World Academy of Science, Engineering and Technology
International Journal of Civil and Environmental Engineering
Vol:10, No:2, 2016

Investigation of Fire Damaged Reinforced Concrete Walls with Axial Force

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Abstract**—**Reinforced concrete (RC) shear wall system of residential buildings is popular in South Korea. RC walls are subjected to axial forces in common and the effect of axial forces on the strength loss of the fire damaged walls has not been investigated. This paper aims at investigating temperature distribution on fire damaged concrete walls having different axial loads.

In the experiments, a variable of specimens is axial force ratio. RC walls are fabricated with 150mm of wall thicknesses, 750mm of lengths and 1,300mm of heights having concrete strength of 24MPa. After curing, specimens are heated on one surface with ISO-834 standard time-temperature curve for 2 hours and temperature distributions during the test are measured using thermocouples inside the walls. The experimental results show that the temperature of the RC walls exposed to fire increases as axial force ratio increases.

To verify the experiments, finite element (FE) models are generated for coupled temperature-structure analyses. The analytical results of thermal behaviors are in good agreement with the experimental results. The predicted displacement of the walls decreases when the axial force increases.

Keywords**—**Axial force ratio, coupled analysis, fire, reinforced concrete wall, temperature distribution.

I. Introduction

THERE is high possibility of fire damage on reinforced concrete (RC) walls, because RC shear wall system is widely used in residential buildings of South Korea. When the walls are exposed to the fire for a long time, it can occur the significant structural damage to the overall building or selective structural members due to the loss of the strength.

Many experimental studies have been reported and can be used to examine structural behaviors of fire damaged concrete structures. Studies about fire damaged RC beams and columns have been performed by many researchers [1]-[3]. For example, [1] performs experiments for thermal and structural behavior of normal strength concrete beams at elevated temperatures. However, there are relatively few researches about fire damaged RC walls have been reported [4]-[6]. Among them, [4] performs experiments for temperature distributions of one side heated RC walls. Crozier et al. [5] perform fire test of load-bearing large-scale slender RC walls under standard fire conditions. This paper reports structural behavior of walls with different height-to-thickness ratios, reinforcement covers, concrete strengths, mixture proportions, and varying levels of eccentric in-plane load. Ngo et al. [6] perform the fire tests on large-scale concrete wall panels which are partially loaded with an eccentricity of 10mm.

Regarding testing method of RC structural members under fire, KS F 2257-1 [7] and KS F 2257-4 [8] in Korea recommends that fire performance of the RC walls is investigated by heating on one side surface following ISO-834 standard time-temperature curve.

Even though fire accidents are frequently occurred in residential buildings, researches about fire damaged RC walls are relatively few. In addition, studies of axially loaded RC walls under fire have not been nearly done. Therefore, it is important to understand thermal and structural behaviors of the fire damaged RC walls by conducting fire tests on RC walls having different axial force ratios.

II. Experiment Approach

A. Fabrication of Test Specimens

For experiments, four reinforced concrete walls, W15, W15C0, W15C10 and W15C20, having concrete strength of 24MPa are fabricated to investigate the effects of axial forces. Sizes of the specimens are 150mm, 750mm, and 1300mm, for thickness, length, and height, respectively. List of test specimens is shown in Table I. Compressive test is performed on cylindrical shaped specimen after 28days of curing according to Korean standard for compressive test method (KS F 2403 [9]: Standard test method for making and curing concrete specimens). Mix proportion for the concrete are listed in Table II. In addition, the horizontal and vertical reinforcement ratio was 0.0047 and steel bars having 10mm diameter are used as main rebars. The thermocouples are placed in the mid-point(C), 335mm left(L) and 375mm above(T) from the mid-point on the wall surface as illustrated in Fig. 1. Fig. 1 also shows details of the test specimen and the location of the thermocouples.

TABLE I
List of Test Specimens

Specimen	Fire test	Axial load ratio
EXP_W15	-	-
EXP_W15C0	○	-
EXP_W15C10	○	0.1
EXP_W15C20	○	0.2

TABLE II
Mix Proportion for Concrete

28 days' compressive strength	W/C (%)	s/a (%)	Weight per unit volume (kg/m^3)				
			W	C	S	G	AD
26.08MPa	51.2	49.8	162	315	893	913	1.71

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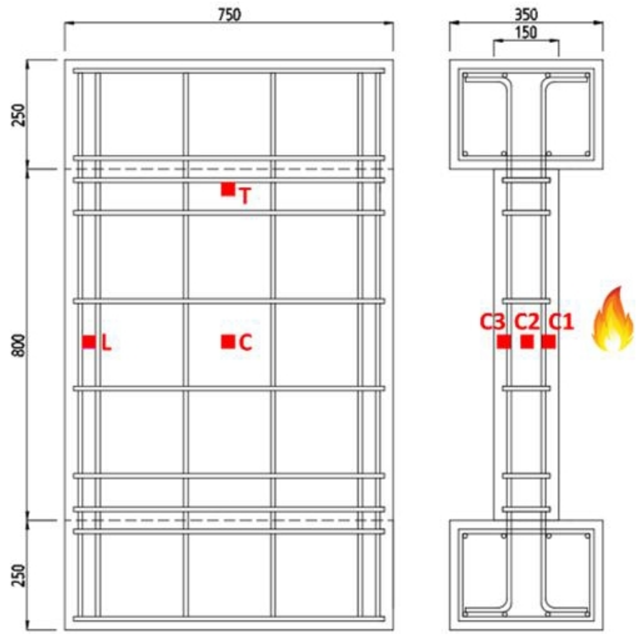

Fig. 1 Location of thermocouples in specimen

B. Fire Test Set-Up and Procedure

After 5 months of curing, three specimens are placed in horizontal heating chamber having dimensions of 10,000mm × 3,000mm × 2,100mm (width × depth × height) as shown in Fig. 2. Then, heat is applied to the one surface of the fabricated specimens for 2 hours and the study uses ISO-834 standard time-temperature curve for heating (see Fig. 3). During the fire tests, axial loads of 260kN and 520kN are applied to the top of the walls of W15C10 and W15C20, respectively. Axial load of 260kN and 520kN correspond to 0.1 and 0.2 of the uniaxial compressive strength of the wall cross section, respectively, according to (1) by [10].

$$P_{nw} = f_{ck} A_g \left[1 - \left(\frac{k l_c}{32\, h} \right)^2 \right] \tag{1}$$

where, P_{nw} = Required axial load strength of the wall (N); f_{ck} = Concrete compressive strength (MPa); A_g = Total cross section of reinforced concrete wall (mm^2); k = Effective length factor of the buckling; l_c = Vertical length between the supporting points (mm); h = Wall thickness (mm).

Detail of the loading system is shown in Fig. 4.

Fig. 2 Specimens placed in horizontal heating chamber

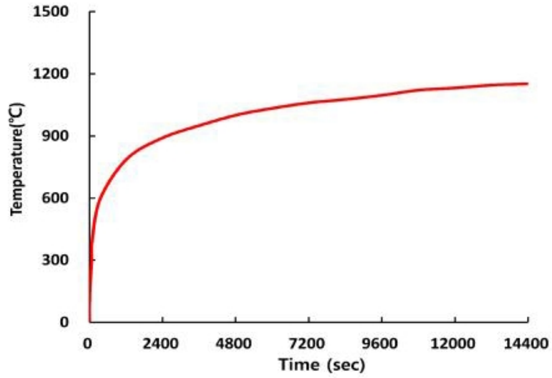

Fig. 3 ISO-834 standard time-temperature curve

Fig. 4 Loading test set-up

III. Experimental Results

A. Temperature Distribution

Fig. 5 shows the specimens after heated for 2 hours and Fig. 6 shows the temperature distribution results from the fire tests. At C1 (30mm from the surface exposed to fire), the temperature increases rapidly until 120 min of heating. However, the temperatures at C2 (center from the surface exposed to fire) and C3 (120mm from the surface exposed to fire) are much lower than the temperature at C1. After 120 min of heating, the temperature of the walls at C1 increases as axial force ratio increases.

Fig. 5 Specimen after heated for 2 hours

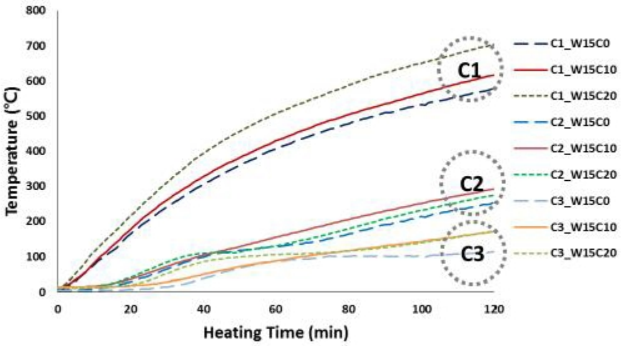

Fig. 6 Temperature distribution results

IV. Analysis

During the fire test, it is difficult to examine the structural behavior. So, FE models including temperature dependent thermal and mechanical material properties are generated for coupled temperature-structure analyses. From the analyses, the predicted thermal behaviors are compared to the experimental results and the structural behaviors are also presented.

A. FE Analysis Approach

For the analyses, Finite Element (FE) models of RC walls (W15C0, W15C10 and W15C20) including temperature dependent thermal and mechanical material properties are generated for coupled temperature-structure analyses using commercial software, ABAQUS 6.10-3.

The walls are modeled having same conditions as the experiment. Three dimensional continuum eight-noded brick elements of reinforced concrete walls are generated as shown in Fig. 7. All these models consist of concrete and reinforcing steel bars and the concrete and bars are assumed as perfectly bonded to each other. Boundary conditions and loads are also prescribed to the concrete wall models according to the experimental conditions.

B. Analytical Results

The time-temperature curves at different locations inside the three FE models are compared to the experimental results as illustrated in Figs. 8-10. As seen, the analytical results are in good agreement with the experimental results. In addition, time-displacement curves of the RC walls having 0, 10% and 20% of axial force ratios (W15C0, W15C10 and W15C20) are predicted as illustrated in Fig. 11. As shown, heights of the walls are decreased in the very beginning of the fires tests due to the applied axial forces. However, the walls are elongated gradually due to heating and the heights are increased during the fire tests. At the end of two hour of fire tests, all the simulated walls show increased wall height, even though the differences between the models are within ranges of 0.6~1.3mm. In addition, elongated length of the wall decreases as the axial force increases. Especially, the walls axially loaded with 20% of axial force ratio show decreased height until one hour of heating.

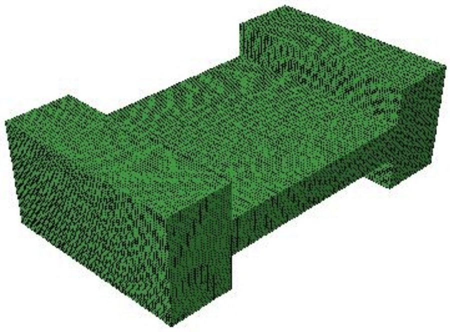

Fig. 7 FE model

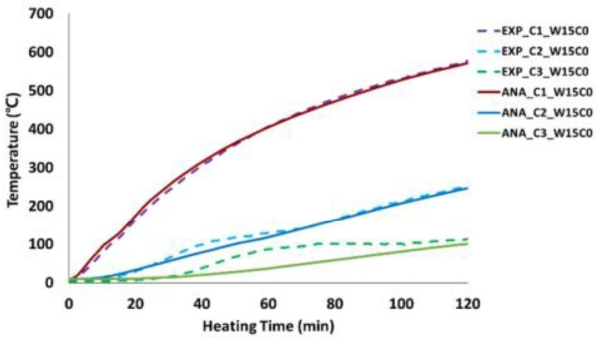

Fig. 8 Time-temperature curves from experiment and analysis of W15C0

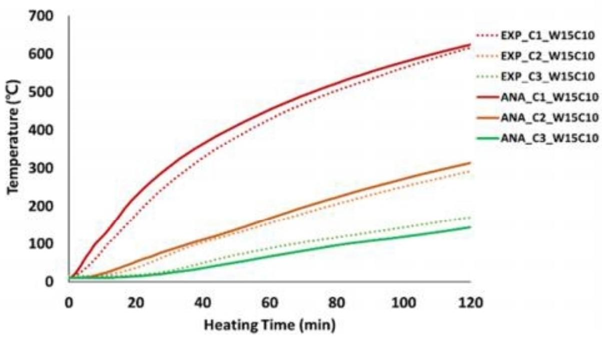

Fig. 9 Time-temperature curves from experiment and analysis of W15C10

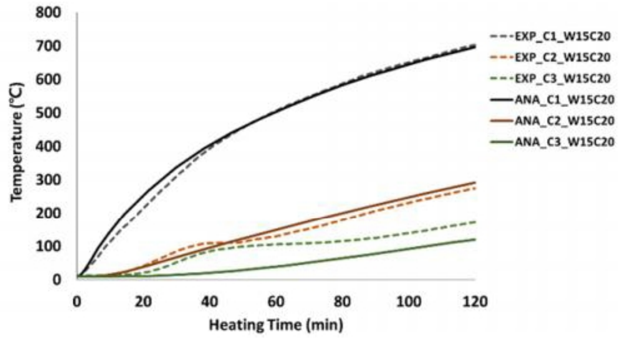

Fig. 10 Time-temperature curves from experiment and analysis of W15C20

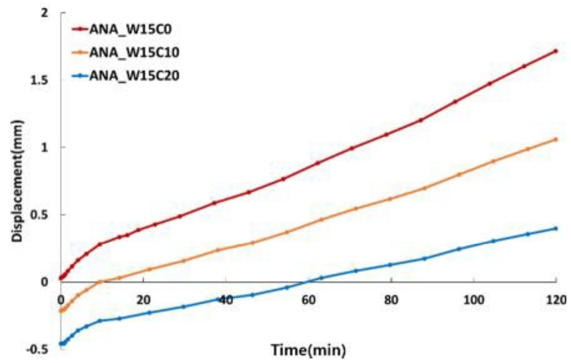

Fig. 11 Time-displacement curves from analysis of W15C0, W15C10 and W15C20

V. Conclusion

This study reports thermal and structural behaviors on fire damaged reinforced concrete walls having different axial force ratios. The following conclusions can be drawn:

1) During the fire tests, the temperature at C1 (the closest point to heated surface) increases rapidly in the beginning. In addition, the temperature of the RC walls at C1 increases as axial force increases.
2) From the coupled temperature-structure analysis, the results of temperature distribution analyses are predicted and in good agreement with the experimental results. In addition, the analytical results show that the elongated length of the wall decreases as the axial force increases.

Acknowledgment

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MEST) (No. NRF-2013R1A2A2A01015603).

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