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Experimental Study on the Fire Resistance Performance of Prestressed Composite Beam with Corrugated Web under Standard Fire with Loading Condition

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ABSTRACT

In this study, fire resistance tests were performed on a conventional slim floor beam and a prestressed composite beam with corrugated webs, which is suitable for a long-span structure with a reduction in story height by utilizing the prestress and accordion effect. In the fire test program, the ISO 834 standard fire curve was adopted. Key test variables were the effect of prestress, shape of corrugated webs, and thickness of sprayed fireproofing material. All of the test specimens demonstrated enhanced fire resistance performance exceeding the expected performance level. The prestressed composite beams with corrugated webs especially showed excellent fire performance, considering these specimens had thin fireproofing thickness compared to the conventional slim floor specimen.

1. INTRODUCTION

Currently, the demand for longer spans and to reduce the height of the buildings is increasing as buildings are built on a larger scale and are high rises. Therefore, although many studies are conducted on the effectiveness of the new composite beam, the development of the composite beam fails to be effective for reducing building height and being used for long-span structures (Kim, Lee, Choi, Choi, & Jung, 2011; Oh Lee, & Kim, 2012). Recently, long-span composite beams with various shapes have been reviewed; the weak point of steel members and reinforced concrete have been complemented. (Kim & KIM, 2012) Therefore, prestressed composite beams with corrugated web have been proposed to obtain the proper structure type for reducing building height and increasing its long span, as shown in Figure 1 in the previous study of the authors. The purpose of the proposed composite beam is to increase the introduction efficiency of prestress by using stress concentration in the upper and lower flange as much as possible, known as the accordion effect, by introducing corrugated web to improve the poor introduction efficiency of prestressing caused by high axial rigidity of the existing I-type and composite sections (Abbas, Sause, & Driver, 2007). Also, steel beams with the corrugated web are embedded into the concrete. Therefore, the composite capacity can be increased by securing the additional bearing area caused by the increase in contact area with the concrete by the height of corrugated web in the bond stress generated between the existing steel and concrete. In addition, it can be highly effective by preventing the local buckling which is the disadvantage of composite beams with corrugated web through the composition of the concrete. However, the current design criteria demand a proper level of fire resistance performance for all the structures. Therefore, in the study, a fire resistance performance experimentas w carried out to evaluate the fire resistance performance for composite beams with the corrugated web developed in the previous study. In particular, the major experiment factors were the introduction of prestress, shape of the corrugated web, and the depth of the fire resistance cover; the performance was evaluated in accordance with the ISO 834 Standard Fire Curve.

2. EXPERIMENT PLAN

2.1. General Experiment

The fire resistance experiment was carried out, depending on the shape of the section and the fire resistance cover depth in the lower part of the beam, to evaluate the fire resistance performance of the composite beam with the corrugated web introducing the PS. The fire resistance performance for the

Figure 1. Description on prestressed composite beam with corrugated webs

composite beam with the corrugated web was analyzed by dividing the two-layer corrugated web and one-layer corrugated web, as shown in Figure 2. In particular, the fire resistance cover material hydrometallurgy pearlite was sprayed during the construction to secure the required fire resistance performance based on existing case studies. The fire resistance experiment was carried out for the minimum section to satisfy the fire resistance performance for over two hours under the noncovered condition based on the results of the structure experiment and numerical analysis in the air temperature. In addition, the specimen was fabricated with a 7.5 m heating face and a 7.7 m length to analyze the fire resistance performance for the long-span composite beam.

2.2. Materials

2.2.1. Steel

An H-shape beam used in the study was fabricated with SS400 steel. The mechanical properties of SS400, the steel member for the architectural structure, are regulated, as shown in Table 1 (KS D3503, Rolled Steels for General Structure).

2.2.2. Concrete

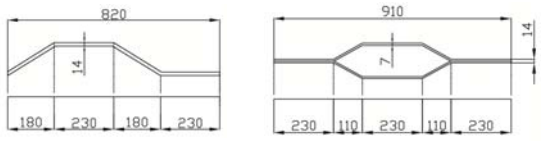
24 MPa concrete was applied to the fabrication of the composite beam; the measurement result on the compressive strength of the concrete specimen is shown in Table 2.

2.2.3. Cover Material for Fire Resistance

The fire resistance cover material hydrometallurgy pearlite was sprayed for the fire resistance cover of the steel member exposed in the lower part of the composite beam. For the cover material, E product of K company was used, which has been accredited for the fire resistance. The cover depth in each required fire resistance performance is shown in Table 3 in case the product is applied to the beam.

2.3. Fabrication Details of the Specimen

To evaluate the fire resistance performance of the composite beam with the PS corrugated web under a standard fire with loading conditions, the specimen was composed, as shown in Table 4. The corrugated web is divided into the two-layer web [S-1] and one-layer web [S-2]. The fire resistance performance was compared depending on the type of the web. In the previous study, there were 89 minutes of fire resistance performance in the specimen with the same section size in the noncovered condition. Therefore, the composite beam of the corrugated web was sprayed with 19 mm (for 2 hours) for the two-layer web and 9 mm (for 1 hour) for the one-layer web to secure the fire resistance performance for 3 hours, considering the accordion effect caused by the corrugated web. The specimen with the minimum size of the section [S-3] was fabricated considering the structure performance of the one-layer web composite beam in the air temperature to verify the fire resistance performance under the noncovered condition.



(a) 1Layer (b) 2Layer

Figure 2. The shape of corrugated web

Table 1. The results of the tensile test

Type / Test	Spec.	Testing Method	Testing Result
Yield strength (MPa)	≥ 245	KS B 0802	251
Tensile strength (MPa)	400–510		422
elongation (%)	≥ 20		29

Table 2. The resultsof the concrete test

Type / Test	Spec.	Testing Method	Testing Result
Compression strength (MPa)	≥ 24	KS F 2405	26

Table 3. Mixing ratio of concrete

Fire resistance performance	Thickness (㎜)
1 hour	9
2 hour	19

Table 4. Composition of specimen

Specimen	Parameter	Thickness of covering material (㎜)	H-beam Size (㎜)
S-1	2 layer corrugated web	19	360×236 ×346×14×22
S-2	1 layer corrugated web	9	
S-3	1 layer corrugated web	-	320×236 ×346×14×22

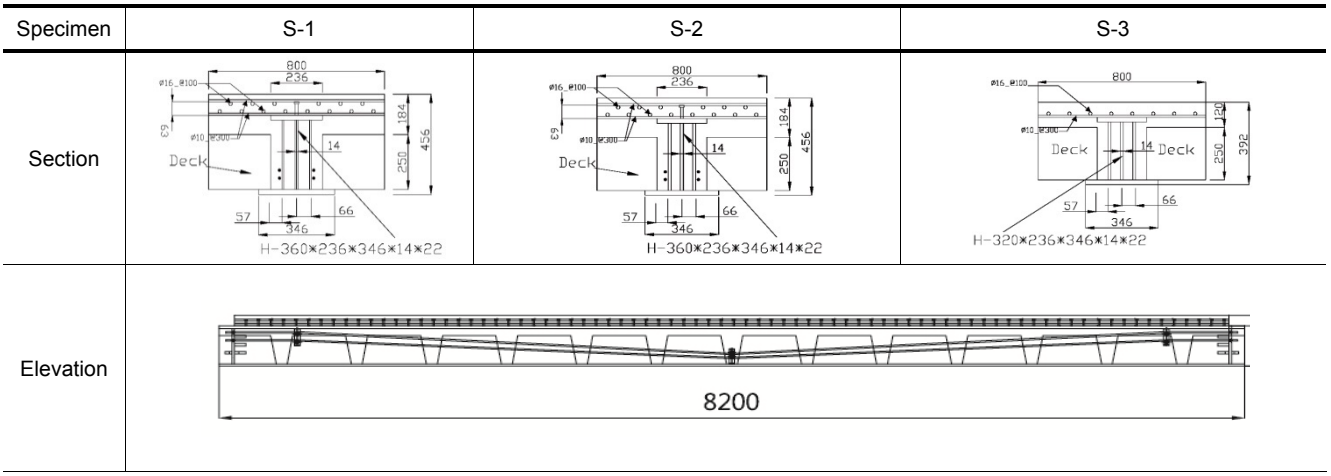


Figure 3. Drawing of specimen

2.4. Experiment Method

The fire resistance experiment has been carried out in accordance with the KS F 2257-5, Fire Resistance Experiment Method of Architectural Member-Performance Condition of Parallel Internal Force District Member. The fire resistance experiment was carried out under the uniformly distributed loading condition, as shown in Figure 4. The design load and loading condition of the specimen is shown in Table 5.

The evaluation of the fire resistance performance under the loading condition is carried out by the deformation, and its rate is in accordance with KS F 2257-1, Fire Resistance Experiment Method of Architectural Member–General Requirement. It is considered as nonresponsive status only if it exceeds both standards of the deformation (Equation 1) and its rate (Equation 2). Since the shape can be rapidly and relatively deformed until reaching a stable status, the performance standard of the deformation is not applied until the deformation exceeds L/30.

Deformation : $$D = \frac{L^2}{400d} mm \quad (1)$$

Deformation rate: $$\frac{dD}{dt} = \frac{L^2}{9000d} mm/\min \quad (2)$$

Where *L* is the span of a specimen (mm), and *d* is the distance between the location for the maximum compressive force of the structure section and the location for the maximum tensile strength (mm).

3. EXPERIMENT RESULT

As a result of the fire resistance experiment, depending on the type of web and cover depth, it was shown that over 180 minutes of fire resistance performance could be secured for S-1 and S-2. For S-1, a -82.2 mm deformation and -0.70 mm/min deformation rate were seen at 180 minutes, the end of the fire resistance experiment. For S-2, a -73.6 mm deformation and -0.28 mm/min deformation rate were seen. For S-3, the fire resistance performance was lost because the deformation and its rate exceeded the limit value at 139 minutes after starting the experiment. According to the fire resistance performance standard, for S-1 and S-2, the standard for the deformation was -325.1 mm, and the deformation rate was -14.4 mm/min. For S-3, the standard for the deformation was -378.1 mm, and the deformation rate was -16.8 mm/min.

Table 5. Design load and loading condition for fire test

Specimen	Design Load (ton)	Load Ratio	Test Load (ton)
S-1, S-2, S-3	82.7	0.4	33.1

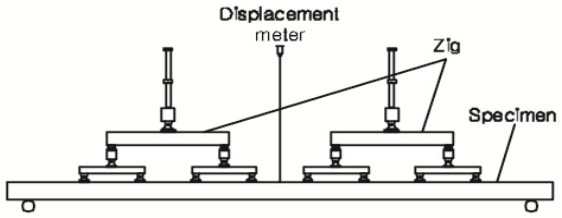


Figure 4. Testing setup

Table 6. Fire resistance performance by displacement and rate of displacement

Specimen	Time (min)	Displacement (mm)	Rate of displacement (mm/min)	Fire resistance (min)
S-1	60	-24.9	-0.08	180
	120	-50.0	-0.66	
	180	-82.2	-0.70	
S-2	60	-25.4	-0.04	180
	120	-48.5	-0.16	
	180	-73.6	-0.28	
S-3	60	-212.0	-0.3	138
	120	-255.8	-3.0	
	139	-402.3	-49.8	

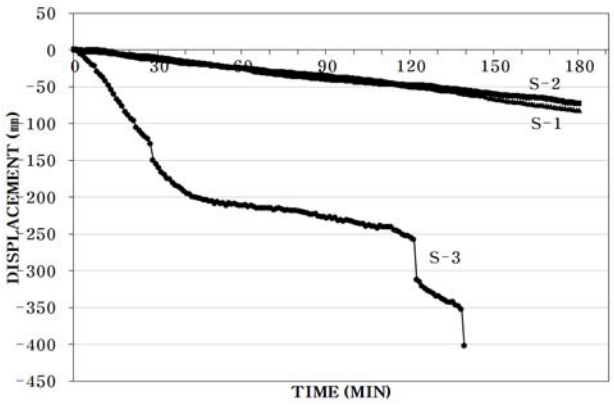


Figure 5. Displacement of long span composite beam

For S-1 and S-2, 25.3% and 22.6%, respectively, were deformed based on the standard of the allowable deformation limit. Fire resistance performance for S-1 and S-2 was similar. However, considering S-1 used 2 times the fire resistance cover material compared to S-2, it is considered that one-layer corrugated web is more effective than the two-layer corrugated web for the ease of the stress concentration in the upper and lower part of flange caused by the accordion effect. Although noncovered conditions and minimum section size conditions were applied to S-3, the fire resistance performance was secured at 138 minutes. The deformation depending on the time in each specimen is shown in Figure 5.

4. CONCLUSION

In this study, the web shape and the fire resistance cover depth were used as the major factors to evaluate the fire resistance performance of the composite beam; based on that, the experiment could reach a conclusion as follows.

1. For the two-layer corrugated web, a hollow space was formed inside the beam so that the high deformation was generated under the loading condition. For the corrugated web, it is considered that the improved fire resistivity was shown by blocking the effect mentioned.
2. As a result of the fire resistance experiment using the actual loading, it was shown that the specimen of the composite beam applying the fire resistance cover material fully satisfied the standard of bending performance (deformation and its rate) for 3 hours exposed to the fire limited in accordance with ISO 834-1.
3. Although the size of the section was minimized and fire resistance cover material was not used, the fire resistance performance was secured for 138 minutes. It can be concluded that the fire resistance performance can be secured for over 3 hours with no cover which can be applied to the actual site by adjusting the size of section and type of the corrugated web.

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