Resilient Structures and Sustainable Construction
Edited by Pellicer, E., Adam, J. M., Yepes, V., Singh, A., and Yazdani, S.

ISBN: 978-0-9960437-4-8

EXPERIMENTAL STUDY ON STRUCTURAL BEHAVIOR OF FIRE PROTECTED DOUBLE CFT COLUMN SUBJECTED TO FIRE LOAD

KYUNG SOO CHUNG[1], JAE SUNG LEE[2], JONG EUN SONG[3], WOO CHUL KIM[3],
HEUNG YOUL KIM[4], and JONG MOON CHOI[5]

[1] *Steel Business Division Steel Solution Marketing Dept, POSCO, Incheon, Korea*
[2]*Dept of Architectural Engineering, Hannam University, Daejon, Korea*
[3]*Sunghyun Chemicals CO., Seoul, Korea*
[4]*Fire Research Institute, KICT, Whasung, Korea*
[5]*Architectural Engineering Research Group, POSCO E&C, Incheon, Korea*

New concrete filled double-tube (CFDT) sections consist of an inner and outer tube with fire protection mortar (FPM) filling the cavity between them and the inner tube also filled with concrete or not. An investigation into the fire performance of CFDT during the standard fire test is reported. Six full size FPM filled CFDT columns were designed for the fire tests. Detail failure modes of overall specimens and each component in the columns as well as temperature, deformation and fire endurance were presented. It showed that the fire resistance in the CFDT columns is significantly higher than that in concrete filled steel tubular (CFT) columns. Investigation into the fire performance of the columns reveals possible solutions to improve the fire resistance of CFT members.

Keywords: Fire performance, Concrete filled double tubes (CFDT), Fire protection mortar (FPM).

1 INTRODUCTION

CFT columns elongate at an early stage of heat loading, and then shorten until failure. CFT columns can sustain axial load from filled concrete after the capacity of the steel tube is lost heating, and thus, fire proof material can be reduced or omitted.

In recent years, concrete-filled double steel tubes have been found to be increasingly used in a number of structural forms (Lu *et al.* 2010, Remero *et al.* 2015, Yang and Han 2008). They consist of two generally concentric steel tubes with the space between them filled with fire protection mortar. Filling hollow structural steel sections with concrete has several advantages. One of the main benefits is substantial increase in the load-bearing capacity if the column owing to the filling of concrete. In addition, a higher fire resistance can be obtained in comparison with bare steel tubular columns under same fire load level. In the other hands, an investigation into the fire performance of fire protection mortar (FPM) filled double tubular columns (CFDT) during the standard fire test is limited.

In this paper, the results of an experimental study on the performance of circular CFDT columns subjected to standard fire on all sides are presented in detail.

2 EXPERIMENTAL STUDY UNDER ELEVATED TEMPERATURE

2.1 Column Specimens

The length of the columns was 3300 mm, although only 3000 mm were directly exposed to the fire inside the furnace. For each column specimen, two vent holes of 15 mm diameter were drilled in the outer steel hollow section wall at 100 mm from each column end. These went holes were provided for relieving the water vapour pressure produced during the experiment. An additional hole, located near the bottom end of the columns, was used for connecting the thermocouple wires.

In this experimental program, six CFDT columns were subjected to a fire test. For the circular CFDT, both the outer and inner tubes are circular hollow sections. Table 1 illustrates the dimensions of CFDT cross-section, where D_o is the outside dimension of the outer steel tube; D_i is the outside diameter of the inner circular steel tube; and t_o and t_i are the wall thickness of the outer and inner steel tube respectively.

Table 1. Details of the column specimen.

Specimen	**Inner steel tube**		**Outer steel tube**		**FPM**	**Test load**	
	D_i(mm)	**t_i(mm)**	**D_o(mm)**	**t_o(mm)**	**Clear distance (mm)**	**Load (kN)**	**Ratio**
UN-1	318.5	9	355.6	6	12.5	0	0
FN-1	318.5	9	355.6	6	12.5	0	0
UN-3	318.5	9	406.4	9	35.0	0	0
FN-3	318.5	9	406.4	9	35.0	0	0
UC-1	318.5	9	406.4	9	35.0	1,700	0.6
FC-1	318.5	9	355.6	6	12.5	3,800	0.6

2.2 Material Properties

2.2.1 *Steel tubes*

Cold formed steel hollow sections were used in the experimental program, with external dimensions ○-318.5, 355.6 and 406.4 mm, and wall thickness of 6 and 9 mm. The steel grade was STK400 (S235), although the real yield strength of hollow steel tubes was obtained for each column specimen by performing the corresponding coupon test. It is worth noting that although the nominal yield strength of steel was the same for all the hollow sections (235 MPa), the actual yield strength (300, 330, and 295 MPa respectively) was for all higher than the nominal value.

2.2.2 *Concrete*

In this experimental program, only one type of concrete was used, with nominal compressive strength of 50MPa. In order to obtain the real compressive strength concrete, sets of concrete cylinder were prepared and cured in standard conditions during 28 days. The real cylinder compressive strength of concrete for all samples is 55 MPa. All samples were tested on the same day as the column was tested.

2.2.3 *Fire protection mortar*

The new mortar product is based on standard concrete technology. The normal concrete aggregate was replaced by a different natural resource, and it contains ordinary Portland cement, admixtures and an alkali free shotcrete accelerator is used when applying by spraying. Mixing, transport and filling is executed like for shotcrete.

The fire protection mortar (see Figure 1) used has a thermal conductivity of 0.116 W/m.k, a specific heat of 1.0473 J/kg.k, density 0f 500±50 kg/m3 and water content of less than 5%. The fire protection thicknesses of the columns are 20 mm, 35 mm, and 40 mm for 1h, 2h, and 3h respectively.

(a) FPM slump flowing

(b) FPM after fire test

Figure 1. Fire protection mortar.

2.3 Test Setup

The tests were carried out in a 5 x 3 m furnace equipped with a hydraulic jack of 10,000 kN maximum capacity and a total 16 gas burners, located at mid-height of the furnace chamber. The columns were placed vertically inside the furnace, pinned at their bottom end and pinned at their top end. The load was on a first instance applied to the columns at room temperature, and afterwards and maintaining the load constant, the gas burners were activated, following the standard ISO 834 fire curve.

2.4 Instrumentation

The temperature evolution at different points of the column specimens was registered during the fire tests by means of a set of type K thermocouples. Six thermocouples were located at the mid-length of the column, and identical thermocouples were located at 1/4 and 3/4 times the height of the column, respectively. Thermocouples 1 and 5 were located at the outer steel tube exposed surface, while the other three thermocouples (3 to 5) were embedded in the concrete core. Thermocouple 3 was attached to the outer surface of the inner steel tube (see Figure 2).

The temperature inside the furnace chamber was automatically registered and controlled during the tests with six plate thermocouples and a pressure sensor. The axial elongation at the top end of the columns was measured during the tests with a LVDT located outside the furnace.

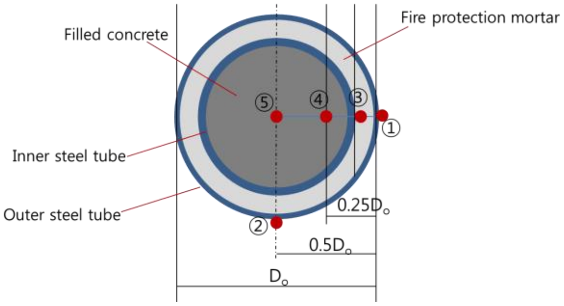


Figure 2. Position of thermocouples attached in specimen.

3 EXPERIMENTAL RESULTS

3.1 Temperature Distribution

Figure 3 shows the measurement of temperatures at the thermocouples located in the surface of both inner and outer steel tubes for the six fire tests. The temperatures in the outer steel tube general develop rapidly at the early stage of fire exposure. There is a relatively stable stage for temperatures in the concrete and inner tubes when the temperatures are above 100℃. This is mainly due to evaporation of the free water in the concrete absorbing a great deal of heat for transformation. The fire endurance of the specimens which is determined through the relationship between temperature of inner steel tube and fire exposure time is shown in Table 2.

Table 2. Test results.

Specimen	**FPM**	**Test load**		**Critical fire resistance time**		**Test result**
	Clear distance (mm)	**Load (kN)**	**Ratio**	**Temperature(C)**	**Deformation(mm)**	**Time (min)**
UN-1	12.5	0	0	538	-	58
FN-1	12.5	0	0	538	-	130
UN-3	35.0	0	0	538	-	126
FN-3	35.0	0	0	538	-	Over 180
UC-1	35.0	1,700	0.6	-	30	180
FC-1	12.5	3,800	0.6	-	30	Over 180

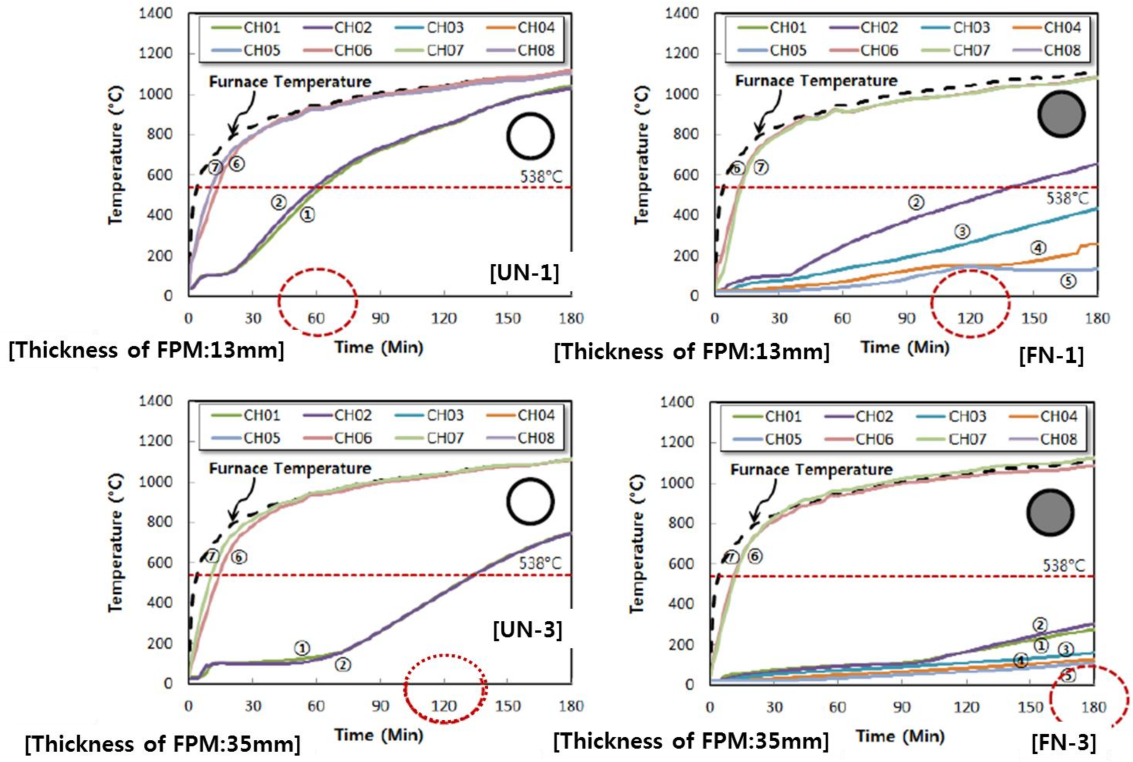
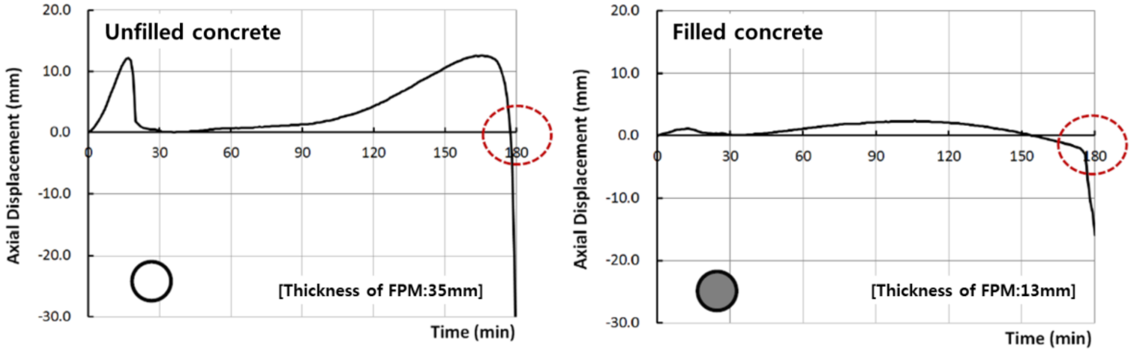


Figure 3. Distribution of temperatures in cross section of CFDT columns.

3.2 Deformation and Fire Resistance

The axial deformation of the specimens, which is used to determinate the fire endurance of the specimens, is shown in Figure 4. For specimen UC-1, the fire exposure time was set to 3 hours in the test by the control system. The specimen still had the ability to sustain the applied load at 3 hours of fire exposure. Specimen FC-3 was tested to failure, unable to sustain the applied load.

Axial deformation of the CFDT specimens generally consists of four stages, (I) expansion, (II) gradual development of compression deformation, (III) gradual expansion and (IV) compression deformation increase dramatically in a short time. It is found that the axial deformation of the FC-3 specimen is generally similar to that of UC-1 specimen. However, because the concrete is filled inner steel tube, such as in FC-3, there is no dramatic deformation stage for the CFDT specimens.



(a) Specimen: UC-1

(b) Specimen: FC-3

Figure 4. Axial elongation versus time curves for the fire tests.

3.3 Fire Resistance

Fire resistance of the specimens is summarized in Table 2. Fire resistance of unfilled concrete CFDT varies from 58 to 126 min, while the filled concrete ones are 130 and over 180 min respectively. It is clear that the filled concrete in inner steel tube is very effective at increasing the fire resistance of the CFDT columns. That is, it is clear that the filled concrete in inner steel tube is very effective at increasing the fire resistance of the CFDT columns even though the thickness of the coating is only 13 mm, comparing to the case of steel structural components with fire resistance of 2 hours, where the required thickness of such spray coating is 35 mm. This implies that CFDT columns have superior fire resistance to unfilled steel hollow columns.

Critical temperatures for steel components under same range of load ratio from design codes are 649 ~538°C in Korea, 645~531°C in AS4100, and 711~496°C in Eurocode3. The load ratio for specimens in this test is only 0.6. Here, the load ratio is also found to significantly affect the fire endurance of the CFDT columns. Comparing the fire endurance of UC-1 and FC-3, the fire endurance increases from 180 to over 180 min as the thickness of FPM decreases from 35 to 13 mm. That is because the joined action of the steel tube and the concrete core filled in inner tube leads to an excellent fire resistance behavior: the concrete core retards the heating of the steel tube, while, at the same time, the steel tube protects the concrete core from direct fire exposure, thus delaying the integrity loss of the concrete, which, furthermore, degrades slower than steel under fire.

4 CONCLUSIONS

The results of an experimental program on dual steel tubular columns filled with normal concrete under elevated temperatures have been presented in this paper.

Based on the test results reported in this paper, FPM filled double tubular columns can have higher limiting temperatures on outer steel tubes than unfilled and concrete filled steel tubular columns. This implies CFDT columns can have better fire endurance than unfilled and concrete filled steel tubular columns.

References

Lu, H., Han, L. H. and Zhao, X. L., Fire Performance of Self-Consolidating Concrete Filled Double Skin Steel Tubular Columns: Experiments, *Fire Safety Journal*, 45, 106-115, February 2010.

Remero, M. L., Espinos, A., Portoles, J. M., Hospitaler A. and Ibanez, C., Slender Double-tube Ultra-High Strength Concrete-filled Tubular Columns Under Ambient Temperature and Fire, *Engineering Structures*, 99, 536-545, 2015.

Yang, Y. F. and Han, L. H., Concrete-filled Double-skin Tubular Columns Under Fire, *Magazine of Concrete Research*, 60(3), 211-222, January 2008.