FIRE RESISTANCE PERPORMANCE OF WELDED BUILT-UP SQUARE CFT COLUMNS WITH REDUCED INTUMESCENT PAINT

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Abstract
Welded built-up square CFT columns are widely employed in construction field thanks to their structural efficiencies by avoiding stress concentration area and improving workability in fabrication and maximizing the composite effect enabled by bent ribs. Although welded built-up square CFT columns have structural advantages over other members and are widely used, they are classified as non-fireproof in Korea because the steel tubes are directly exposed to a fire. Thus, fire coating required for the columns by the law results in inefficient design. This study suggests welded built-up square CFT columns with reduced coating to enable improved fire-resistance performance for 2 ~ 3 hours. The purpose of the study is to analyse their fire-resistance performance using the variable of axial ratio which is the major factor in the performance and suggest efficient functional design with reduced coating.

Keywords: intumescent paint, BS5950-8, fire-resistance, temperature distribution

INTRODUCTION

In this study, ACT columns without fire protection and fire Intumescent paint were fabricated for loaded heating test to verify the fire resistance performance of interior anchor type concrete filled steel tube columns.

1 BACKGROOUND OF RESEARCH

The studies on concrete filled steel tubular columns have been made since early 1990s. Due to the rise in steel price and the development of high-strength materials, the methods to reduce steel amount and use structural members more efficiently have been suggested. Kyongsoo Yom suggested L-channel bending unit with rib shown in Fig 1(a) to utilize the composite effect between the concrete and steel tube. Placing the welding joints at the centre of the 4 sides enhances workability in fabrication and avoid stress concentration area in the corner. Fig. 1(b) shows the cross-section of the column called ‘Advanced Construction Technology (ACT)’ column developed in 2006. Water pressure test was carried out to verify the welding performance of the columns and evaluate the safety of their welding throat depth. In addition, the studies on the seismic performance and structural behaviour of the columns have been made continuously. Since the construction technology of the ACT columns was certified in Korea in 2011, they have been used in the structures which require high axial force. Although CFT column is recognized as a fire resistant member thanks to its thermal storage effect, it does not provide the fire resistance performance required for high-rise buildings. In order to deal with this shortcoming, reinforcement using steel fibre or steel bar was developed. Most of the studies dealt with the CFT columns less than 400mm in width and those without fire protection. Major studies on the fire resistance of CFT columns were made by the researchers of NRCC (National Research Council of Canada) such as V. K. R Kodur(2004) and T. T. Lie (1995,2005) and those in Fuzhou University, China led by Lin-Hai Han(2003) and sponsored by CIDECT (Comite´ International pour le Development et l’E´ tude de la Construction

Tubulaire). Kodur and T.T. Lie (2005) observed the thermal and dynamic characteristics of the concrete-filled columns reinforced with steel fibre and developed the numerical approach to forecast the fire resistance of the columns. The employment of CFT columns without fire protection is considered for economic reasons and many studies have been made on their fire-resistance performance. In order to evaluate the fire resistance performance of non-fire protection columns and fire intumescent resistance paint, loaded heating tests were conducted and axial deformation and in-plane temperatures were analyzed.

(a) unit member (b) built-up square tube column

Fig. 1 ACT (Advanced Construction Technology) Column (Choi S.M 2011)

2 FIRE RESISTANCE TEST UNDER A LOAD

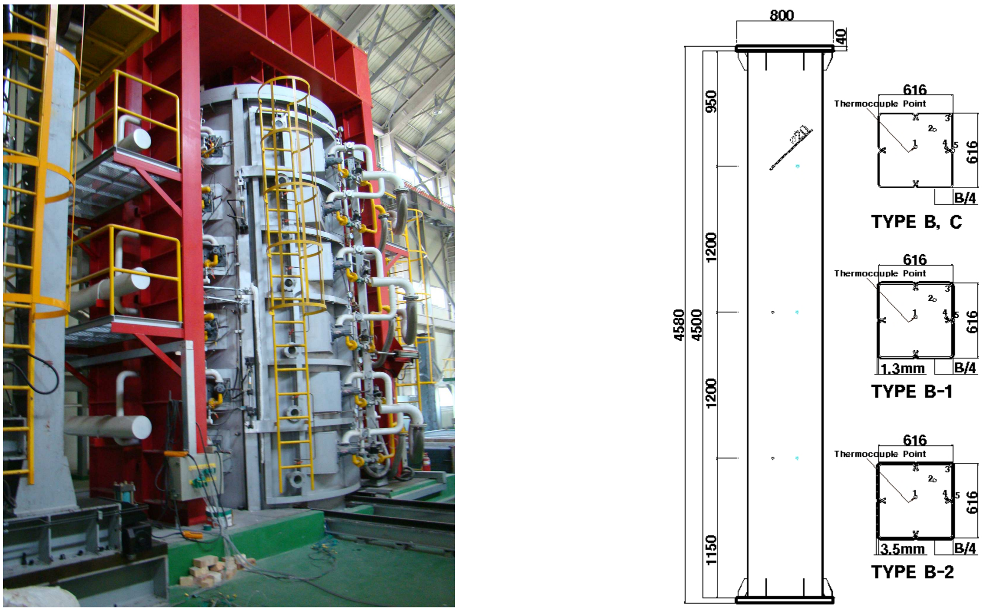
The columns employed in high-rise buildings should satisfy 3 hour fire resistance requirement. However, it is difficult to secure fire resistance for 3 hours only with steel bar or steel fibre reinforcement because high-rise buildings should deal with greater load. Therefore, fire resistance paint was applied to the ACT columns and their fire resistance was examined. While this method of reinforcement has advantages such as no requirement of finishing touches after painting and easy application of the paint even to joint ends and small spaces, it costs more than fire resistance spray or board. Therefore, thinner layer of the fire resistance paint was applied. Tab. 1 shows the specimen details. All of the 4 columns were made of the same steel (F_y = 325 MPa) and concrete (42.5 MPa). The variables in the test were load ratio and thickness of intumescent coating. Tab. 1 shows the specimens and their specification. 5 thermo couples were installed to measure the temperatures and deformation of the steel and the concrete. The test was carried out in accordance with KS-F 2257-1 standard heating curve and equation 1 and a 1,000 ton heating furnace shown in Fig. 2(a) was used. End-plates (800x800x40mm) were placed at the top and bottom of the specimens to place them at the heating furnace. 6 vent holes consisting of 3 sets were made to release pressure generated in the column. The dimension of the vent holes was 20 mm. Fig. 2(b) shows specimen details including the location of thermo couples and vent holes.

Tab. 1 Specimens List of ACT Column

Type	PARAMETER		B(mm)	t(mm)	L(mm)	Load Ratio	Test Load C (kN)
	Main	Sub					
B	Non-Protection	Basic	610	10	4512	0.6	8972
C		Load ratio	611	10	4485	0.5	7476
B-1	Intumescent coating	Paint 1.3mm	616	10	4576	0.6	8972
B-2		paint 3.5mm	616	10	4579	0.6	8972

$$T = 345 \log 10_{10}(8t + 1) + 20 \quad (1)$$

where T is Heating Temperature (℃), t is time (min)



(a) 10,000 kN heating furnace (b) specimens details

Fig. 2 Heating furnace, specimen details and location of thermo couples

(a) painting of column (b) boundary condition

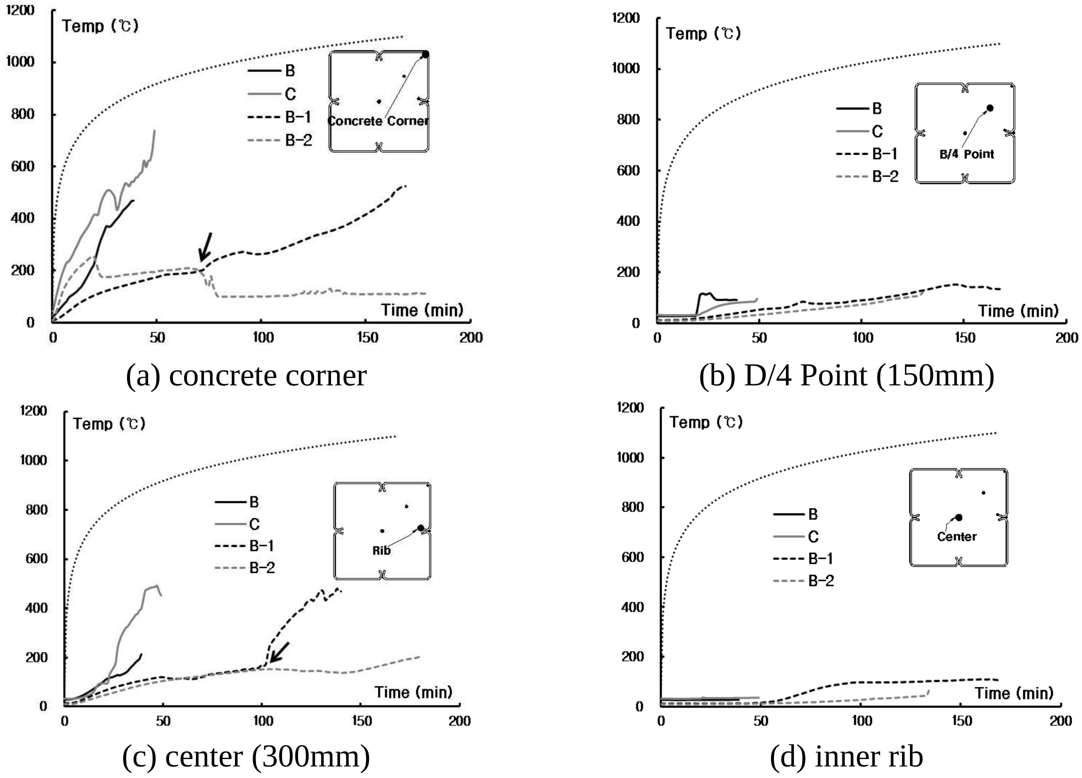
Fig. 3 Application of fire resistance paint and boundary condition

3 CROSS SECTIONAL TEMPERATURE DISTRIBUTION

As shown in Fig. 4(a), the temperatures measured at the corners of the concrete (Specimens B and C) rose rapidly. Temperature that measured in specimens B-2 at Concrete centre has decreased. It is estimated that the thermocouple location in an unstable state is gradually stabilized?. The temperatures at 1/4 point from the surface did not exceed 100 ℃ as shown in Fig. 4(b). The temperatures of the interior anchors in specimens B-1 rose rapidly from 100 minutes due to rapid contraction as shown in Fig. 4(d). Deformation was accelerated when gaps were made between the steel tube and the concrete and interior anchors were separated from the concrete due to the expansion of the steel tube exposed to fire.

BS5950-8 has presented simplified equation for the temperature distribution prediction. Predicting Parameter is Fire Resistance time, cross-sectional size and steel tube thickness. Cross-sectional depth of up to 70 mm can be predicted. If the cross-sectional depth greater than 70 mm, can be set to a constant temperature. Simplified method using BS5950 presented internal temperature of steel tube with 600 mm width and 10mm thickness cross-section as shown in Fig. 5. Results are compared with experimental results. Temperature of D/4 point (measurement depth is 150 mm) is less than 100 ℃ until 60 minutes as shown in Fig. 5.

Temperature of Concrete edge position reaches 400 ℃ before 30 minutes, which is showing similar behaviour to the experimental results.



(a) concrete corner (b) D/4 Point (150mm)

(c) center (300mm) (d) inner rib

Fig. 4 Cross-sectional temperature distribution of ACT columns

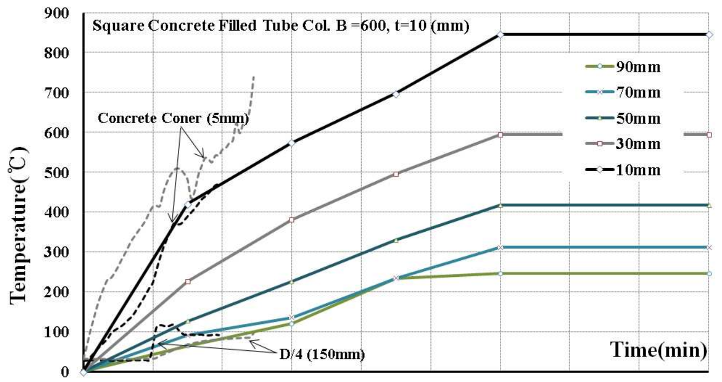


Fig. 5 Temperature distribution verification

4 HIGH TEMPERATURE COMPRESSIVE DEFORMATION BEHAVIOR

Fig. 6 shows the axial deformation of the specimens. The thermal expansion of the steel tubes upon heating caused axial expansion of the specimens B and C. The deformation reached peak in 20 minutes of heating when the furnace temperature was 600~700 ℃. Then, axial expansion stopped and contraction deepened due to the deterioration in the load capacity of the steel tubes and the local buckling of the tubes at their ends and the load to the exterior tubes was transferred to the concrete and interior tubes. Therefore, specimens B and C showed rapid contraction. The specimen with 3.5mm-thick-layer of fire resistance paint displayed gradual axial expansion for the 180 minutes of heating and the steel tube did not contract. As the fire resistance paint was exposed to fire, it formed fire-blocking layers. The layers turned white and finally became like black lumps of charcoals. Since temperature rise was delayed, the specimen resisted fire for 180 minutes. In the specimen with 1.3mm-thick-layer of fire resistance paint, the steel tube expanded gradually and resisted fire for 170 minutes.

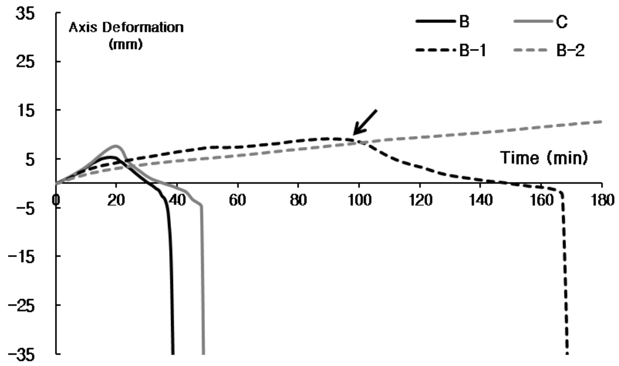


Fig. 6 Axial Deformation of ACT Column as Exposure Time

Tab. 2 summarizes the weight, length and width of the specimens before and after the test. Fig. 7 shows the failure mode of the specimens at the termination of the test. The difference in weight was the biggest in specimen B-2 because the moisture in the concrete vaporized and the surface of the steel tubes was oxidized during the 3 hours of heating.

Tab. 2 The dimensions of Specimens before and after heating
(A: Before Heating , B : After Heating // Unit : mm or kg)

	A Weight	B Weight	Weight gap	A Length	B Length	Length gap	A Width	B Width	Axial Expansion
B	4820	4740	80	4578	4512	66	610	632	5.3
C	4860	4750	110	4576	4485	91	611	635	7.6
B-1	4910	4710	200	4576	4515	61	612	658	10
B-2	4960	4810	150	4579	4575	4	614	615	13

As shown in Fig. 7, the center of the specimen with 1.3mm-thick-layer of fire resistance paint turned black, while the 3.5mm-thick-layer of fire resistance paint swelled with tiny cracks on it.

(a) B Type (b) C Type (c) B-1 Type (d) B-2 Type (e) Tumescent depth

Fig. 7 Failure mode of specimens

In the latter, the swell was about 15mm deep, indicating fire resistance duration of over 180 minutes. It is deduced that 1.8~3.5mm-thick-layer of fire resistance paint is appropriate for economically efficient fire resistance design. Additional studies should be conducted to find the optimal thickness of fire resistance painting. For the verification method, interpretation of the simulation analysis between the result of the experiment and variables is needed. The prime variable is thickness of the steel tube, since the effect of reinforced fire resistant paint in concrete-filled steel tube and general steel tube is different. Therefore, the thickness of the paint can differ by thermal conduction rate of the steel tube. These results could not be included in this study, but continuous research will be in progress.

5 SUMMARY

In this study, ACT columns without fire protection and fire intumescent paint were fabricated for loaded heating test to verify the fire resistance performance of interior anchor type CFT columns. The conclusion of the study to enable economically efficient fire resistance design is as follows. In the ACT specimens without fire protection, the interior anchor was exposed to high temperatures and the fire resistance performance of the columns was deteriorated due to thermal expansion. Since the cracks at the concrete reduced confinement effect rapidly, load ratio should be adjusted downward to below 0.5 to secure the fire resistance duration of more than 60 minutes. Also, the temperatures at the ACT columns reinforced with fire resistance paint were stable and noticeably lower until 180 minutes compared with the other 2 groups of specimens. A member with 3.5mm thickness of the fire-resistant paint has shown only axial expansion for 180 minutes and compressive deformation has not appeared. In other words, strength reduction by high-temperature has not happened and could get satisfying result of three hours of fire resistant performance.

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