Kufa Journal of Engineering (K.J.E)
ISSN 2207-5528
Vol. 5, Issue 2, June, 2014
Printed in Iraq

EXPERIMENTAL AND COMPUTATIONAL STUDY OF CONCRET FILL ALUMINUM TUBULAR COLUMN UNRDR AXIAL LOADS

Lecturer Kadhim Zuboon Nasser
Department of Civil Engineering
University of Basrah, Iraq
Kadhim Zuboon@yahoo.com

Received: 7 /9 / 2011 Accepted: 27 11/ 2013

Abstract

This work deals with an experimental and computational study was carried out on the structural behavior of circular concrete filled aluminum tubular columns subjected to increasing axial load. Twenty four specimens were tested to investigate the effect of diameter, D/t ratio and slenderness ratio of a aluminum tube on the load carrying capacity of the concrete filled tubular columns. Diameter to wall thickness ratio between $23.3 \leq D/t \leq 47.8$, and the length to tube diameter ratio of $3 \leq L/D \leq 10$ was investigated. The structural performance of the concrete-filled aluminum tube columns (CFTa) was investigated using constant concrete cylinder strengths of 24.2 MPa. The main purpose of the computational study aimed to investigate the potential of using fuzzy inference system (FIS) to predict the strength of the composite columns. Fuzzy inference system (FIS) model has been provided to be very effective in predicting the ultimate strength of aluminum-concrete composite columns. The average values of ratios of experimental to predicted ultimate loads are 1.001 for the Sugeno FIS model. The circular hollow section tubes were fabricated by extrusion using 6061-T6 heat-treated aluminum alloy.

Keywords: Columns, Composite, Fuzzy Logic, Concrete, Filled Steel Tube.

دراسة عملية وحسابية للأعمدة المركبة من أنابيب الألمنيوم والكونكريت تحت تأثير الأحمال المحورية

م.كاظم زيون ناصر/جامعة البصرة/كلية الهندسة

الخلاصة

يقدم هذا البحث دراسة عملية وحسابية لخواص الأعمدة الدائرية المكونة من أنابيب الألمنيوم والمملوءة بالكونكريت و المعرضة إلى أحمال محورية متزايدة. تم فحص أربعة وعشرون نموذج لدراسة تأثير القطر ، نسبة القطر \ السمك ونسبة النحافة لأنابيب الألمنيوم وتأثيرها على تحمل الأعمدة الأنبوبية المملوء بالكونكريت. تم اختيار نسبة القطر \ السمك ما بين (47.8 - 23.3)ونسبة الطول \ القطر ما بين (3 - 10). التصرف الإنشائي لأعمدة الألمنيوم والمملوء بالكونكريت تم دراستها باستخدام مقاومة انضغاط ثابتة مقدارها 24.2 MPa. الهدف الأساسي من الدراسة الحسابية هو دراسة كفاءة استخدام نظام الاستدلال الضبابي في تقدير مقاومة الأعمدة المركبة. لقد اثبت بان نظام الاستدلال الضبابي دقيق في تقدير مقاومة الأعمدة المركبة. كانت القيم المتوسطة لنسب المقاومة المختبرية إلى المقاومة المقدرة هي 1.001 باستخدام طريقة Sugeno في الاستدلال الضبابي .الأنابيب الدائرية المجوفة كانت باستخدام سبيكة الألمنيوم نوع 6061 – T6 والمعامل حراريا.

Kufa Journal of Engineering (K.J.E)
ISSN 2207-5528
Vol. 5, Issue 2, June, 2014
Printed in Iraq

1. Introduction

Composite columns have been widely used in the construction industry for a number of years. The increase in the use of the concrete filled steel columns throughout the world in recent years is mainly due to the significant advantages that concrete filled steel columns offer in comparison to more traditional construction methods. Composite columns consist of a combination of concrete and steel, and make use of these constituent material's best properties. The use of composite columns can result in significant savings in column size, which ultimately can lead to significant economic savings. This reduction in column size can provide substantial benefits where floor space is at a premium such as in car parks and office blocks **(Lam D. and Wong 2005).**

It is well known that concrete-filled steel composite columns have the advantages of high-bearing capacity and ductility, easy construction and cost saving **(Schneider 1998, Lam and Wong 2005, Usami 1992, Garder and Jacobson 1967, Han et al 2004, and Yang and Han 2006)**. Similarly, aluminum tube columns filled with concrete can effectively take advantages of these two materials to provide both high strength and high stiffness. There are many advantages in using aluminum alloy as a structural material, such as appearance, lightness, corrosion resistance and ease of production. Furthermore, the aluminum tubes surrounding the concrete eliminate permanent formwork, and as such, construction time may be reduced.

However, little research has been carried out on concrete-filled aluminum tube composite columns. Hence, there is a need to investigate the structural performance of concrete-filled aluminum tube columns **(Zhou and Young 2008, Zhou and Young 2009, and Nasser 2012**).

Composite columns are a very important application of composite construction. The principle of a column is to deliver vertical forces to the base of a structure, with the term 'composite column' **(Hong and Kim 2004)** referring to a compression member in which a steel element acts compositely with the concrete element. The role of the concrete core in a composite column is not only to resist compressive forces but also to reduce the potential for buckling of the steel member. The steel tube reinforces the concrete to resist any tensile forces, bending moments and shear forces.

2. Experimental Study

In the experimental study a total of twenty four columns were tested under axial compression. The aluminum tubes were fabricated by extrusion using 6061-T6 heat-treated aluminum alloy. Standard tensile coupon tests were conducted to measure the material properties of aluminum tubes. Coupon specimens were of 6 mm wide with a gauge length of 25mm were cut from the tube walls. Properties obtained from the tensile coupon tests are summarized in **Table 1**, which includes the static 0.2% tensile proof stress ($\sigma_{0.2}$) obtained from stress - strain curve. Nominal dimensions of each tube are outside diameter and wall thickness are measured at several locations, to determine the properties of tubes. The measured diameter to thickness ratio (*D/t*) of the CFTa ranges from 23.3 to 47.8. The column length to diameter (*L/D*) ratio for the CFTa ranges from 3 to 10 ($3 \leq L/D \leq 10$). The measured dimensions and details of the CFTa columns tested specimen are shown in Table 1. The program consisted of four groups (S_1-S_4).

For each group, six specimens were prepared. The first specimen of each group is without concrete infill and with constant *L/D* equal to 3. The other five specimens from each group were filled with concrete and were of (*L/D*) ranged from 3 to 10.

Concrete with strength of 24.2 MPa was produced using commercially available materials with normal mixing and curing techniques. Mix design was carried out in accordance with the American Specifications **(ACI 2008).**

The aluminum hollow section stub column without concrete infill were also tested as a reference specimen. All specimens were tested up to failure.

Table1 gives the details of the columns including their designation. The specimens designation which shown in the second column of **Table 1** as follow:

- The first two number indicated the diameter (D) of specimens.
- The second two letter indicated the slender ratio (*L/D*) of specimens.
- For specimens without concrete infill follow by letter (*E*).

2.1Testing of CFTa

Twenty four tubes including four hollow tubes **(as shown in Table 1)** were tasted after 28 days under axial compression using a Torsee's universal testing machine with a capacity of 1000 kN at the laboratory of construction materials-University of Basrah. The vertical displacement of the lower movable head of the testing machine was measured in relation to the upper head of the testing machine by a dial gauge with magnetic base. This measured displacement was assumed to be equal to the vertical shortening of the test specimen. Readings of applied load and displacement were recorded at regular intervals during the tests. **Figure 1** depicts the test setup.

Kufa Journal of Engineering (K.J.E)
ISSN 2207-5528
Vol. 5, Issue 2, June, 2014
Printed in Iraq

*Table 1 Measured Test Specimens Dimensions of Circular Hollow Sections and Test Results**

Group No.	Column designation	External Diameter, *D* (mm)	Tube Thickness *t* (mm)	Length, (mm)	*L/D*	*D/t*	$\sigma_{0.2}$ (MPa)	P_{al} (kN)	Ultimate compressive load(P_{co})(kN)	P_{co}/P_{al}
	$38S_3E$	38.1	1.62	114.3	3	23.5		49.7		1.59
	$38S_3$	38.1	1.62	114.3	3	23.5			79.3	
S_1	$38S_4$	38.1	1.62	152.4	4	23.5	243.1		78.2	
	$38S_6$	38.1	1.62	228.6	6	23.5			76.7	
	$38S_8$	38.1	1.62	304.8	8	23.5			75.6	
	$38S_{10}$	38.1	1.62	381.0	10	23.5			74.3	
	$50S_3E$	50.2	1.6	150.6	3	31.4		65.2		2.00
	$50S_3$	50.2	1.6	150.6	3	31.4			130.8	
S_2	$50S_4$	50.2	1.6	200.8	4	31.4	251.4		127.6	
	$50S_6$	50.2	1.6	301.2	6	31.4			124.5	
	$50S_8$	50.2	1.6	401.6	8	31.4			121.5	
	$50S_{10}$	50.2	1.6	502.0	10	31.4			118.5	
	$60S_3E$	60.0	2.58	180.0	3	23.3		120.8		1.672
	$60S_3$	60.0	2.58	180.0	3	23.3			202.0	
S_3	$60S_4$	60.0	2.58	240.0	4	23.3	249.7		198.7	
	$60S_6$	60.0	2.58	360.0	6	23.3			194.5	
	$60S_8$	60.0	2.58	480.0	8	23.3			191.8	
	$60S_{10}$	60.0	2.58	600.0	10	23.3			189.6	
	$100S_3E$	100.3	2.1	300.9	3	47.8		165.4		2.54
	$100S_3$	100.3	2.1	300.9	3	47.8	241.7		420.7	
S_4	$100S_4$	100.3	2.1	401.2	4	47.8			414.7	
	$100S_8$	100.3	2.1	802.40	8					
	100S10	100.3	2.1	1003.0	10	47.8			398.5	

* P_{co} is the ultimate load of Aluminum-concrete composite columns and P_{al} is the ultimate load of aluminum tube columns.

2.2 Test Result

The test strengths were measured for each column specimens. Also, load–axial shortening relationship were measured for series S_2 and S_3. The test strengths (P_{co}) of the concrete-filled aluminum tube columns are shown in **Table 1**.

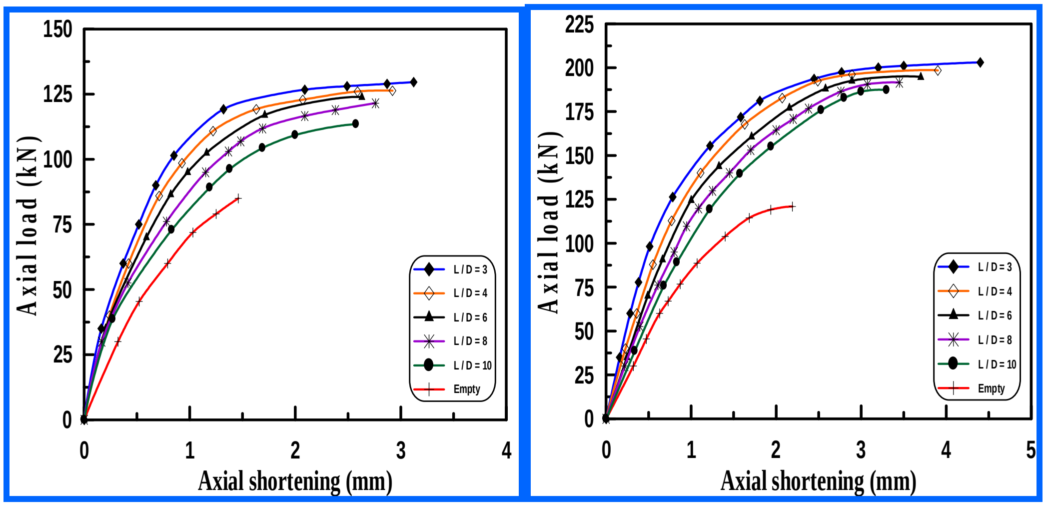
Fig. 1 Test Setup

From this table, it can be seen that the use of aluminum tubes increases the load carrying capacity of concrete columns. For all the specimens, the ratio P_{co}/P_{al} is always larger than one, ranging between 1.596 and 2.554.The average increase in strength is of the order of 95.45 %. As explained above,this increase in strength is due to the confinement of the concrete by the aluminum tube.

The load-axial shortening relationship of the concrete-filled aluminum columns for series S_2 and S_3 obtained from the displacement readings are shown in **Figure 2**.

The initial parts of the load-axial shortening curves of the concrete-filled aluminum tube columns have larger slopes compared with the aluminum tube columns without concrete infill. It is shown that the stiffness of the composite columns improves. It is also noted that the ductility of concrete- filled aluminum tube columns increase with using aluminum tube columns especially for the relatively slender section of S_2 and S_3 as shown in **Figure 2**.

Kufa Journal of Engineering (K.J.E)
ISSN 2207-5528
Vol. 5, Issue 2, June, 2014
Printed in Iraq



a :S_2 b :S_3

Fig. 2 Load-Displacement Relationship of Specimens: (a) S_2 and (b) S_3

Table 1 demonstrates the effect of the column slenderness ratio on the ultimate strength of aluminum-concrete composite columns. As it evidents from this table, the increase of the slenderness ratio led to decrease ultimate strengths.

The failure mode for the aluminum–concrete composite column are shown in Figure 3. The typical failure mode for short and intermediate length columns (*L/D* = 3-4) is a classical shear mode failure.

For the most slender composite columns (*L/D* = 6-10), the failure mode of specimens fail by a long column buckling mode failure as shown in Fig. 3a,b for series S_2 and S_3 respectively.

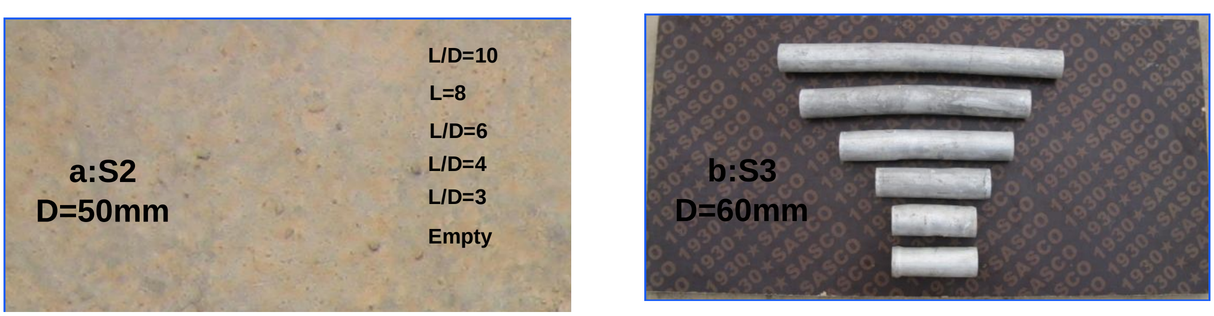


Fig. 3 Failure Modes of Specimens

Kufa Journal of Engineering (K.J.E)
ISSN 2207-5528
Vol. 5, Issue 2, June, 2014
Printed in Iraq

3. Fuzzy Sets and Logic

Zadeh 1965 introduced the concept of fuzzy logic instead of two-valued Aristotelian logic (1 or 0, exist or not exist) in dealing with logical statements. Fuzzy approach considers cases where linguistic uncertainties play some role in the control mechanism of the phenomena concerned. Herein, uncertainties do not mean random, probabilistic and stochastic variations, all of which are based on the numerical data. **Zadeh** has motivated his work on fuzzy logic with the observation that the key elements in human thinking are not numbers but levels of fuzzy sets. Further he saw each linguistic word in a natural language as a summarized description of a fuzzy subset at a universe of discourse representing the meaning of this word. In consequence, he introduced linguistic variables as variables whose values are sentences in a natural or artificial language **(Mustafa Sarıdemir 2009)**.

linguistic variables of ultimate strength of aluminum-concrete composite column is adopted. The fuzzy logic definition in the following sequel is tailored to this study, however, a simplified view of application to ultimate strength of aluminum- concrete composite column modelling which in many ways is very similar to the established use of fuzzy logic in the control of dynamic systems, also known as “fuzzy logic control”. In both contexts, fuzzy propositions, i.e. IFTHEN statements are used to characterise the state of a system and the truth value of the proposition is a measure of how well the description matches the state of the system. Fuzzy logic has been developed since then and is now being used especially in Japan for automatic control for commercial products such as washing machines, cameras and robotics. Many textbooks provide basic information on the concepts and operational fuzzy algorithms **(Sagban 2010,Klir and Fogel 1988,Kosko 1992, Zadeh and Kacprzyk 1992)**. The key idea in the fuzzy logic is the allowance of partial belonging of any object to different subsets of the universal set instead of belonging to a single set completely. Partial belonging to a set can be described numerically by a membership function which assumes values between 0 and 1 inclusive. For instance, Figure 4 shows typical membership functions for small, medium and large class sizes in a universe, U. Hence, these variables assignments are the fuzzy subsets of the universal set. In this figure, set values less than 2 are definitely “small”; those between 4 and 6 are certainly “medium” and values larger than 8 are definitely “large”. However, intermediate values such as 2.2 partially belong to the subsets “small” and “ medium”. In fuzzy terminology 2.2 has a membership value of 0.9 in “small” and 0.1 in “medium” but 0.0 in “large” subsets. The literature is rich with references concerning the ways to assign membership values or functions to fuzzy variables. Among these ways are intuition, inference, rank ordering, angular fuzzy sets, neural networks, genetic algorithms, inductive reasoning, etc.**(Topcu and Saridemir 2008)**. Intuition involves contextual and semantic knowledge about an issue; it can also involve linguistic truth values about this knowledge **(Kirschfink and Liven 2000)**. Even if the measurements are carefully carried out as crisp quantities they can be fuzzified. Furthermore, if the form of uncertainty happens to arise because of imprecision, ambiguity or vagueness, then the variable is fuzzy and can be represented by a membership function. Unlike the usual constraint where, say, the variable in Fig. 4 must not exceed 2, a fuzzy constraint takes the form as saying that the same variable should preferably be less than 2 and certainly should not exceed 4. This is tantamount in fuzzy sets terms that values less than 2 have membership of 1 but values greater than 4 have membership of 0 and values between 2 and 4 would have membership between 1 and 0. In order to simplify the calculations, usually the membership function is adopted as linear in practical applications. The objective then can be formulated as maximizing the minimum membership value, which has the effect of balancing the degree to which the objective is attained with degrees to which the constraints have to be relaxed from their optimal values **(Mustafa Sarıdemir 2009).**

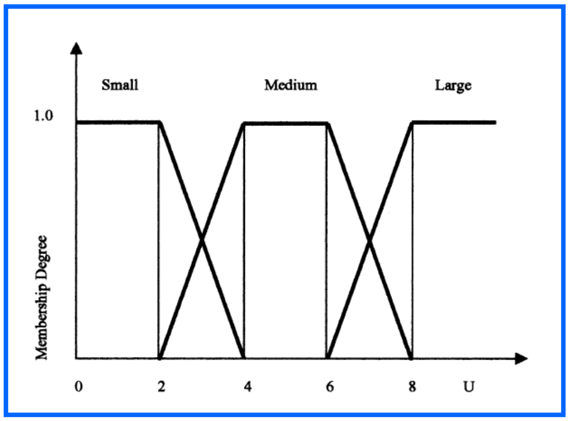


Fig. 4 Fuzzy Subsets.

3.1 Fuzzy Rule Base

In the present study, fuzzy logic is used to estimate the ultimate strength of aluminum-concrete composite columns under axial compression loads. For control purposes, fuzzy sets can be used to set up rules of the following forms:

R: IF the value of variable X_1 is “large” and variable X_2 is “medium” THEN

the result *Y* is “small”…………………….eq. (1)

This statement resembles human thinking more closely than any explicit mathematical rules. Therefore, FLS can be used for modeling the behavior of a human expert. Besides, it is also very effective in relating a set of outputs to a set of inputs without specifying a mathematical model, and here a ‘‘fuzzy inference procedure’’ becomes dominant. In the modeling of human expert thinking, the input variables are first specified by fuzzy subsets such as ‘‘large’’ andthen fuzzy rules similar to Eq. (1) are developed on the basis of the experts’ knowledge and experience. In the fuzzy inference method, sets of corresponding input and output measurements are provided to the FLS, and it learns how to transform a set of inputs to the corresponding set of outputs through a Fuzzy Associative Map. The fuzzy logic approach does not provide a rigorous way for developing or combining fuzzy rules, which can be achieved through many ways. The method adopted in this paper is outlined below.

First the input and output variables are divided into a number of subsets with simple triangular fuzzy membership functions. Generally, there are n^m fuzzy rules where n and m are the numbers of subsets and input variables, respectively.

In the case, say, of two inputs X_1 and X_2 with m subsets each, the rule base takes the form of an output Y_k (k=1,2,…,m^2). If there are two input variables as X_1 with "very small" and "small" fuzzy subsets and X_2 say, "medium" and "large" subsets then there will be four rules as:

R_1: IFX_1 is very small and X_2 is medium THEN Y_1
R_2: IFX_1 is very small and X_2 is large THEN Y_2
R_3: IFX_1 is small and X_2 is medium THEN Y_3
R_4: IFX_1 is small and X_2 is large THEN Y_4

For each triggered rule the membership degrees for both X_1 and X_2 are computed and these are multiplied to give the weight W_k to be assigned to the corresponding output Y_k. Hence, the weighted average of the outputs from four rules gives a single output, y, as

$$y = \frac{\sum_{k=1}^{4} W_k Y_k}{\sum_{k=1}^{4} W_k} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots eq.(2)$$

Thus once the rule base is set up, values of the output can be computed from Eq. (2) for any combination of input variables fuzzy subsets. A common method in deciding about the fuzzy rule base is to use sample data and derive the necessary rule base by the fuzzy inference procedure. This involves computing the weight of each rule triggered, accumulating weights and outputs for each rule and finally computing the weighted output for each rule and, finally, computing the weighted output for each rule **(Nataraja et al 2006, and Unala et al 2007)**.

3.2 Fuzzy Inference System Model

In general, a good training data set should include comprehensive information about the characteristics of the materials behavior. In this study, the collected experimental data include the results of 45 aluminum-concrete composite columns of which 25 specimens were taken from the tests carried out by(Zhou and Young 2009, and Nasser 2012) and 20 specimens were taken from the experimental work of the present study. The complete list of the data is given in **Table 2**. Among the collected data, 36 experimental data were sampled randomly and used for the training data (constructing rules) and the remaining 9 data for the testing data of the FIS model, as shown in **Table 2.**

The FIS model is implemented using Fuzzy Logic Toolbox in MATLAB program version 7 (R14). This program implements the FIS model. In this section, the results of using this FIS model is presented and discussed to examine the ability of this model to predict the ultimate strength of concrete-filled aluminum tube columns (CFTa).

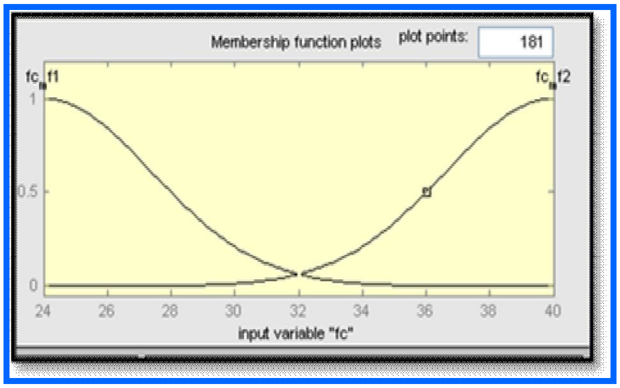
The four major input variables are listed in Table 3 as follows:

1- f'_c = cylinder compressive strength of concrete (MPa),
2- L/D= column slenderness ratio.
3- t = wall thickness of a aluminum tube (mm), and
4- D = diameter of a aluminum tube (mm).

Kufa Journal of Engineering (K.J.E)
ISSN 2207-5528
Vol. 5, Issue 2, June, 2014
Printed in Iraq

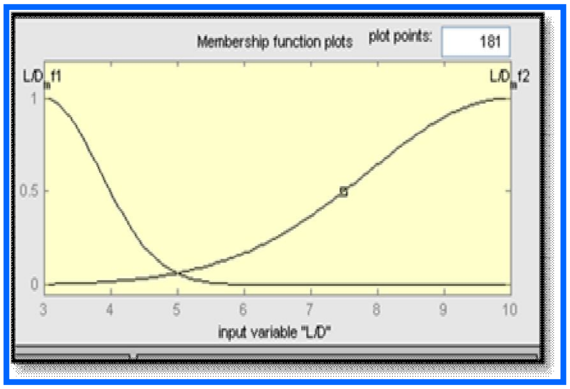
The output includes one output variable represents the ultimate axial load *P* (kN).
The limit values of input variables used in Sugeno-type fuzzy inference model are listed in **Table 3**. In the rule base, fuzzy variables were connected with ‘‘prod” operators and the implication of the each rule was calculated using ‘‘wtaver” (weighted average) defuzzification method. In this study, Gaussian membership functions, for the input variables f_c, *L/D*, *t*, and *D* were fuzzyfied by dividing them into 2, 2, 3, and 4 partitions, respectively. While the output variable is modeled using a constants (equal in value to the correspond actual (experimental) output membership function. The membership function plots of input variables is shown in **Figures(5-8).**

Obviously, all of these fuzzy sets are complete and consistent on their domains and of course they are convex.



Concrete strength (f'_c) (MPa)

Fig. 5 Membership Functions for Concrete Strength (f'_c)



Column slenderness ratio (*L/D*)

Fig.6 Membership Functions for Column Slenderness Ratio (L/D)

Kufa Journal of Engineering (K.J.E)
ISSN 2207-5528
Vol. 5, Issue 2, June, 2014
Printed in Iraq

Table 2 Measured Test Specimen Dimensions of Circular Hollow Sections.

Column No.	Column Designation	External Diameter, *D* (mm)	Tube Thickness,*t* (mm)	Length, (mm)	*L/D*	*D/t*	σ 0.2 MPa	Ultimate Compressive load(kN)	Reference
1	$38S_3$	38.1	1.62	114.3	3	23.5	243.1	79.3	Present study
2*	$38S_4$	38.1	1.62	152.4	4			78.2	
3	$38S_6$	38.1	1.62	228.6	6			76.7	
4	$38S_8$	38.1	1.62	304.8	8			75.6	
5	$38S_{10}$	38.1	1.62	381.0	10			74.3	
6*	$50S_3$	50.2	1.6	150.6	3	31.4	251.4	130.8	
7	$50S_4$	50.2	1.6	200.8	4			127.6	
8	$50S_6$	50.2	1.6	301.2	6			124.5	
9	$50S_8$	50.2	1.6	401.6	8			121.5	
10	$50S_{10}$	50.2	1.6	502.0	10			118.5	
11	$60S_3$	60.0	2.58	180.0	3	23.3	249.7	202.0	
12	$60S_4$	60.0	2.58	240.0	4			198.7	
13	$60S_6$	60.0	2.58	360.0	6			194.5	
14*	$60S_8$	60.0	2.58	480.0	8			191.8	
15	$60S_{10}$	60.0	2.58	600.0	10			189.6	
16	$100S_3$	100.3	2.1	300.90	3	47.8	241.7	420.7	
17	$100S_4$	100.3	2.1	401.20	4			414.7	
18	$100S_6$	100.3	2.1	601.80	6			406.9	
19	$100S_8$	100.3	2.1	802.40	8			402.3	
20*	$100S_{10}$	100.3	2.1	1003.0	10			398.5	
21	D_1S_3	38.0	3.2	114.0	3	11.9	241.4	148.5	Nasser 2012
22	D_1S_4	38.0	3.2	152.0	4			145.8	
23*	D_1S_6	38.0	3.2	228.0	6			143.7	
24	D_1S_8	38.0	3.2	304.0	8			141.9	
25	D_1S_{10}	38.0	3.2	380.0	10			138.9	
26	D_2S_3	50.0	3.0	150.0	3	16.7	253.6		

Kufa Journal of Engineering (K.J.E)
ISSN 2207-5528
Vol. 5, Issue 2, June, 2014
Printed in Iraq

27	D_2S_4	50.0	3.0	200.0	4			168.6	
28	D_2S_6	50.0	3.0	300.0	6			165.1	
29*	D_2S_8	50.0	3.0	400.0	8			162.8	
30	D_2S_{10}	50.0	3.0	500.0	10			161.8	
31	D_3S_3	60.0	4.2	180.0	3			302.7	
32*	D_3S_4	60.0	4.2	240.0	4			298.5	
33	D_3S_6	60.0	4.2	360.0	6	14.3	254.8	289.6	
34	D_3S_8	60.0	4.2	480.0	8			278.5	
35	D_3S_{10}	60.0	4.2	600.0	10			275.4	
36	D_4S_3	100.1	4.4	300.3	3			571.4	
37	D_4S_4	100.1	4.4	400.4	4			566.7	
38*	D_4S_6	100.1	4.4	600.6	6	22.8	242.1	562.7	
39	D_4S_8	100.1	4.4	800.6	8			551.5	
40	D_4S_{10}	100.1	4.4	1001.0	10			545.8	
41	CHS_1C_{40}	38	3.91	114	3	9.7	242.4	158.9	Zhou and Young 2009
42	CHS_2C_{40}	50	3.13	150	3	15.9	238.4	217.0	
43*	CHS_3C_{40}	60	2.55	180	3	23.5	237.8	244.1	
44	CHS_4C_{40}	76.1	2.06	228.3	3	36.9	237.0	329.9	
45	CHS_5C_{40}	99.8	2.02	299.4	3	49.4	244.3	543.6	

* Testing data, and the remaining are training data.

Moreover, training continued for over 10 epochs and process terminated by the observation of the stability in error reduction Mustafa 2009. Thus, 48 rules are obtained for the *P* as in the following:

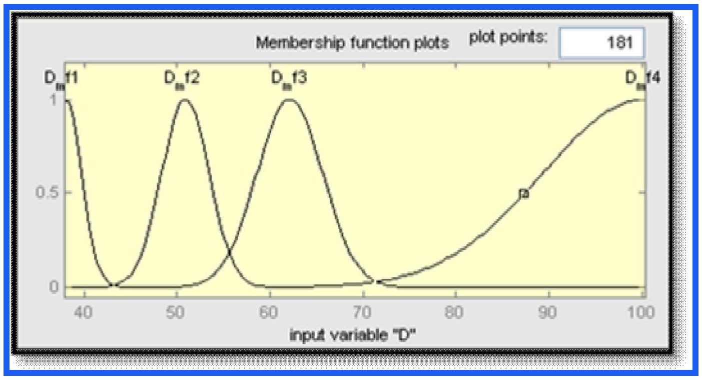
R_i: IF (f'_c is $f'_c mf_j$) and (L/D is L/Dmf_k) and (t is tmf_n) and (D is Dmf_m) THEN (P is Pmf_i),i=1,….,48 ; j,k=1,2 ; n=1…,3; m=1,…,4

Figure 9 shows sample of the rule base , while the rule viewer is shown in **Figure 10.**

Kufa Journal of Engineering (K.J.E)
ISSN 2207-5528
Vol. 5, Issue 2, June, 2014
Printed in Iraq

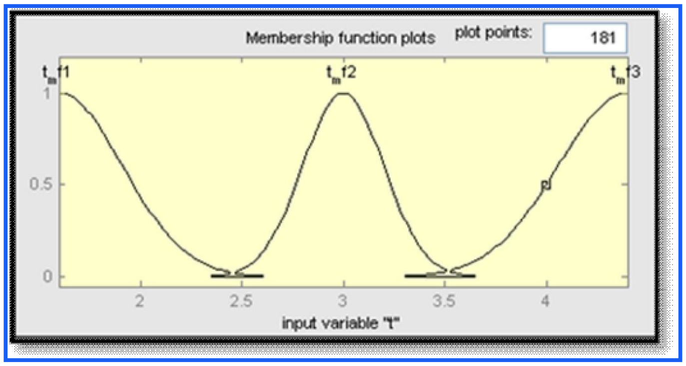
Table 3 Range of Input Parameters

Parameter	Range
Concrete Cylinder Compressive Strength (f'_c) (MPa)	24 - 40
Column Slenderness ratio (*L/D*)	3 - 10
Wall Thickness of a Aluminum Tube (*t*) (mm)	1.6 – 4.4
Diameter of a Aluminum Tube (*D*) (mm)	38 -100.3



Column Diameter (D)mm

Fig. 7 Membership Functions for Column Diameter (D)



Aluminum Tube Thickness (*t*) (mm)

Fig. 8 Membership Functions for Aluminum Tube Thickness (t).

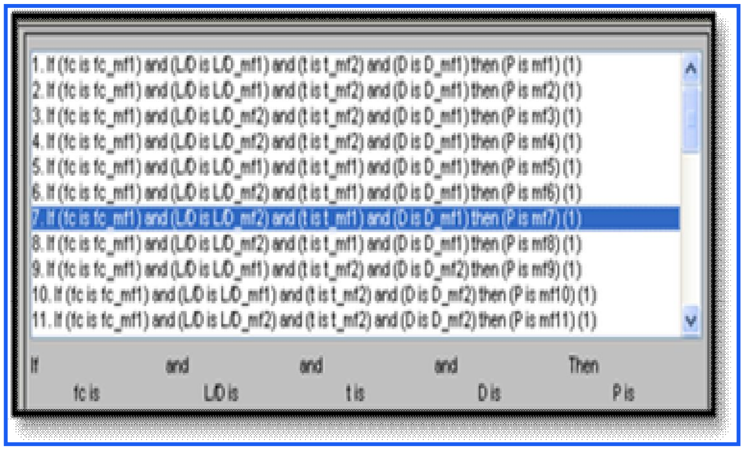


Fig. 9 A Segment of the Rules Frame (for Sugeno Model)

3.3 FIS Model Validation

Model validation must be carried out using the input-output data that are not used for training (i.e., testing data) to evaluate the efficiency of the FIS model in predicting ultimate strength. The testing data are combined in the model validation, which resulted in a total of 9 testing data for the FIS model. The FIS model predicted and target (actual) ultimate strength are used for models validation. Table 4 presents the actual and predicted ultimate load capacity of the FIS model for testing data. As seen from this table, the values obtained for the FIS model are very close to the experimental results. The average values of ratios of actual to predicted ultimate loads are 1.001 for the Sugeno_model. These results demonstrate that the FIS can be successfully applied to establish accurate and reliable prediction model.

The performance of a FIS model can be measured to some extent by the errors on the training and testing sets, but it is often useful to investigate the model response in more detail. One option is to perform a regression analysis between the model response and the corresponding targets. **Figures 11 and 12** show the results of the regression analysis between the output of the Sugeno model and the corresponding target for training and testing data respectively.

From **Figures 11 and 12**, R^2 = 0.9943, 0.9914 for training and testing data of Sugeno model, respectively. These values indicate an excellent agreement between the predicted and the actual values for the model.

Kufa Journal of Engineering (K.J.E)
ISSN 2207-5528
Vol. 5, Issue 2, June, 2014
Printed in Iraq

Table 4 Actual and Predicted Ultimate Load Capacity for Testing Columns.

Column No.	Cylinder Compressive Strength (f'_c)(MPa)	Slenderness Ratio (L/D)	Tube Thickness (t)(mm)	Diameter (D) (mm)	Actual Ultimate Compressive Load (P_{ac}) (kN)	Predicted Ultimate Compressive Load (P_p) (kN) Sugeno model	
						P_p	P_{ac} / P_p
2	24.2	4	1.62	38.1	78.2	78.9	0.991
6	24.2	3	1.6	50.2	130.8	128	1.022
14	24.2	8	2.58	60	191.8	192	0.999
20	24.2	10	2.1	100.3	398.5	405	0.984
23	24.1	6	3.2	38	143.7	140	1.026
29	24.1	8	3	50	162.8	164	0.993
32	24.1	4	4.2	60	298.5	301	0.992
38	24.1	6	4.4	100.1	562.7	555	1.014
43	40	3	2.55	60	244.1	248	0.984
Average							1.001

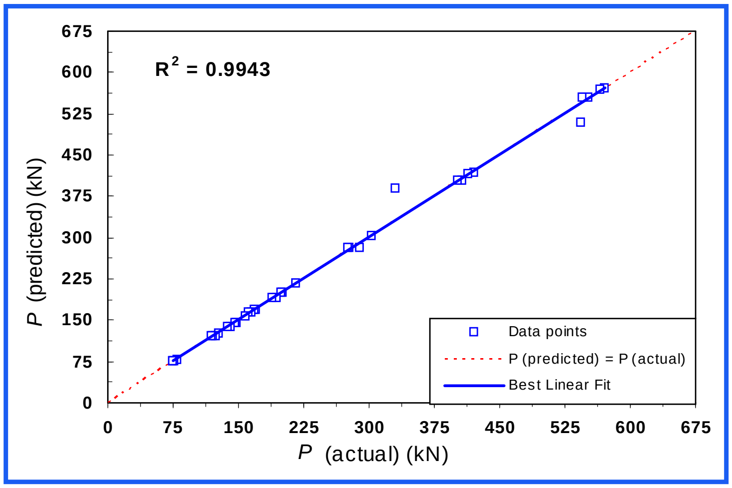


Fig. 11 Regression Analysis between Predicted and Actual Values for Training Data.

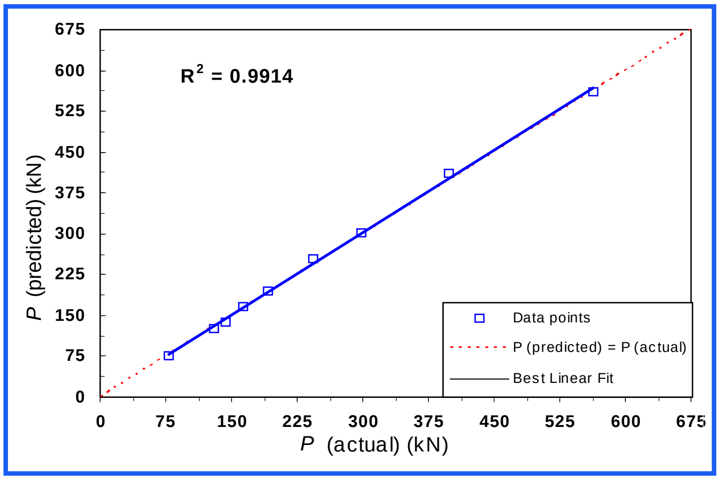


Fig. 12 Regression Analysis between Predicted and Actual Values for Testing Data.

5. Conclusions

This paper present an experimental and theoretical study on concrete-filled aluminum circular hollow section columns. A series of tests were performed subjected to uniform axial compression to investigate the structural performance of the concrete-filled aluminum. , the following conclusions can be drawn within the scope of these test:

1. The aluminum pipe tube provide sufficient lateral support to the concrete core and increase the ultimate strength of the column.
2. The ratio of strength of aluminum-concrete composite column to strength of aluminum tube column ranged between 1.596 and 2.544 for columns with slenderness ratio = 3.
3. The ductility of concrete- filled aluminum tube columns increase with using aluminum tube columns especially for the relatively slender section.
4. The failure mode of short and intermediate length composite columns (L/D = 3 – 4) is a classical shear mode failure. For the most slender composite columns (L/D = 6-10), the failure mode of specimens was a long column buckling mode failure.
5. In order to predict the ultimate compressive strength of aluminum-concrete composite columns without attempting any experiments, fuzzy inference system (FIS) was used. The model, FIS model, having four inputs, one output, and thirty six linguistic rules were constructed. The models were trained with input and output data. Using only the input data in trained models, the ultimate strengths values of aluminum-concrete composite columns were found. According to the coefficients of correlations, the model has high prediction performance. The obtained values are very close to the experimental results. The average value of ratios of experimental to predicted ultimate loads is 1.001 for the FIS model. As a result, ultimate strength of aluminum-concrete composite columns can be predicted by the constructed FIS model without attempting any experiments in a quite short period of time with tiny error rates. The obtained results have shown that FIS is practicable method for predicting the ultimate strength of aluminum-concrete composite columns.

6.References

1. ACI. "Building code requirements for structural concrete and commentary", ACI 318-08. Detroit (USA): American Concrete Institute; 2008.

2. **Garder J, and Jacobson R.** "Structural behavior of concrete filled steel tubes", ACI J Struct. Div. 1967; 64(7):404-13.

3. **Han LH, Yao GH, and Zhao XL.,** "Behavior and calculation on concrete filled steel CHS (circular hollow section) beam-columns", Steel Compos Struct 2004;4(3):169–88.

4. **Hong, W.K., and Kim, H.C.,** "Behavior of concrete columns confined by carbon composite tubes", Canadian Journal of Civil Eng., 31, 2, 2004, pp. 178–188.

5. **Klir GJ, and Fogel TA.** "Fuzzy sets uncertainty and information", New York (NY): Prentice Hall, 1988.

6. **Kosko B.** "Neural networks and fuzzy systems", Englewood Cliffs (NJ): Prentice Hall, 1992. **Kosko B.** "Fuzzy thinking: The new science of fuzzy logic", New York (NY): Hyperion, 1992.

7. **Kirschfink, H., and Lieven, K.,** "Basic tools for fuzzy modeling", Liebigstrasse 20, D-52070, Aachen, Germany, 2000.

8. **Lam, D., and Wong, K.K.Y.,** "Axial capacity of concrete filled stainless steel columns", ASCE Journal of Structures 2005, pp. 1107-1120**.**

9. **Mustafa Sarıdemir**, "Predicting the compressive strength of mortars containing metakaolin by artificial neural networks and fuzzy logic ", Advances in Engineering Software 40 (2009) 920–927.

10. **Nataraja, M.C., Jayaram, M.A., and Ravikumar, C.N.,** "Prediction of early strength of concrete: a fuzzy inference system model", International Journal of Physical Sciences, Vol. 1, 2, 2006, pp. 047-056.

11. **Nasser, K. Z.**, "Structural behavior of concrete filled aluminum tubular columns", acceptable to be publish in Basrah Journal for engineering science, 2012.

12. **Sagban, A.S.**, "Experimental and theoretical investigation of PVC-concrete composite columns ", Ph.D., Department of Civil Engineering, University of Basrah, 2010.

13. **Schneider, S.P.**, "Axially loaded concrete-filled steel tubes", Journal of Structural Engineering, Vol. 124, No. 10, October 1998, pp.

Kufa Journal of Engineering (K.J.E)
ISSN 2207-5528
Vol. 5, Issue 2, June, 2014
Printed in Iraq

14. **Topcu, I.B.,** and **Saridemir, M.,** "Prediction of rubberized concrete properties using artificial neural network and fuzzy logic", Construction and Building Materials, 22, 2008, pp. 532–540.

15. **Usami T.** "Strength of concrete-filled thin-walled steel box column: experiment" ,J Struct. Eng. ASCE 1992;118(11):3036–54.

16. **Unala, O., Demir, F., and Uygunoglua, T.,** "Fuzzy logic approach to predict stress–strain curves of steel fiber-reinforced concretes in compression", Building and Environment, 42, 2007, pp. 3589–3595.

17. **Yang, Y.F., and Han, L.H.,** "Experimental behavior of recycled aggregate concrete filled steel tubular columns", Journal of Constructional Steel Research, 62, 2006, pp. 1310-1324.
18. **Zhou, F., and Young, B.,** "Tests of concrete-filled aluminum stub columns", Thin-Walled Structures, 46, 2008, pp. 573-583.

19. **Zhou, F., and Young, B.,** "Concrete-filled aluminum circular hollow section column tests", Thin-Walled Structures, 47, 2009, pp. 1272-1280.

20. **Zadeh, L.A.,** "Fuzzy sets", Journal of Information and Control, 8, 1965, pp. 338-353.

21. **Zadeh L, Kacprzyk J,** "editors. Fuzzy logic for the management of uncertainty". 1992.

Notation

The following symbols are used in this paper:
CFTa Concrete-filled aluminum tube
D Outer diameter of aluminum circular hollow section tube, mm
f_c Measured concrete cylinder strength, MPa
L Length of column specimen, mm
P_{ac} Actual load, kN
P_{al} Ultimate strength of aluminum tube column, kN
P_{co} Ultimate strength of aluminum-concrete composite columns, kN
P_p Predicted load, kN
R^2 Correlation coefficient
t Thickness of aluminum circular hollow section tube, mm
$\sigma_{0.2}$ Static 0.2% proof stress, obtained from stress - strain curve by pausing the applied straining for 1.5 near the 0.2% tensile proof stress. MPa