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Finite Element Analysis of Concrete-filled Aluminum tube columns

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Abstract

The most important challenge facing the simulation of composite columns is possession of materials enter in into different properties .In concrete-filled aluminum tube column, there is an additional ingredient which is confining provided by the aluminum tube for the concrete infill. This study developed a nonlinear finite element model using cod ANSYS (R 15.0) to deal with characteristics for both concrete and aluminum accurately and reconcile with confining effect by the aluminum tube to concrete core. This model was approved by comparison of the previous experimental results of ultimate load capacity, load-axil shortening curves and their corresponding failure mode. The approved finite element model was then used to consider the influence of high strength concrete on the behavior of concrete-filled aluminum tube column circular section under axial load .The findings indicate the specimens with higher concrete strength (120MPa) experienced a significate increase of ultimate load capacity but decrease in ductility after failure due to the concrete infill attains to ultimate capacity before aluminum tube attains yield stress.

Keywords: Composite columns, aluminum tube, finite element, ANSYS (R 15.0), load capacity, ductility.

INTRODUCTION

Recently many different types of composite material systems have been widely applied to concrete column design to provide better performance in terms of high strength, stiffness and ductility, while most theses composite columns are fully encased steel concrete. So excessive experimental and analytical studies have done to comprehend the behavior of composite columns essential from the 1960, [1] .while the disadvantage of these compound is the impact of corrosion with time of construction or buildings. Which become pressing to find solution of this term was use for an alternative to steel, some of them stainless steel which expensive and tricky satisfied column requirement, so the material suitable for use is aluminum alloys practically advance in industrial can be jumbled with certain components and the outcome would be powerful alloy that resists the rust and have minus than steel weight. However, very few studies have been focused on composite columns concrete filled aluminum alloy. And that is available fixed on the experimental work.

Zhou and Young. [2] reported experimental studied of normal and high strength concrete filled Aluminum tube column; the specimens of concrete filled Aluminum tube were chosen with different geometrical dimension and subjected to axial load .The column strengths capacity, axial-load shortening effect, axial-load strain effect and modes of failure of columns were investigated Nayak et al. [3] examined the self-compacted concrete filled a hollow aluminum. The behavior, strength limited and compatibility were studied. The study has shown the combination of Aluminum tubes with self-compacted concrete is better use for construction.

Nasser. [4] created 24 specimens to investigate the structural behavior of concrete filled aluminum tubular columns under axial compression load, these tests were focused the effect of slender ratio and diameter ratio D/t of aluminum alloy on the axial load capacity. He found the experimentally magnitudes of predicted ultimate load agreed with the theoretical values from empirical equations.

From the Finite element method has appeared a state of precocity; numerical analysis can be used as good alternative to experiments to exam the conduct of composite columns.

There for the aims of this study is to understand the behaviors concrete-filled aluminum tube columns under axial static loading with simulation by Finite Element (FE) ,in order to reach this a nonlinear FE model was developed in ANSYS workbench (R15.0) software program .

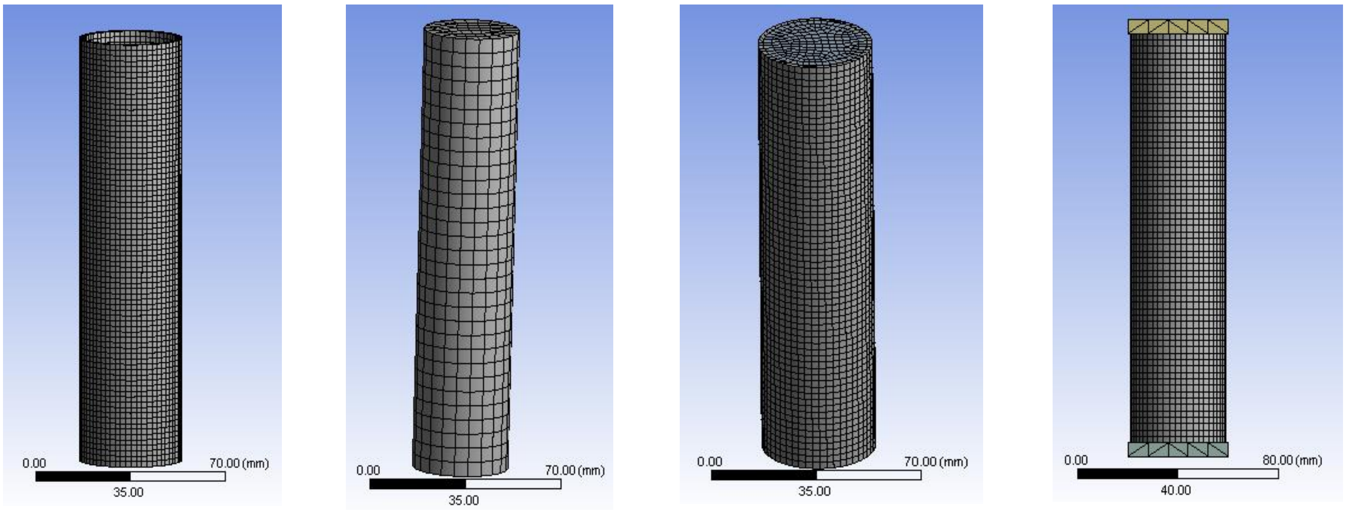
Pervious experimental results on concrete-filled aluminum tube got by Nayak at el. [3] and Nasser. [4] Used to verify the approval model.

FINITE ELEMENT MODELING

Meshing

The general purpose nonlinear finite element program ANSYS (R15.0) was used in the present study a Finite element for concrete-filled aluminum tube column. The concrete core was modeled by 8-node brick elements having three translation of freedom at each node. While the aluminum alloy was modeled by 4-node shell elements having three translation of freedom additional to passes rotational.

However, the size of element affects the computational time and accuracy. Based on the some tries to estimate an optimal elements size, the average mesh size taken was 5mm for the composite material concrete and aluminum tube. Fig. (1) illustrates the meshing array of the concrete –filled aluminum tube column circular cross section.



Aluminum tube | Concrete core | Concrete-filled aluminum tube | Column for test

Figure 1. Meshing of the concrete-filled aluminum tube columns

Loading and boundary conditions

The axial load must be accurately disturbed between two combination materials concrete and aluminum alloy, so two stiff steel caps placed one each at the top and the bottom of concrete-filled aluminum tube, these stiff steel caps models using solid element, to ensure the composite column dose not penetrate the steel caps, the stiffness of steel caps granite by taking the elastic modules of 2E+6Mpa.

While to the bottom steel cap was fixed completely against all degrees of freedoms, the concrete core and the aluminum tube are lifted free in all directions to examination the deformation that will happen in the column.

The axil compression load was applied at the top steel cap in vertical (Z axis) direction as piecemeal increase till achieve a load that caused the composite column infirm (high deformity with slight increases in axial load). Fig. (2) Shows the loading and boundary condition.

To represent the real behavior of concrete-filled aluminum tube columns under load and boundary conditions mentioned above the nonlinear buckling analysis was used because it is more efficient in placement nonlinear large deformation in ANSYS (R15.0).

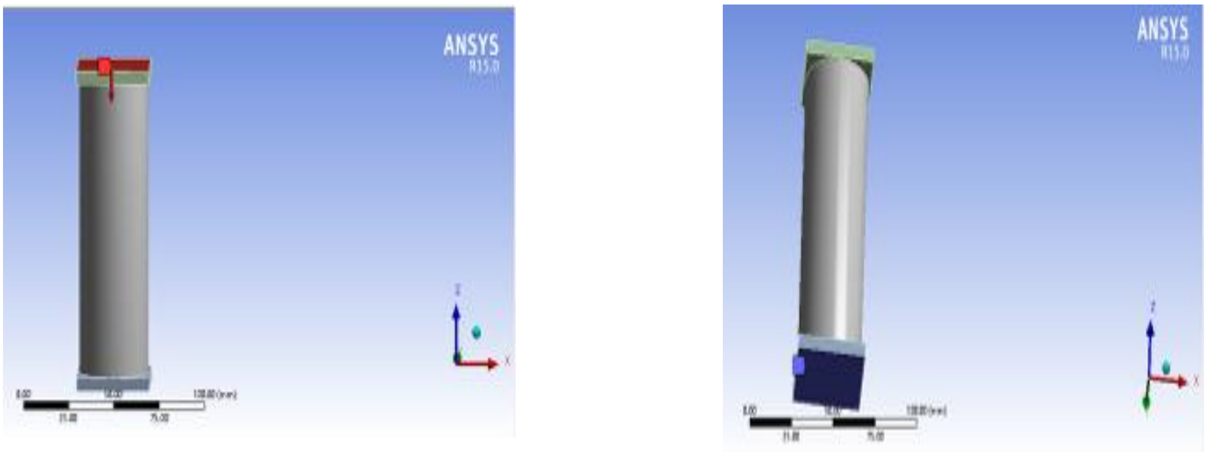


Figure 2. Loading and boundary condition

Body interaction

Body interaction means a body contact other body, the interaction between the component the concrete-filled aluminum tube column need to be defined in order to achieve no penetration in column component.

In steel tube filled by concrete surface to surface contact with provided friction widely used [5], and the fraction coefficients of 0.6, 0.3 and 0.25 were used by Han et al.[6], Lam et al.[7] and Schneider [8]respectively. In the current study, perfect connection between surface of the aluminum tube and concrete core surface and the coefficient of friction was taken as 0.6.

Which causes the compression to be commute across the two surface when there is a contact between them and the separation happens through the tension, while the pond type of connection which available in ANSYS (R15.0) laboratory was used for both top and bottom steel caps interaction with the concrete core and aluminum tube.

Material Modeling

For concrete-filled the aluminum tube column circular section under axial load represent clear picture shown the concrete core restricted laterally because it is confined by the aluminum alloy, so to simulate remarkable confinements provided by aluminum tube to concrete core a confined stress-strain model developed by Mander et al.[9]was used .Which provide increasing the strength and ductility of concrete. Fig.(3) depicts the comparison between confined and unconfined concrete, that graph for confined concrete is linear elastic up to $0.5f_{cc}$ and it is lead to using Poisson's ratio equal to 0.2.

While the aluminum alloys have anisotropic mechanical properties according to mix element and manufacture request Chen at el.[10],so in this study the stress strain curve for aluminum tube chosen the must fitted with the experimental tests provided by Nasser.[4]. Fig.(4) shows the stress strain curve for aluminum tube used in this study.

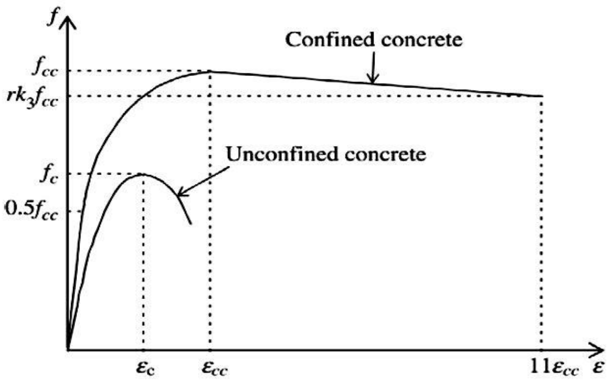


Figure 3. Stress-strain curves for both confined and unconfined concrete

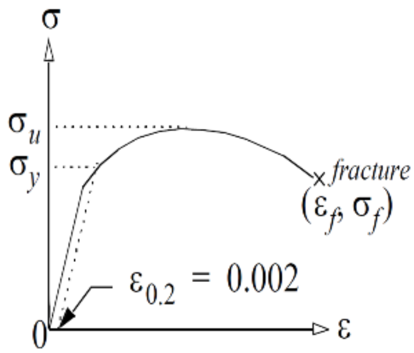


Figure 4. Typical stress-strain curve for aluminum tube

VALIDATION OF STUDY MODEL

To validate the current FE model represented in this study, previous experimental results obtained by other researcher for concrete filled aluminum tube columns circular section were comprised against results of the current FE model were carried out by ANSYS (R 15.0). A total 14 specimens were selected for this purposes, ten from Nasser.[4] and the remaining four from Nayak et al.[3].Table (1) gives the mentioned specimens dimensions and material properties, as shown all specimens group are shared of aluminum tube dimeter to wall thickness ratio (D/t) and varied in length to dimeter ratio(L/D).

Here three parameters are used to evaluate and compare the current model with the experimental investigation: the ultimate load capacity, the load-axial shortening and the failure models of columns.

Firstly, the comparison of the results obtained with the ANSYS (R15.0) model and experimental studies for ultimate load capacity was recorded in table (1), which clearly note the good agreement, with experiment to current model ratios approach to unity. Despite the change in values of D/L, the current model was no sensitive to produce well results compared with experimental result for composite column.

Table 1. Specimens dimensions and properties with the simulated results

Group No.	Source	Specimen No.	Outer Diameter, D(mm)	L/D	D/t	f_c (MPa)	$\sigma_{0.2}$ (MPa)	Experimental Load Capacity ,P_{exp} (KN)	FE Model Load Capacity ,P_{FE} (KN)	P_{exp}/P_{FE}
G1	Nasser	D1S3	38.0	3	11.9	24.1	241.4	148.5	154.69	0.96
		D1S4	38.0	4	11.9	24.1	241.4	145.8	150.31	0.97
		D1S6	38.0	6	11.9	24.1	241.4	143.7	148.8	1.02
		D1S8	38.0	8	11.9	24.1	241.4	141.9	137.77	1.03
		D1S10	38.0	10	11.9	24.1	241.4	138.9	136.18	1.03
G2		D2S3	50.0	3	16.7	24.1	253.6	170.4	181.28	0.94
		D2S4	50.0	4	16.7	24.1	253.6	168.6	175.63	0.96
		D2S6	50.0	6	16.7	24.1	253.6	165.1	168.47	0.98
		D2S8	50.0	8	16.7	24.1	253.6	162.8	167.84	0.97
		D2S10	50.0	10	16.7	24.1	253.6	161.8	158.63	1.02
G4	Nayak et al.	19	100.0	3	33.3	24.1	214	547.2	521.14	1.08
		20	100.0	4	33.3	24.1	214	539.1	518.36	1.04
		21	100.0	6	33.3	24.1	214	535.0	509.52	1.05
		22	100.0	8	33.3	24.1	214	537.3	488.45	1.10
Average										1.01

While the load-axial shortening behavior of five specimens of concrete –filled aluminum tube namely D2S3, D2S4, D2S6, D2S8 and D2S10, was also compared, the specimens were chosen according availably experimental date. Fig(5) illustrates the comparison between the experimental and currant FE model load-shortening relation. With supper success the current model presents the relationship between load and axial shortening, it can be shown the correlated the FE current model with experiment through elastic and plastic stages, and the proposed current model display offer an excellent ductile for its experiment match.

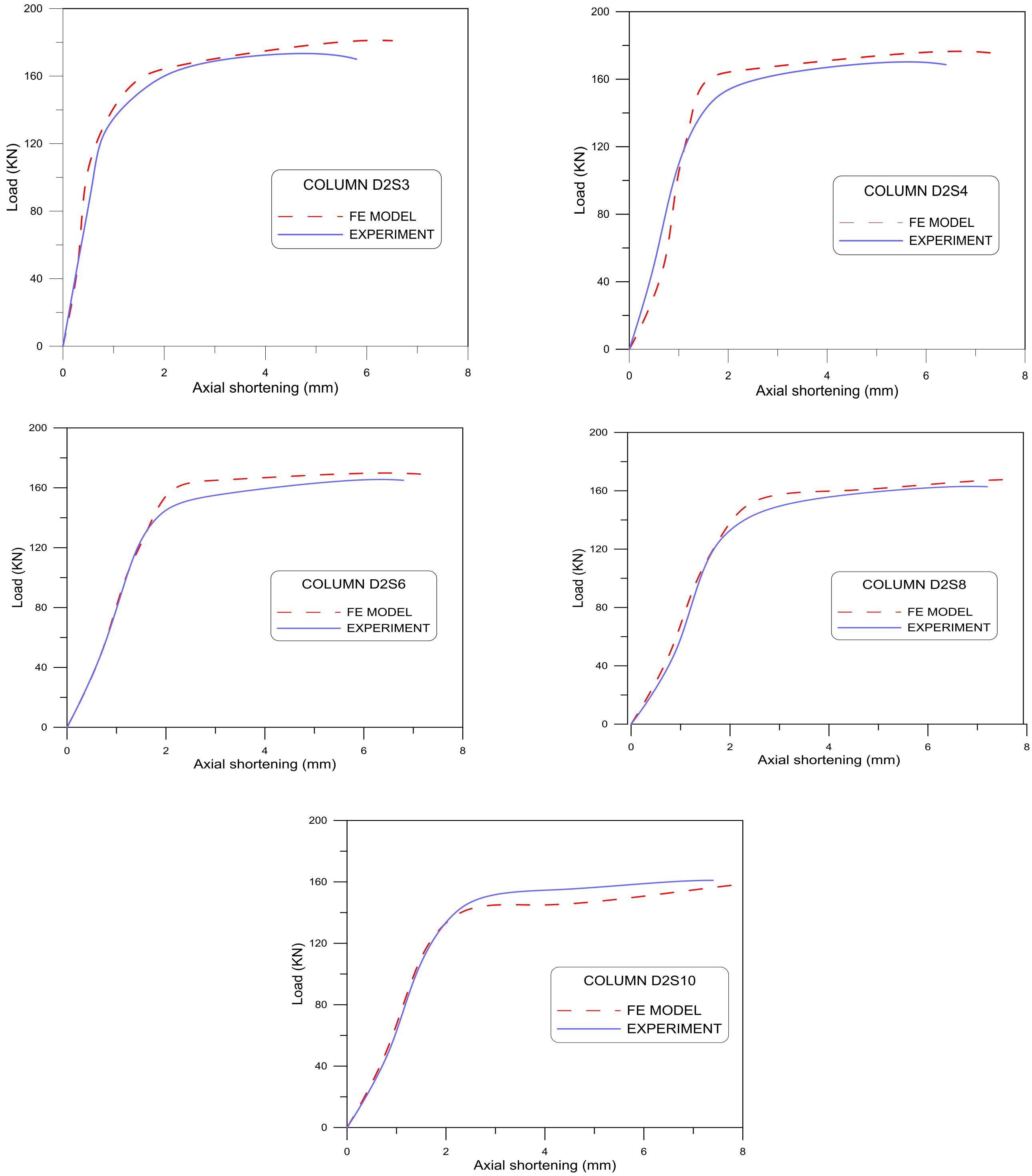


Figure 5. Experimental versus current FE model for columns in G1.

Once again, the current FE model was used in this study continues its level in simulating the behavior of concrete-filled aluminum tube column when the failure mode was compared with experimental failure shape. Fig(6) elucidated this comparison between deformation shape priors to failure to experimental failure mode for specimens namely D1S3 and D1S8 .

Shorting specimen (D1S3) has failed by shear mode near the applying load end .while the specimen (D1S8) ,which most slender composite column failed by local buckling at the mid height of composite column. Both types of failure mod were fairly matching with observed experimental failure mode.

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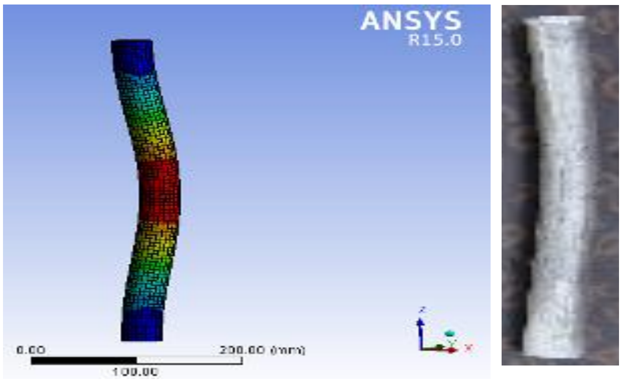
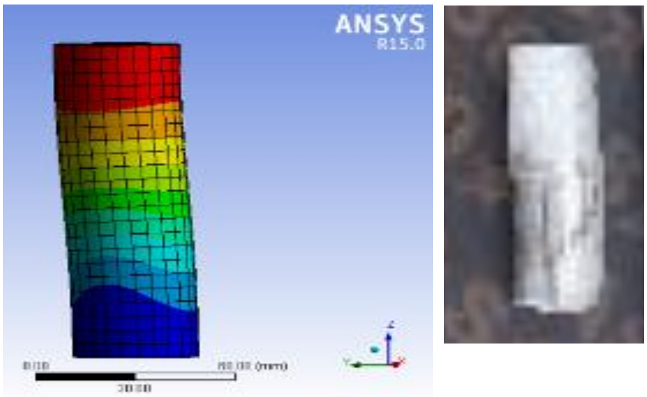


(a) (b)

COLUMN D1S8



(a) (b)

COLUMN D1S3

Figure 6. Typical (a) FE model and (b) Experimental deformed shapes for columns D1S8 and D1S3

PARAMETRIC STUDY

At present high quality construction material, such us high grade concrete is being accelerated used in engineering structures as a score of the continued improvement of materials technology [11]. And with the interesting results were obtained using the current FE model compared to experimental test of concrete-filled aluminum tube column, so this study invests that model to simulate the high concrete strength in concrete-filled aluminum tube column.

A total of 9 columns were presumed to investigate the effect of high grade concrete on the behavior of concrete-filled aluminum tube columns. Table [2] summaries the dimensions and properties of the specimens modeled in ANSYS (R15.0). The grade of concrete was taken 40,80 and 120MPa.The D/t was fixed in each of group and variable for other set, while the D/L was chosen a constant for all the columns to focus the study for leverage of high concrete strength to the behavior of concrete-filled aluminum tube column.

DISCUSSION

The ultimate resistances for the concrete-filled aluminum tube column circular section was derived by FE model using program ANSYA (R15.0) are shown in the table no.[2]it was clear that for all the specimens under the investigation effect by changing the grade of concrete and pointed the ultimate load resistances of the composite columns shared to rise with increasing grade of the concrete infill.

While the obtained peak ultimate loads values compared to approach values which are predicted by specification for composite columns in the ACI Code[12] using for concrete infill ($0.85A_cf_c$) and additional to strength of the aluminum alloys ($A_a\ F_L$) as shown in Equ(1)

$$P_{ACI} = A_a\ F_L + 0.85A_cf_c \quad (1)$$

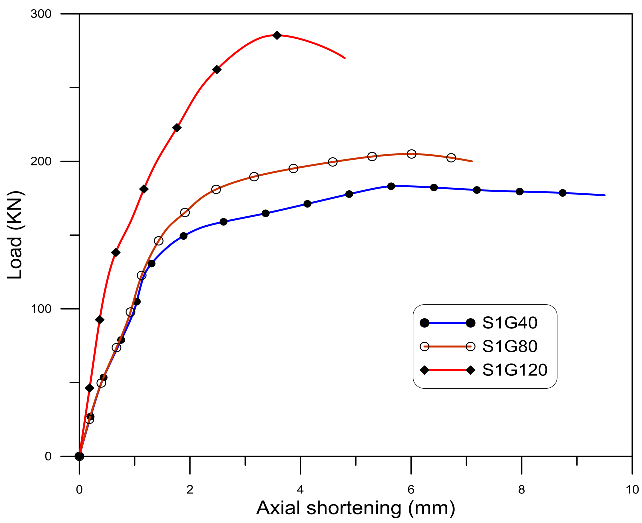
Where A_a and A_c are the cross-sectional areas of the aluminum tube and the concrete core respectively, F_L is the limit state stress obtained from laboratory tensile test done by Zhou and Young [2], f_c is cylinder strength of the concrete.

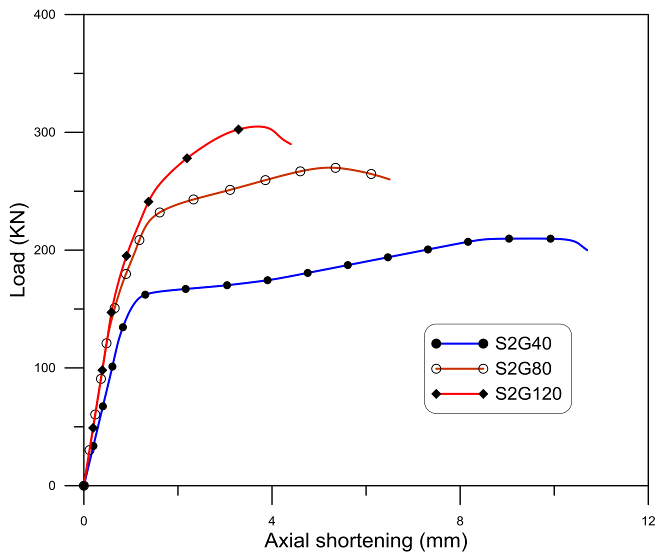
Table 2: Summaries the dimension and properties of the specimens with the results

Group No.	Column No.	Outer Diameter, D(mm)	L/D	D/t	f_c (MPa)	$\sigma_{0.2}$ (MPa)	FE Model Load Capacity ,P_{FE} (KN)	ACI Approach Load Capacity, P_{ACI}	P_{FE}/P_{ACI}
1	S1G40	38	3	9.7	40	242.4	183.48	125.67	1.46
	S1G80	38	3	9.7	80	242.4	205.57	150.05	1.37
	S1G120	38	3	9.7	120	242.4	228.49	174.42	1.31
2	S2G40	50	3	16.0	40	238.4	209.30	161.00	1.30
	S2G80	50	3	16.0	80	238.4	270.20	211.10	1.28
	S2G120	50	3	16.0	120	238.4	302.69	263.21	1.15
3	S3G40	60	3	23.6	40	237.8	222.17	189.89	1.17
	S3G80	60	3	23.6	80	237.8	294.70	270.41	1.09
	S3G120	60	3	23.6	120	237.8	396.55	350. 93	1.13
Average									1.25

It has been investigated that current FE model results significantly over estimated the ACI approach ones, this is because the rising strength of concrete by the confinement behaver output from the existence of the aluminum tube as coat. The ratio of the ultimate load capacity amounts of current FE model to product by ACI approach ones were tabulated in table (2).

On the other hand, applied load-axial displacement relationship was measured and plotted for concrete filled aluminum tube column for all the specimens .Fig(7) demonstrates the valuation that obtained from ANSYS (R 15.0)by current FE model. It was clear the slop of the curve at elastic part was large for greater concrete infill strength; grade 80 and 120 MPa, while the ductility was greater in specimens with less concrete infill strength.as well as there was a significant difference in patterns with columns have large strength infill than lower strength infill lead to believe in specimens with large strength infill the aluminum tube attain the yield stress after the concrete-infill attain ultimate load, this is not the status lower strength infill where the aluminum tube reach yield stress before concrete-infill attain the ultimate load.





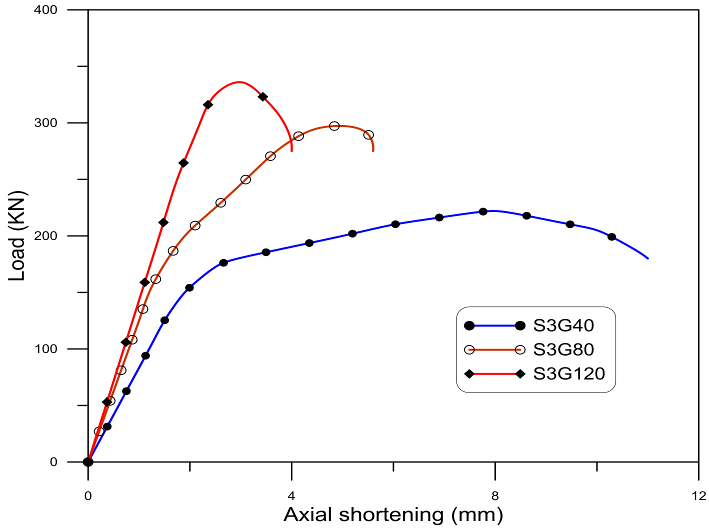


Figure 7. Load- Axial shortening curves for high grade concrete infill specimens

CONCLUSION

The paper presents a study of behavior of concrete-filled aluminum tube columns with circular sectional subjected to axial compression load. The finite element formula ANSYS (R 15.0) was invested to perform nonlinear buckling. A confine and typical stress-strain curves were used for concrete infill and aluminum tube respectively. Previous experimental outcomes were used to validate that the reliable of the applied model as ultimate load capacity, axial load displacement curves and deformed shape were compared to applied model .It is investigated the applied model gave equitable results to discover the behavior of concrete-filled aluminum tube columns with circular section. The excellent correlation obtained between the experimental and applied FE model so encourage one to expand critical analysis of simulated high quality materials such as the concrete. Herein the effect of high grade concrete infill investigated as parameter study. The ultimate load resistances of the concrete-filled aluminum tube also were estimated using approach ACI cod for composite column.

It is noted that:

1- The proposed FM model in this study is considered to be highly accurate in simulating behavior of concrete-filled aluminum tube column circular section and able to perform critical specifications that difficult to control in the laboratory such as highly strength concrete.

2- The applicate axial load resistance of concrete-filled aluminum cube column increases due to raising the strength for concrete infill. Meanwhile for high strength concrete infill (120 MPa) the concrete attain ultimate load capacity before aluminum attains the yield stress, that lead to constricts the ductility of composite column.

3- The ultimate load capacity provided by the proposed FE model was overestimated against ACI approach equation due to the confined effect the aluminum tube to concrete core, while that effect was not included in rule of ACI approach for composite column.

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NOTATION

The following symbols are mentioned in this paper:

D Outer diameter of aluminum circular hollow section tube, mm

f_c Unconfined concrete cylinder strength, MPa

f_{cc} Confined concrete cylinder strength, MPa

σ_u Static ultimate stress, MPa

$\sigma_{0.2}$ Static 0.2% proof stress, MPa

L Length of column specimen, mm

t Thickness of aluminum circular hollow section tube, mm

P_{FE} Proposal FE model load capacity, KN

P_{exp} Experimental load capacity, KN

A_c Cross –section area of concrete core, mm^2

A_a Full cross- section area of aluminum tube, mm