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Fire resistance of tunnel concrete depending on various heating curves and fire resistance methods

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ABSTRACT: This study is to investigate experimentally fire resistance characteristics of small size tunnel concrete structure depending on types of heating curve such as RABT and RWS and fire resistance method to obtain safety of tunnel concrete against fire. The fire resistance methods applied in this study include addition of polypropylene (PP) fiber, attachment of fire proof board and application of spray on materials, respectively. As for the fire resistance characteristics according to RABT heating curve, both of PP fiber addition and fire proof board attachment methods resulted in favorable spalling prevention effect, while spraying method had severe spalling over 100mm depth occurred along with exposure of structural concrete including spray coat. For the influence of RWS heating curve, although PP fiber addition had fair spalling prevention, surface of concrete was melt up to 5 mm of its thickness due to extremely high temperature. Application of spraying method resulted in severe spalling to the depth around 100 mm and re-bar was exposed. Attachment of the fire proof board method had no effect on spalling prevention. The fire proof board was detached from the concrete and then concrete was exposed to abrupt high temperature and severe spalling occurred. Accordingly, existing spalling prevention method including PP fiber addition and fire proof board attachment is not available under extremely high temperature exposure and it is thought that special preparations for the concrete are needed to secure stability against extremely high temperature exposure condition like RWS curve.

1 INTRODUCTION

A number of studies have reported that there are high risks of economic loss in driveways by car accidents. This is particularly dangerous when the car accidents happen in tunnels, because it causes dramatic increase of temperature, up to a thousand degree in five minutes, and sometimes results in the collapse of tunnel structures induced by concrete spalling. The level of risk is recently becoming increased, because of the increasing number and length of tunnel, and uncontrolled speed limit of cars as well as high number of vehicles loading petrol, gas and other inflammableness.

However, research on mitigation methods for concrete spalling in tunnel structures has not been studied and the matter has not been considered to be regulated in Korea. In previous research by the authors, three ways of mitigation methods regarding spalling in tunnel concrete was suggested, such as fiber addition in concrete, spray on concrete surface and adhesion of finishing materials using fire proof boards on concrete.

This study is to investigate experimentally fire resistance performance of the reinforced concrete specimens according to not only RABT heating curve but also to more severe condition of elevated temperature, RWS, and confirmed the results. Final objective of this study is to evaluate fire resistant methods and to secure the safety of tunnel structures in fire.

2 DESIGN OF EXPERIMENT

2.1 *Experimental plan*

Experimental plan of this study is presented in Table 1. The concrete with 34% of water to binder ratio (W/B) was fabricated. Target slump and air content was fixed to 150±25 mm and 4.5±1.5%, respectively. For spalling prevention methods applied in this study were included with fiber polypropylene(PP) fiber adding method, combination of spraying material containing PP fiber and metal fabric attachment, and

a fire proof board attachment method. For heating curve applied in this study, RABT and RWS curves, which are widely used for tunnel fire test, are adapted, respectively. Six reinforced concrete specimens with the dimension of 1000×1300 ×500 mm were prepared to study fire resistance subjected to RWS and RABT curve.

Table 1. Design of experiments.

Factors	W/C (%)	34
	Slump (mm)	150±25
	Air content (%)	4.5±1.5
	Spalling prevention method	· Fiber adding method (PP fiber 0.10 %) · Spraying method (PP fiber +metal fabric 1.6 T) · Fire proof board method (dry method + fastener+ fire protection paint)
	Temperature heating curve	· RABT · RWS
Experimental	Hardened concrete	· Compressive strength - Standard curing, field curing · Fire resistance test - Spalling extent - Temperature history

2.2 *Materials*

A ready mixed concrete manufactured by T company in Korea was used and mixture proportion is presented in Table 2. PP fiber made in Korea is used and its physical properties are shown in Table 3. Metal fabric with the thickness of 1.6 mm was applied to confine the concrete. Spray on mortar manufactured from Y company in Korea was also used and mixture proportion of spray on mortar is presented in Table 5. A fire proof board was made using PP fiber added cement mortar and confined with metal fabric at the same time. Metal fastener (L-50×50×4) was used to attach the fire proof board. To protect the metal fastener from fire damage, fire proof paint is applied at the surface of the fastener.

Table 2. Mix proportion of the concrete.

Slump (mm)	Air content (%)	W/C (%)	S/a (%)	Unit weight(kg/m^3)					
				W	C	S	G	SP agent	AE agent
150	4.5	34	46	170	500	752	899	2.60	0.28

Table 3. Physical properties of PP fiber.

Density (g/cm^3)	Length (mm)	Diameter (mm)	Tensile Strength (MPa)	Melting point(℃)
0.91	19	0.04	560	160

Table 4. Physical properties of metal fabric.

Metal fabric size			Density (g/cm^3)	Tensile strength (MPa)	Melting point (℃)
SW (mm)	LW (mm)	T (mm)			
24	48	1.6	7.85	439	1250

Table 5. Table of mix proportion of mortar.

W/C (%)	Unit weight(kg/m^3)				
	W	C	S	PP fiber	SP
41	266	650	1300	4.55	1.30

Table 6. Physical properties of fire proof paint.

Density (g/m^3)	Color	Viscosity (cps)	Nonvolatile (%)	Drying test time(h)
1.5	Violet	30000	64	4

2.3 *Test method*

The compressive strength was measured using cylindrical specimen with the size of ϕ100×200 mm in accordance with KS F 2403 before and after the fire test. For the fire test, six reinforced concrete specimens with the size of 500×1000×1400 mm were prepared as shown in Figure 1. After demolding, the specimens were subjected to moisture curing for 7 days and then, they were also cured at the air condition for 91 days. Thermocouples were imbedded to monitor the temperature variation depending on section depth as shown in Figure 2. Three different spalling prevention methods such as PP fiber addition, spray on material and fire proof board attachment were applied to the reinforced concrete specimens as shown in Figure 3.

To conduct a fire test according to RWS and RABT (see Fig. 4), special furnace was used as shown in Figure 5. Spalling extent was measured with naked eye observation. For calculating spalling extent area, binary digit pictorial processing technique was applied. The spalling extent area is calculated by dividing white area of the specimen, which

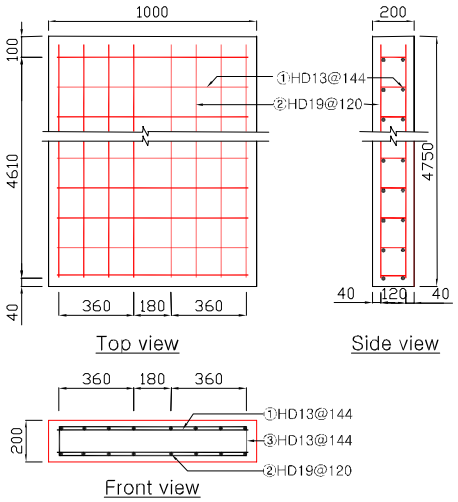


Figure 1. Specimen preparation and re-bar arrangement.

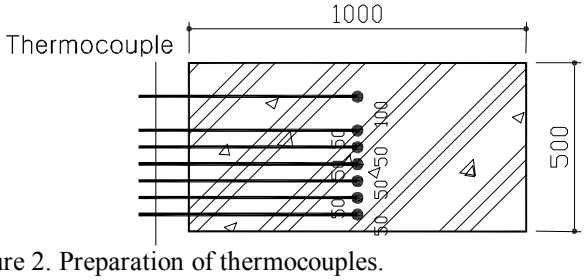
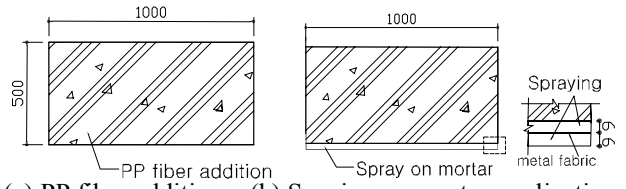
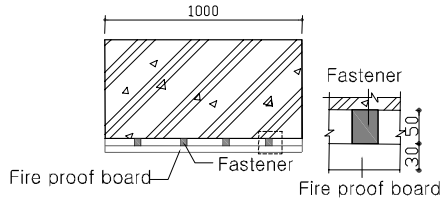


Figure 2. Preparation of thermocouples.



(a) PP fiber addition (b) Spaying on mortar application.



(c) Fire proof board attachment

Figure 3. Specimens applying fire resistance methods.

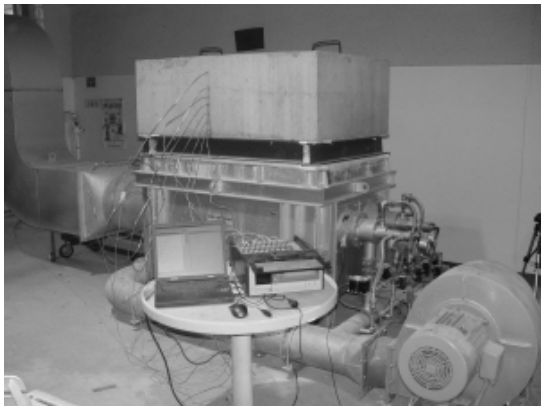


Figure 4. Preparation of a furnace for RABT and RWS curves.

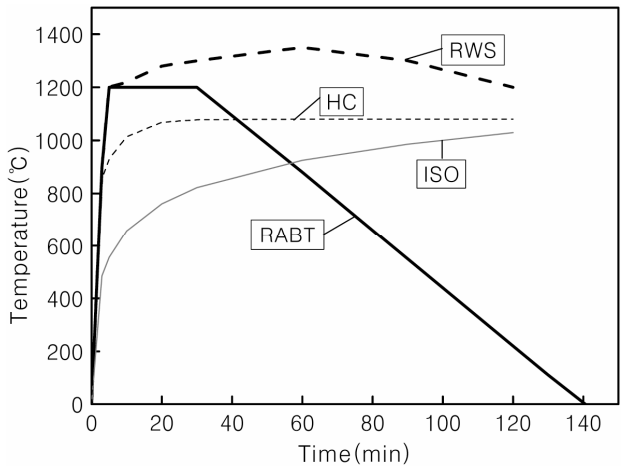


Figure 5. RABT and RWS heating curves.

is obtained by pictorial processing, and total area of the specimen.(See Fig. 8) K type thermocouple was used to monitor temperature history of the specimen.

3 RESULTS AND DISCUSSION

3.1 *Compressive strength*

Figure 6 shows the compressive strength of the concrete with and without PP fiber cured at standard and field condition respectively at 91 days. The addition of PP fiber results in a slight decrease in the compressive strength compared with that of plain concrete.

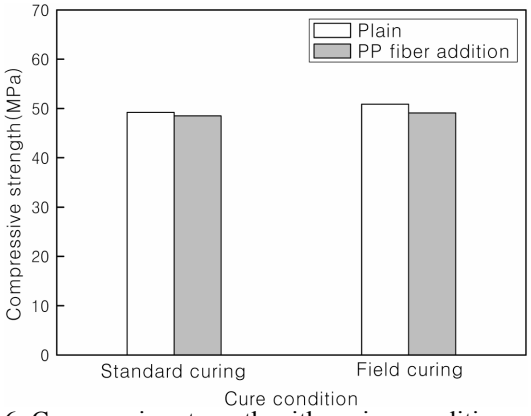
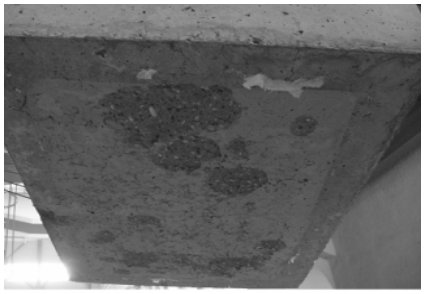


Figure 6. Compressive strength with curing condition.

3.2 *Fire resistance according to heating curve types*

3.2.1 *Fire resistance according to RABT curve*

Figures 7-8 illustrate the spalling extent and spalling area calculated by binary image processing method after the fire test in accordance to RABT. The specimen adding 0.1% of PP fiber showed only slight surface peeling due to vapor evaporation from inside of the concrete resulting from PP fiber melting subjected to fire. The spalling area of PP fiber added specimen was calculated to 19.7%. However, the



(a) Mixing PP fiber method

(b) Spraying method

(c) Fire proof board method

Figure 7. Spalling extent of the specimens depending on fire resistance method according to RABT.

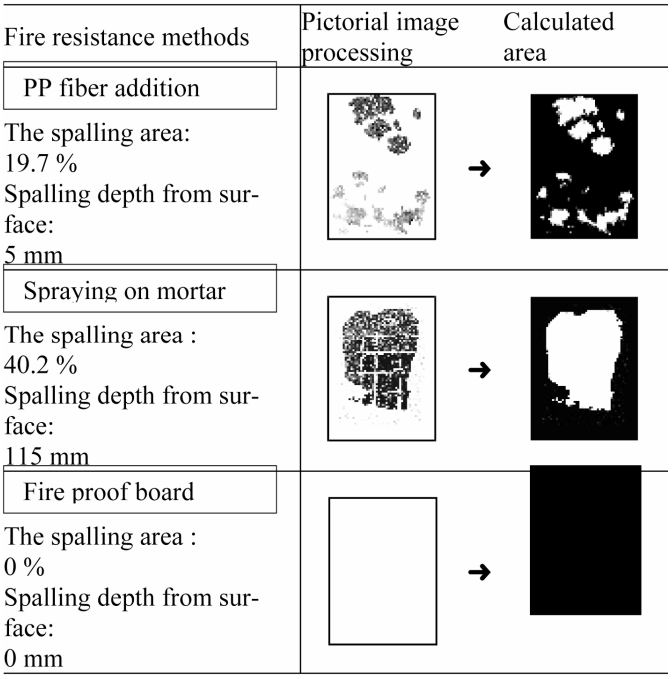


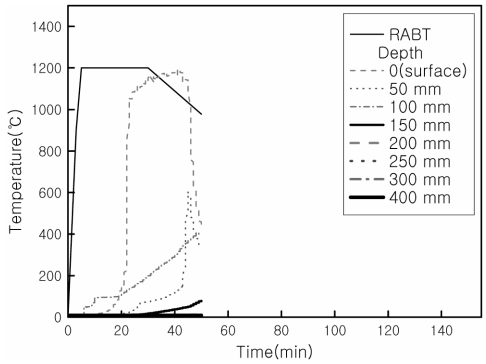
Figure 8. Evaluation of spalling area based on binary image processing according to RABT.

specimen applying spray on mortar and metal fabric confinement had severe spalling, which showed detachment of both metal fabric and spray on mortar and then re-bar was exposed after 50 minutes. The spalling area was 40.2%, which is somewhat larger than that of PP fiber addition. Meanwhile, it is interesting to note that spalling did not occur with the specimen attached with the fire proof board. This is explained by the fact that the PP fiber existed in the fire proof board secures the stability against fire attack by discharging vapor pressure and the fire proof board provided the shield with the inside concrete to avoid temperature transfer. For this reason, the spalling area was calculated to 0%.

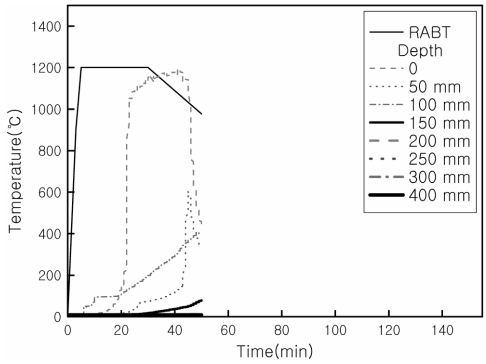
Figures 9-10 show the temperature history and the peak temperature depending on the depth of the specimen. For the specimen adding PP fiber, the peak temperature at the main bar was 685℃ and the temperature at 10 mm depth from the surface of the specimen was 260℃. For the specimen applying spray on mortar, the peak temperature at the surface was 1190℃ and at main bar was 605℃ and 100 mm depth from the surface was 404℃. However, the specimen attached with the fire proof board had 287℃ of the peak temperature at the surface, 146℃ at the main bar and 95℃ at the 100 mm depth from the surface.

3.2.2 *Fire resistance according to RWS curve*

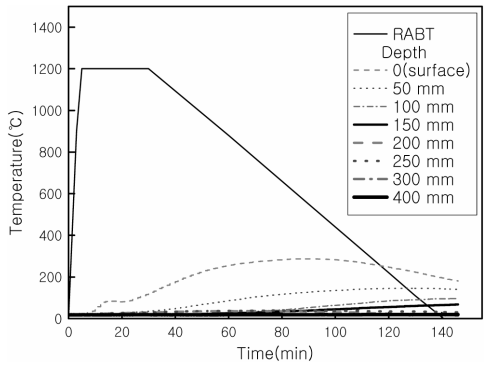
Figures 11-12 illustrate the spalling extent and spalling area calculated by binary image processing method of the specimens after the fire test in accordance with RWS curve. As seen in Figure 11, although the addition of 0.1% of PP fiber protects spalling occurrence due to moisture evaporation, the specimen was melt within 5 mm depth from the surface



(a) Mixing PP fiber method



(b) Spraying method



(c) Fire proof board method

Figure 9. Temperature history of the specimens applying fire resistance methods according to RABT.

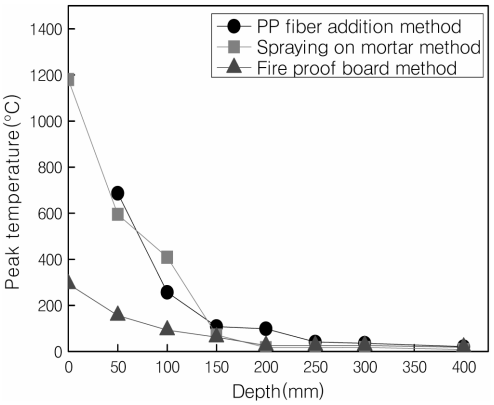
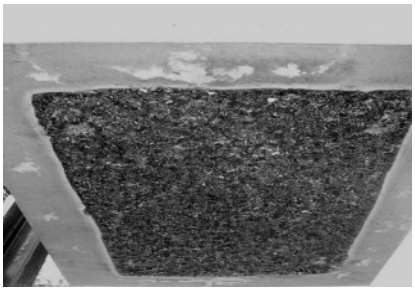


Figure 10. The peak temperature of the specimens applying fire resistance methods according to RABT.

due to exposure to extremely high temperature over 1300℃.

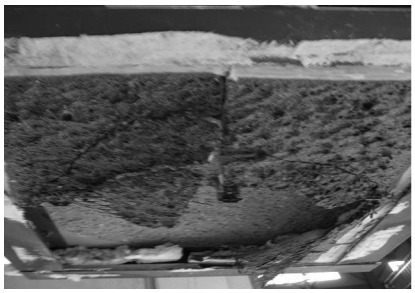
The spalling area was 87%. Furthermore, the case for spray on mortar application experiences falling off of the spray on mortar and exposure of re-bar due to severe spalling. The fire test was terminated after

63 min. Due to severe spalling, maximum spalling depth was 122 mm. The same situation happened with the case for the fire proof board attachment. The fire proof board was detached from the specimen and then severe spalling occurred with the specimen due to extremely high temperature. The spalling area was 71.4% and maximum spalling depth was 30 mm.



(a) PP fiber addition method

(b) Spray on mortar method



(c) Fire proof board attachment method

Figure 11. Spalling extent of the specimens depending on fire resistance method according to RWS.

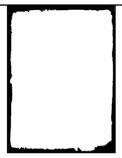
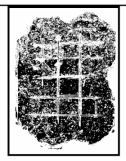
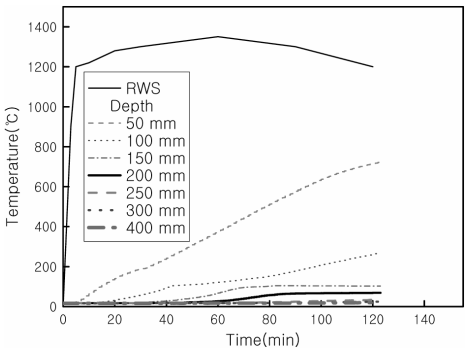
Fire resistance method	Pictorial image processing	Calculated area
PP fiber addition Spalling area ratio : 87.0 % Spalling depth from surface : 5 mm		
Spray on mortar Spalling area ratio : 74.2 % Spalling depth from surface : 122 mm		
Fire proof board Spalling area ratio: 71.4 % Spalling depth from surface : 30 mm		

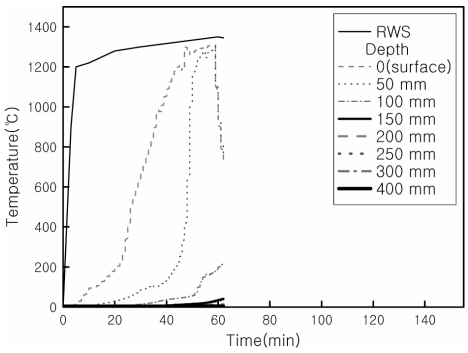
Figure 12. Calculation of spalling area according to RWS curve based on binary image processing.

And also, fire test was terminated after 71 min.

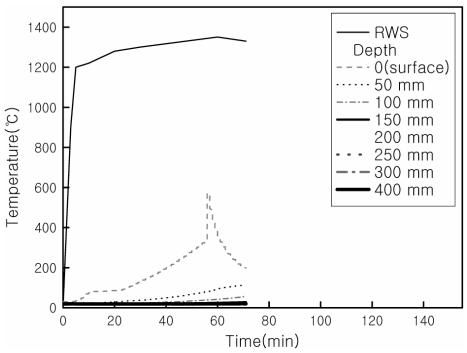
Figure 13-14 shows the temperature history and the peak temperature of the specimen according to RWS heating curve. The case for PP fiber addition showed more than 721℃ of the peak temperature at main bar, which is located from 50 mm of the surface. At 100 mm depth from the surface, the temperature was 268℃. For the specimen applying the spray on mortar, the maximum temperature at the



(a) PP fiber addition method



(b) Spraying on mortar method



(c) Fire proof board method

Figure 13. Temperature history of the specimens applying fire resistance methods according to RWS.

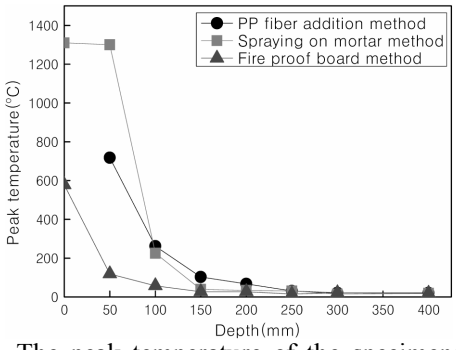


Figure 14. The peak temperature of the specimens applying fire resistance methods according to RWS.

surface was 1307℃ and 1299℃ at the main bar and 213℃ at 100 mm depth from the surface. However, the specimen attached with the fire proof board had only 567℃ of the maximum temperature at the surface and 113℃ at the main bar. This is due to the fact that an attached fire proof board prevents the specimen from being exposed to high temperature until the fire proof board was detached.

Hence, it is thought that under the RABT heat curves, PP fiber addition and fire proof board attachment methods can be available for fire protection method, whereas PP fiber addition and alternative measurement such as increasing the cover depth of the concrete should be considered to secure fire safety under the RWS heating curve condition.

4 CONCLUSIONS

In this paper, fire resistance properties of the concrete applying three different fire resistance methods were studied depending on RABT and RWS heating curves, which is severer heat condition than ISO-834 curve. The results of this study could be summarized as follows.

PP fiber addition and fire proof board attachment are available for fire resistance methods based on the results of spalling extent and temperature history under RABT heating curve. However, the application of spray on mortar resulted in severe spalling occurrence, and moreover, re-bar embedded in the specimen was exposed due to severe spalling.

Under the RWS heating curve, although spalling did not occur with the specimen adding PP fiber, the specimen was melted within 5 mm depth from the surface due to extremely high temperature. Furthermore, the application of spray on mortar and the fire proof board attachment are not available for spalling protection, and re-bar was exposed due to spalling of cover concrete.

In the scope of this study, existing fire resistance methods such as spray on material or fire proof board attachment to protect the concrete from severe fire attack did not bring desirable results subjected to the condition of RABT and RWS heating curves. Hence, it is necessary to consider PP fiber addition or increase of the depth of cover concrete to secure fire safety of tunnel concrete under the severe temperature exposure for long time such as RABT and RWS heating curves.

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