrete Filled Aluminum Tubular (CFT) Columns under Concentric Load

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ABSTRACT

This paper introduces an experimental study on the behavior of confined concrete filled aluminum tubular (CFT) column to improve strength design, ductility and durability of concrete composite structures under concentrically loaded in compression to failure. To achieve this: seven column specimens with same concrete diameter 100mm and without steel reinforcement have been examined through experimental testing, which are used to study the effects of the thickness of the aluminum tube encased concrete (thickness : 0mm, 2mm, 3mm, 4mm and 5mm with same length of column 450mm), length of column (thickness 5mm and length of column 700mm) and durability (thickness 5mm and length of column 450mm) on the structural behavior of (CFT) columns.

It is concluded from this work that the compression force capacity is affected by thicknesses of the aluminum tube with respect to reference specimen. Where the used of aluminum tube thicknesses in column specimens led to increased in load carrying capacity in range (16% for C2 -224% for C5). The specimen has a length of 700mm with 5mm thickness the decreased of strength was 0.06% than the specimen with 5mm thickness and length 450mm. For slender column the overall buckling was observed while the local buckling for the short column is the dominant failure shape. Regarding durability, no apparent difference has been found between the structural behavior of the specimen that immersed in aggressive solution and specimen in air.

Keywords: circular, column, aluminum, CFT, confinement

السلوك الإنشائي للأعمدة الخرسانية الدائرية والمحاطة بالألمنيوم تحت تأثير حمل محوري

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الخلاصة

يقدم هذا البحث دراسة عملية لتصرف الأعمدة الدائرية المكونة من انبوب الألمنيوم ذو املاء خرساني لتحسين المقاومة التصميمية والمطيلية و الديمومة تحت حمل انضغاط محوري. لتحقيق ذلك تم فحص سبع عينات مختبريا بقطر خرساني ثابت 100ملم وبدون حديد تسليح لدراسة تأثيرات سمك انبوب الألمنيوم المغطي للخرسانة (سمك :0 ملم , 2 ملم ,3 ملم ,4 ملم و 5 ملم بطول ثابت 450 ملم) , طول العمود (سمك 5 ملم وطول 700 ملم) والديمومة (سمك 5 ملم وطول 450 ملم) على التصرف الإنشائي للأعمدة.

النتائج المختبرية بينت أن مقاومة الأعمدة للانضغاط تعتمد على سمك أنبوب الألمنيوم، حيث عند استخدام سمك انبوب الالمنيوم الاقل 2 ملم لعينات العمود أدى إلى زيادة في التحميل بمقدار من 16% وعند استخدام سمك انبوب الالمنيوم الاعلى 5 ملم لعينات العمود أدى إلى زيادة في التحميل بمقدار 224% . العينة التي طولها 700ملم و ذات السمك 5ملم انخفضت القوة بمقدار 0.06% عن العينة التي يبلغ طولها 450ملم و ذات السمك 5ملم.

تم ملاحظة أن العمود النحيف يكون الفشل فيه بانبعاج كلي بينما العمود القصير يعاني من انبعاج محلي. وفي ما يتعلق بالديمومة, لم يظهر فرق بين التصرف الإنشائي للعينة المغمورة في المحلول الملحي القاسي والعينة في الهواء.

1. INTRODUCTION

Concrete-filled steel tubes (CFTs) are practical and economical structural elements that permit rapid construction because the steel tube serves as formwork and reinforcement to the concrete fill, negating the need for either. The deformation capacity of the system is increased by the combined action of the concrete fill with the thin steel tube. The concrete fill significantly increases inelastic deformation capacity and the compressive stiffness and load capacity of the CFT member. The fill also increased global buckling resistance by increasing the slenderness ratio; KL/r value, where K is effective length factor, L is the column length and r is the radius gyration of the column section. This increased deformation capacity benefits the use of CFT components for blast resistance and seismic design, **Roeder, et al., 2010** also durability of concrete.

It is well understood that lateral confinement can enhance both the strength and ductility of concrete. CFTs owe their improved deformation capacities to the confinement action provided by the surrounding FRP tube, **Ozbakkaloglu, 2013**.

CFTs are circular or rectangular composite members. Shear stress transfer is needed between the steel and concrete to develop composite action. Researches, **Yu, et al., 2007 and Han, and Yao,2004** showed that circular CFTs provide greater bond stress transfer, better confinement, and greater shear reinforcement to the concrete fill than rectangular CFTs.

Confining reinforced concrete (RC) columns can significantly increase their strength and ductility **Wu and Jiang, 2013**. There are a number of situations where it may become necessary to increase the load-carrying capacity of a structure in service. These situations include change of loading or usage, and the cases of structures that have been damaged. Deterioration of reinforced concrete (RC) columns due to corrosion of the reinforcing steel and spalling of concrete has been a major problem for the aging infrastructure, **Arya, et al, 2002.** In this study aluminum alloy 6061- T6 was used as a circular tube to confining column concrete. The strength to unit weight ratio of the aluminum alloys is more than of the steel, the aluminum alloy 6061- T6 have good resistance to corrosion without any protective covering, the aluminum structure are light in weight and the column structure have better appearance and require less maintenance, **Kissell and Ferry 2002.**

To study the effects of thickness, length and durability on the structural behavior of column, seven concrete-filled aluminum tubes (CFT) column specimens with same concrete diameter 100mm and without steel reinforcement were examined through experimental testing.

2. ADVANTAGE OF CONCRETE - FILLED ALUMINUM TUBE

The concrete-filled aluminum tube (CFT) column system has many advantages compared with the ordinary steel or the reinforced concrete system. The main advantages are:

- The strength of concrete is increased by the confining effect of aluminum tube.
- The aluminum tubes can be used as the formwork for casting concrete and the shoring system in construction, thus labor for forms and reinforcing bars is omitted. This efficiency leads to a cleaner construction site and a reduction in manpower, construction cost, and project length.
- Better cost performance is obtained by replacing reinforced concrete column with a concrete filled aluminum tubular CFT column.
- The environmental burden can be reduced by omitting the formwork.

3. EXPERIMENTAL PROGRAM

3.1 Materials:

3.1.1 Aluminum

Concrete filled aluminum tubes (CFT) are composite structures of aluminum tube and in filled concrete. The combination is ideal since concrete core has high compressive strength and stiffness while the aluminum tube has high strength and ductility **Mursi, and Uy, 2004.** The CFT columns have high strength, high ductility and high energy absorption capacity.

One myth is that aluminum is not sufficiently strong to serve as a structural metal. The fact is that the most common aluminum structural alloy, 6061-T6, has a minimum yield strength of 35 kpsi [240 MPa], which is almost equal to that of A36 steel. This strength, coupled with its light weight (about one-third that of steel), makes aluminum particularly advantageous for structural applications where dead load is a concerned, **Kissell and Ferry 2002.** In this study circular tube made of aluminum alloy; 6061- T6 was used to encase column concrete. The aluminum alloy; 6061- T6 and A36 steel were tested in the laboratory by taking the specimens according to **ASTM E8, 2003,** which is a standard test method for tension testing of metallic materials and **ASTM B557, 2003,** which is standard test methods of tension testing wrought and cast aluminium and magnesium alloy products. The tensile testing is carried out by applying axial load at a specific extension rate to a standard tensile specimen till failure. **Fig. 1** shows the results of the stress strain curves for A36 steel and 6061-T6 and this figure showed converge between two metals especially in the elastic region between them. **Table 1** shows the properties of the aluminum alloy 6061-T6

Aluminum is inherently corrosion-resistant. Carbon steel has a tendency to self-destruct over time by virtue of the continual conversion of the base metal to iron oxide, commonly known as rust, **Kissell and Ferry 2002.** Properties that affect the performance of the aluminum alloy; 6061- T6 and A36 steel of structural members are summarized in **Table 2**.

3.1.2 Concrete material properties and mix proportions

Type I Portland cement, fine aggregate with (4.75mm) maximum size, coarse aggregate with (10mm) maximum size, water are used in casting columns. All the concrete of column are made from a single mix proportion (Cement: Sand: Gravel) of 1:1.5:3 by weight with a water /cement ratio 0.45, average compressive strength of concrete for three cylinder (150mmx300mm) at the time of column tests was 28.5 Mpa.

3.2 Test Specimens

A series of tubular concrete columns were manufactured and tested under concentric compression. The columns were prepared from the same batch of concrete. The experimental program is consisted of testing seven column specimens with same concrete diameter 100mm and without steel reinforcement and have been examined through experimental testing. Details of the columns are given in **Table 3**; four of them have aluminum tube thicknesses 2mm (C1), 3mm (C2), 4mm (C3) and 5mm (C4) which have the same length 450mm and the fifth specimens (CR) unconfined concrete column which is the reference specimen to study the effect of the thicknesses on the structural behavior of column as shown in **Fig. 2** and **Fig. 3**, the sixth specimens has thickness 5mm and length 700mm C7 to study the effect of length on the structural behavior of column as shown in **Fig. 4(a)** and the seventh specimen has thickness 5mm and length 450mm to study the effect of durability on the structural behavior of column the specimen exposed to aggressive solution for 120 days as shown in **Fig. 4(b)**. For the study the effects length and durability on the structural behavior of column the reference specimen was C5 which has thickness 5mm and length of 450mm.

3.3. Instrumentation and Testing

A total of 7 test specimens were constructed and tested under concentric axial compression loads. The columns were instrumented with dial gauges to measure axial deformation as well as circumferential strains.

Six electrical strain gauges were placed on the exterior surfaces of each column specimens to measure the vertical deformations and the perimeter expansion of the aluminium tubes in the mid-height region at symmetric locations, bonded either on the concrete surface in the case of unconfined column or on aluminium tubes in the case of confined columns, as shown in **Fig.5**.
The column specimens were placed directly into the testing machine for compression tests. A typical column test layout and instrumentation location is shown in **Figs. 6 and 7**. Prior to testing, all columns were capped with wood - bearing plate at both ends to ensure uniform distribution of the applied pressure. The columns were tested under axial compression using a 5000 kN-capacity universal testing machine. The specimens were loaded continuously until failure. A load interval of less than one-tenth of the estimated carrying load capacity was used. The progress of deformation, the mode of failure and the maximum load taken by the specimens were recorded.

4. TEST RESULTS AND DISCUSSION

The variable parameters in this study are the aluminum thickness that covered the columns from outside, the length of the column and durability

4.1 Aluminum Thickness

Five column specimens with same length 450mm are used to study the effect of the thicknesses on the structural behavior of column, four specimens have aluminum tube thicknesses 2mm (C1), 3mm (C2), 4mm (C3) and 5mm (C4) and the fifth specimen (CR) unconfined concrete column which is the reference specimens. For all five column specimens axial deformation and ultimate load were measured. **Table 4 and Fig. 8** show the ultimate load - axial deformation curves. These curves and table show that the strength of concrete is increased by the confining effect of aluminum tube for C2, C3, C4, C5 by 16%, 74%, 105%, 224% with respect to reference specimens CR respectively.
To the study the effect of columns thicknesses on the strength, the impact of the failure was as follows: reference specimen CR failure was by crushing the concrete at mid height, while C3-C4-C5 specimens have failed by buckling. It is therefore concluded that the use of aluminum tube with high resistance to confine the concrete from abroad led to a column thinness affected and thus led to the failure by buckling as shown in **Figs. 9, 10, 11** and **12**.
While C2 column has 2mm thickness failed by local buckling, as shown in **Fig. 13**. This is because the thickness of aluminum tube did not achieve the width thickness ratio for the tube, which is according to **Table 5** where the sections are classified as compact, noncompact, or slender-element sections. If the width thickness ratio D/t compression elements less than λp the section is compact. If the width thickness ratio D/t compression elements exceeds λp, but does not exceed λr the section is noncompact. If the width-thickness ratio of any element exceeds λr, the section is referred to as a slender-element section, from table B4.1in the steel construction manual, **AISC MANUAL, 2014**.

4.2 Length of the Column

To the study the effect of columns length on the strength, the specimen C6 has a length of 700mm with 5 mm thickness the decreased of strength was 0.06% than the specimen C5 with 5 mm thickness and length 450mm. The failure of the specimen C6 with a length of 700 have been affected by failure buckling substantially as shown in **Figs. 14** and **15** and **Table 6**. The specimens C6 has length of 700mm with thickness 5mm, the decreased of strength was 0.01% than the specimen C5 with same thickness and 450mm length.

4.3 Durability

The specimens C7 has length of 450mm with thickness 5mm, the decrease of strength was 0.06% than the specimen C5 with same thickness and length. The failures of two specimens (C7 and C5) have been affected by buckling failure. Therefore; no apparent difference has been found between the structural behavior of the specimen C7 that immersed in aggressive solution for 120 days and specimen C5 in air as shown in **Figs. 16, 17 and 18 and Table 7**.

5. CONCLUSIONS

This study deals with seven column specimens with same concrete diameter 100mm and without steel reinforcement. From experimental test results the following conclusions can be listed:

1. The greatest increase in axial compression load at the column has tube thickness 5mm and the lower increase in axial compression load the column has tube thickness 2mm in range (16% for C2 -224% for C5) if compared with reference specimens CR.
2. The specimens C6 decreased in strength by 0.01% than the specimen C5.
3. The specimens C7 decreased in strength by 0.06% than the specimen C5.
4. Five column specimens (C3, C4, C5, C6, C7) fail by buckling, one column specimen (CR) fail by crushing in concrete at mid height and one column specimen (C2) fail by local buckling.
5. It can be found that, the deformation of the top part of aluminium tube becomes more obvious for the specimen C2 with thinner thickness 2mm, in other words the local buckling occurred in the this specimen on the position near the top to outside of the specimen, thus can be concluded that the interaction between the aluminum tube and concrete is delayed by the restraint of the concrete to inside of the specimen but it is not delayed by the restraint of the concrete to outside of the specimen; therefore, it can be concluded in CFT column, local buckling may occur but in the research of, **Morino and Tsuda ,2014, it was** concluded that the local buckling of the steel tube is delayed by the restraint of the concrete to outside and inside of the specimen. Thus, in this work it was proved that possible occurrence of local buckling in CFT column even if there was a significant correlation between the concrete and material blocking confined.
6. The aluminum ratio in the filled aluminum tubular CFT cross section is much larger than in reinforced concrete and concrete-encased steel cross sections. Because of the aluminum of the CFT section is well plastified under bending and it is located most outside the section therefore; the strength of CFT columns increase.
7. Because of the Confining concrete filled aluminum tubular (CFT) columns can significantly increase their strength, ductility and durability thus, the confining concrete filled aluminum tubular (CFT) columns may be used in marine structures, pier of bridges and bearing bored piles in sand soil.
8. The aluminum tubes can be used as the formwork for casting concrete, thus Labor for forms and reinforcing bars is omitted.

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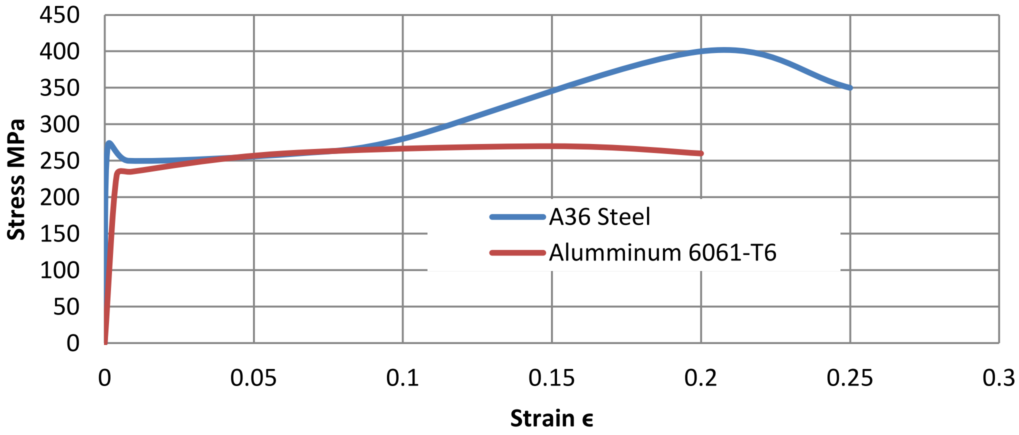

Figure 1. Comparison of the stress strain curve of A36 steel and 6061-T6

Table 1. Results of tensile test on Aluminum Alloy 6061-T6

Aluminum Alloy	**Yield strength**	**Tensile strength**	**Elongation**	**Poisson's ratio**	**Unit weight**	**Modulus of Elasticity, E**
6061-T6	230Mpa	290 Mpa	8%	0.33	27.10 kN/m^3	72000 MPA

Table 2 . Comparing common structural shapes and grades of two metals[7]&[9]

PROPERTY	**ALUMINUM 6061-T6**	**CARBON STEEL A36**
Corrosion resistance	good	fair
Tensile yield strength	230 MPa	275 MPa
Modulus of elasticity, E	72 GPa	207 GPa
Elongation	8% - 10%	20%
Density	27 kN/m^3	78 kN/cm^3
Fatigue strength (Plain metal, 5million cycles)	10.2 ksi	24 kpsi
Relative yield strength - to – weight ratio	2.8	1.0 to 1.4
Poisson's ratio	0.33	0.29
Thermal expansion coefficient, α	10^{-6} mm/(mm°C)	11.7 mm/(mm°C)

Table 3. Details of columns specimens

Specimen symbol	**Aluminum tubular thickness, mm**	**Description**	**Length of columns, mm**	**Exposed to aggressive solution Yes**
CR	0	Plain concrete	450	-
C2	2	Plain concrete - Aluminum tube	450	-
C3	3	Plain concrete - Aluminum tube	450	-
C4	4	Plain concrete - Aluminum tube	450	-
C5	5	Plain concrete - Aluminum tube	450	-
C6	5	Plain concrete - Aluminum tube	450	Yes
C7	5	Plain concrete - Aluminum tube	700	-

(a) (b)

Figure 2. Mould for specimens: (a) – CR and (b) - C2, C3, C4, C5, C6, C7.

Figure 3. Specimens CR, C2, C3, C4, and C5

(a) (b)

Figure 4. Specimens: (a)-C6 and (b)- C7.

Figure 5. Test for columns

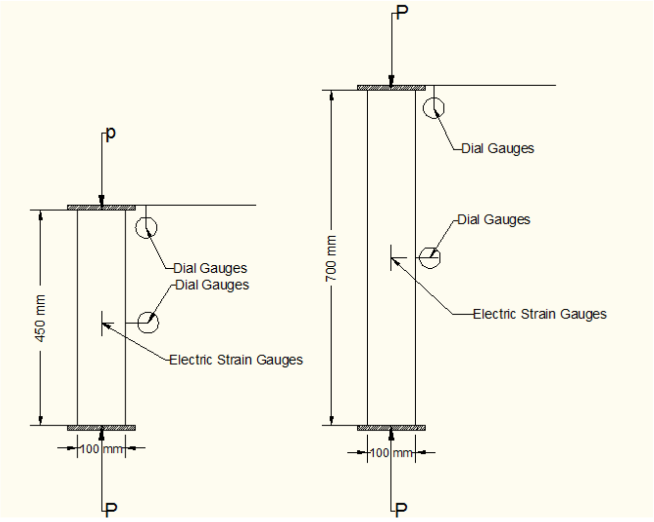

Figure 6. A typical column test layout and instrumentation

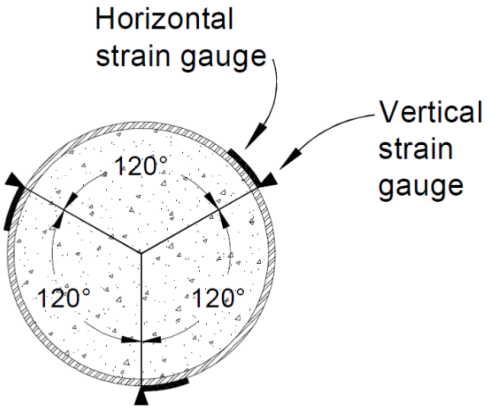

Figure 7. Longitudinal and transverse electric strain gauges

Table (4). Ultimate Load and mode failure for column specimens C2,C3,C4,C5 and CR

Specimen symbol	**Ultimate Load (kN)**	**C2,C3,C4,C5 / CR** ***Pu / Pco***	**Mode failure**
CR	190*	190/190=1.00	crushing
C2	220**	220/190=1.16	Local buckling
C3	330**	330/190=1.74	buckling
C4	390**	390/190=2.05	buckling
C5	426**	426/190=2.24	buckling

**Pco* : the ultimate load of unconfined concrete.

** *Pu* : the ultimate load of the hybrid column.

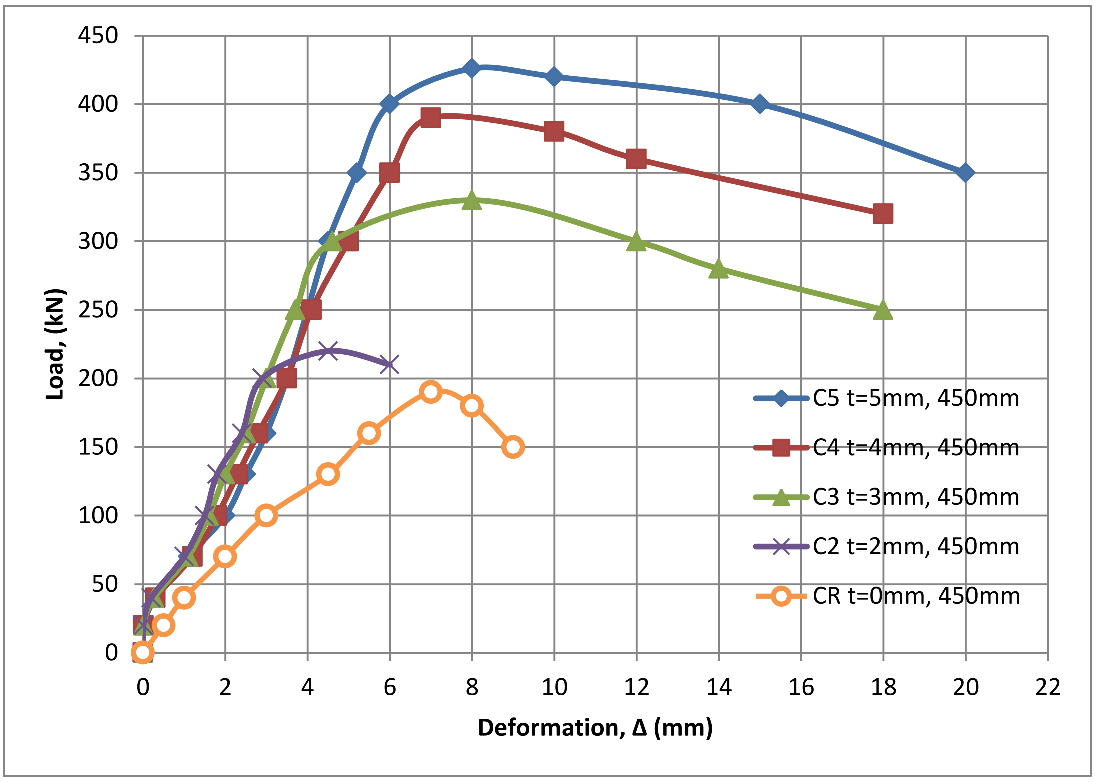

Figure 8. The ultimate load - axial deformation curves for CR, C2, C3, C4, C5.

Figure 9. Reference column CR ,t=0mm (mode failure) **Figure 10.** C3 ,t=3mm (mode failure)

Figure 11 C4 ,t=4mm (mode failure) **Figure 12.** C5 ,t=5mm (mode failure)

Figure 13. C2 ,t=2mm (mode failure)

Table 5. Limiting width-thickness ratios for compression elements

Limiting Width-Thickness Ratios for Compression Elements			
Description of Element	**Limiting Width Thickness Ratios**		
	Width Thickness Ratio	**λp (compact)**	**λr (noncompact)**
In uniform compression	D/t	NA	0.11 E/Fy
D/t =102/2=51 > λr = 0.11x E / Fy=0.11x72000/230 = 34.435 , therefore, The section is referred to as a slender-element section D = outer diameter of aluminum tube t = thickness of aluminum tube			

Table 6. Ultimate Load and mode failure for column specimens C5 and C6

Specimen symbol	Ultimate Load (kN)	C5,C6 / CR *Pu* / *Pco*	Mode failure
C5	426*	426/426=1.00	buckling
C6	422**	422/426=0.99	buckling

**Pco* : the ultimate load of hybrid column C5.

** *Pu* : the ultimate load of the hybrid column C6.

Figure 14. C7 , t=5mmwith length 700mm (mode failure)

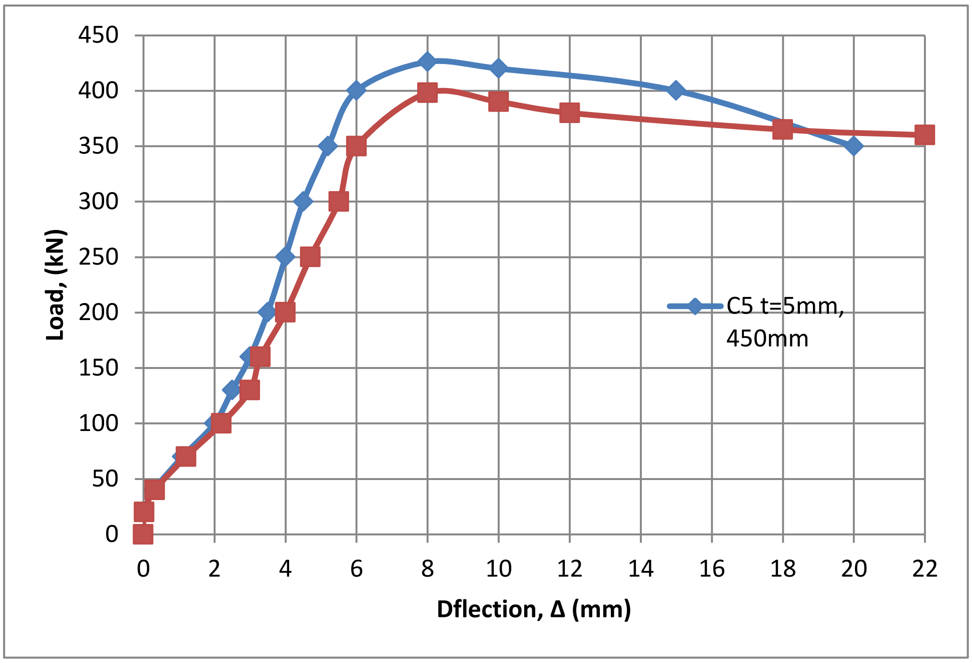

Figure 15. The ultimate load - axial deformation curves for C5 and C7.

Table 7. Ultimate Load and mode failure for column specimens C5 and C7

Specimen symbol	**Ultimate Load (kN)**	**C5,C7** ***Pu / Pco***	**Mode failure**
C5	426*	426/190=2.24	buckling
C7	398**	398/190=2.09	buckling

***Pco* : the ultimate load of hybrid column C5.

** *Pu* : the ultimate load of the hybrid column C7.

Figure 16. C6 ,t=5mm (mode failure)

Figure 17. C6 ,t=5mm, in aggressive solution

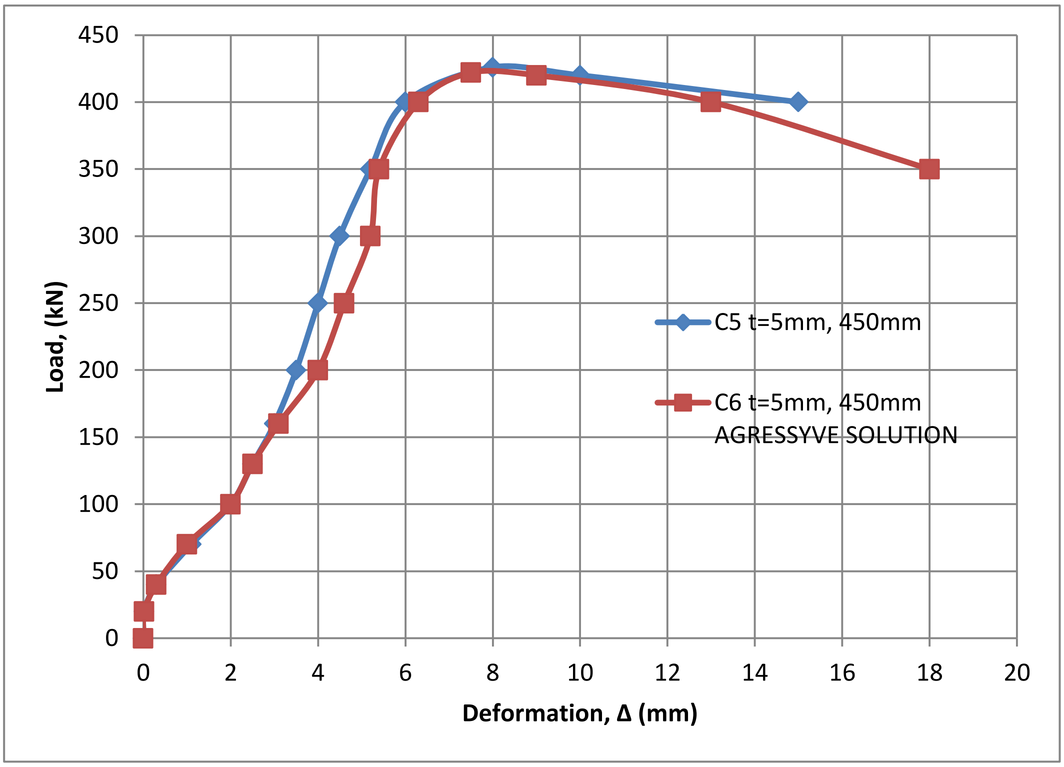

Figure 18. The ultimate load - axial deformation curves for C5 and C6.