BEHAVIOR OF FIBER REINFORCED CONCRETE UNDER FIRE TEMPERATURE

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Abstract

Concrete lining of tunnel are sometimes exposed to very high temperature due to traffic accident. Concrete lining must be designed to having the fireproof performance. In recent years, various fibers have been mixed in concrete structure for higher strength and durability. Such fiber reinforced concretes (FRC) have been employed for tunnel lining, which is constructed rarely as RC structure. Such fibers in tunnel lining are most important to prevent of exfoliation of concrete pieces. However, the property of FRC under fire temperature has not been investigated enough. This paper presents behaviour of FRC obtained from the fire-heating test, and reports gases from plastic fiber after fireproof experiment of concrete element. The experimental result showed that explosion of PFRC was smaller than explosion of normal concrete or SFRC. It was confirmed that poisonous gas for human is hardly occurred from plastic fiber.

1. INTRODUCTION

Fiber reinforced concrete (FRC) has been employed for various concrete structures so that fiber can improve higher durable concrete than normal concrete. Especially, various fibers have become important materials for reinforcing concrete since plastic fiber with high performance has been developed.

Tunnel lining are designed as non-support member of tunnel, and it is generally constructed by using low-strength concrete without reinforcement. In recent years, concrete with steel fiber (SF) are used for materials of tunnel lining so SFRC can prevent to fall concrete piece. Such steel fibers, however, have possibility of troubles in case of inappropriate construction, e.g. corrosion in concrete. Plastic fibers (PF) may be one of appropriate materials for lining concrete in future. Strength of PFRC is not as high as

Table 1: Fire temperature in tunnels

Tunnel	Location	Type	Fire Temperature (Maximum)
Nihonzaka	Japan	Road Tunnel	600 - 1000 ^{o}C
Caldecot	U.S.A	Road Tunnel	945 (1038) ^{o}C
Mont Blanc	France	Road Tunnel	1000 (1832) ^{o}C
Tauern	Austria	Road Tunnel	1000 ^{o}C

Table 2: Ultimate limit temperature of tunnel

Concrete	250 - 380 ^{o}C	---
Reinforcement	250 - 350 ^{o}C	---
Waterproofing sheet	70 - 110 ^{o}C	Melting temperature

strength of SFRC, but it can prevent sufficiently to fall of concrete piece from tunnel ceiling. For this purpose, the durability of lining concrete with plastic fiber is needed to evaluate appropriately by various experiments.

Concrete lining of tunnel are sometimes exposed to fire temperature by traffic accidents. Such fire temperature may cause explosion of concrete, or collapse of tunnel structure [1]. We must avoid at least the human disaster in case of fire accident in tunnel.

Durable concrete to fire temperature are required for infrastructure such as road tunnels. However, fire durability of FRC, especially PFRC, has not been investigated sufficiently even now. In order to employ PFRC to lining concrete, its safety to fire temperature must be evaluated experimentally. In addition, plastic fiber in concrete has possible to generate a poisonous gas for human in case of very high temperature. Thus, it is important to quantify the characteristics of PFRC under very high temperature.

The purpose of this study is to obtain the fundamental characteristics of PFRC for tunnel lining. The present study conducted the fundamental experiment to simulate fire temperature by employing 4 types of concrete. Employed concrete materials were plain concrete (PLC), steel fiber reinforced concrete (SFRC), polypropylene fiber reinforced concrete (PPFRC) and vinyl fiber reinforced concrete (VFRC). The present study investigated experimentally the explosion and cracks in heated surface of these concretes. Employed temperature curve were RWS criterion, which are most severe in various criterion of fire temperature. In addition, gas analysis of plastic fiber was conducted in order to evaluate the dangerousness for human body.

2. EXPERIMENT OF FRC UNDER FIRE TEMPERATURE

2.1 Fire temperature in tunnel

Fire temperature in case of traffic accident was firstly investigated. Table 1 gives some example of traffic accidents in tunnel, and the fire temperature of each accident is summarized in this table. Here, Table 2 gives the ultimate limit temperature. All fire temperature in past accidents is extremely higher than the ultimate limit temperature of each member in tunnel.

In order to simulate appropriately the behaviour of concrete lining, the temperature history due to fire accident is required for experiment. Figure 1 shows various criterion curves for fire temperature. Every temperature history is set as higher development in short time. RWS curve was selected as the temperature history for the fireproof experiment in this study, so it can simulate the most severe condition of concrete lining.

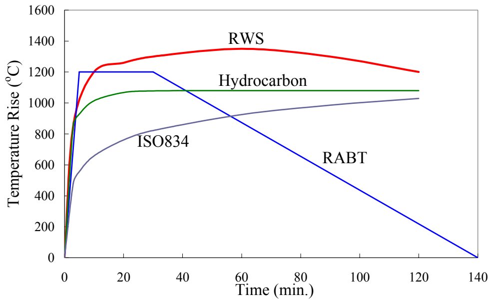


Figure 1: Criterion curves of fire temperature

2.2 Fiber reinforced concrete

Table 3 gives detail of fibers employed in this study. SFRC were mixed with steel fiber of different length, 30 and 60 mm. Employed plastic fibers were polypropylene fiber and vinyl fiber, which have higher bond-strength than usual plastic fibers.

Table 4 gives mix proportion of each concrete. Each mixture was determined to satisfy the designed strength (18MPa) for tunnel lining, and fiber volume was determined as the minimum quantity to have appropriate workability. The fresh and mechanical property of each concrete was summarized in Table 5.

2.3 Experimental program

In order to survey the behaviour of FRC elements, fire-heating test was conducted by using the fireplace apparatus as shown in Figures 2 and 3. Temperature history in the

Table 3: Detail of employed fiber

	Material (Density)	Size	Young's Modulus	Thermal Decomposition Temperature
SF	Steel ($7.86\ g/cm^3$)	L=30 & 60mm D=$800x10^{-6}$m	200 GPa	---
PPF	Polypropylene ($0.91\ g/cm^3$)	L=60mm D=$(1400*750)x10^{-6}$m	9.00 GPa	271 °C
VF	Vinyl ($1.30\ g/cm^3$)	L=50mm D=$660x10^{-6}$m	29.4 GPa	263 °C

Table 4: Concrete mix proportion

	W	C	S	G	Ad	Fiber
PLC	167 kg/m^3	270 kg/m^3	876 kg/m^3	167 kg/m^3	500 g/m^3	---
SFRC	173 kg/m^3	320 kg/m^3	972 kg/m^3	820 kg/m^3	3680 g/m^3	0.5 Vol.%
PPFRC	175 kg/m^3	350 kg/m^3	892 kg/m^3	916 kg/m^3	4030 g/m^3	0.75 Vol.%
VFRC	175 kg/m^3	350 kg/m^3	948 kg/m^3	806 kg/m^3	4720 g/m^3	0.5 Vol.%

Table 5: Concrete properties

		PLC	SFRC	PPFRC	VFRC
Slump (mm)		155	165	125	160
Air (%)		4.4	5.5	5.0	4.5
Compressive Strength (MPa)		33.5	31.8	40.5	40.9
Flexural Strength (MPa)	Crack	3.34	3.75	3.75	3.72
	Max.	3.34	6.09	4.41	5.40

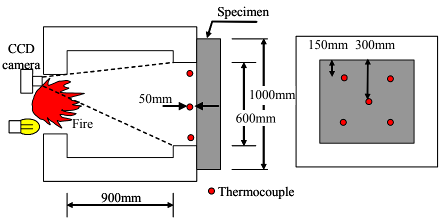


Figure 2: Fire heating apparatus

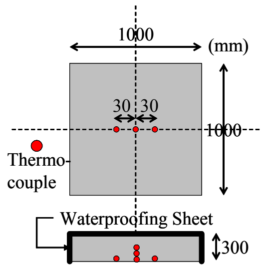


Figure 4: Specimen for fire heating test


Figure 3: Fire heating test

apparatus was controlled based on RWS curve. The back-surface of each specimen was set under room temperature approximately 10^{o}C.

Figure 4 presents detail of concrete specimen for heating test. As shown in Figures 2 and 4, thermocouples were set at various points for obtaining temperature distribution inside and outside of concrete.

Furthermore, the gas form plastic fiber was investigated in order to evaluate the influence to human body.

3. EXPERIMENTAL RESULTS

3.1 Explosion of concrete

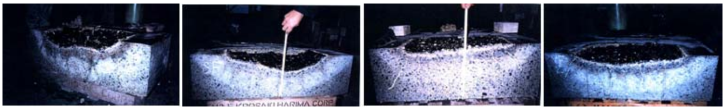
Table 6 gives the explosion of each concrete during fire-heating test. Such condition was investigated by using CCD camera, which is set with the heating machine.

PLC and SFRC had been collapsed with many large explosive; conversely PFRC had been gradually exfoliated with relative small explosive.

The ultimate condition of each concrete after heating test are shown in Figure 5. As shown in Table 6 and Figure 5, the number of explosion and the damage depth in PPFRC were not as remarkable as PFRC or SFRC. These results indicate that PFRC has higher durability to fire-heating than other concrete.

Table 6: Explosive fracturing condition of concrete

	PLC	SFRC	PPFRC	VFRC
Number of large explosion	12	9	3	7
Number of small explosion	0	9	4	0
Number of crack in surface	20	17	22	12
Steady state (min.)	18	30	7	14
Crack width (mm)	0.3-0.9	0.04-0.3	0.1-0.6	0.1-0.7
Damage depth (mm)	108	118	36	78



i) PLC ii) SFRC iii) PPFRC iv) VFRC

Figure 5: Concrete after fire heating test

3.2 Temperature in concrete

Figure 6 presents the temperature history, which was measured from thermocouple embedded in concrete. These figures present the temperature history within 50 minutes, because the temperature of all concrete became almost steady state after 30 minutes.

Temperature at 0 mm of every concrete rose rapidly, however the inside temperature rise of PFRC was not as remarkable as that of PLC. Fiber in concrete contributes the prevention of crack propagation, and the effect depends on the mechanical properties of fiber. Especially, plastic fiber can provide the additional pore so that plastic fiber is melted by fire heating. Thus, plastic fiber can soften the stem pressure, and can prevent the sudden collapse. SFRC has the higher resistance for crack as it took longer time to be steady state than other concrete. SFRC indicated the hardest explosion in employed concrete because that the greater energy was accumulated in the concrete.

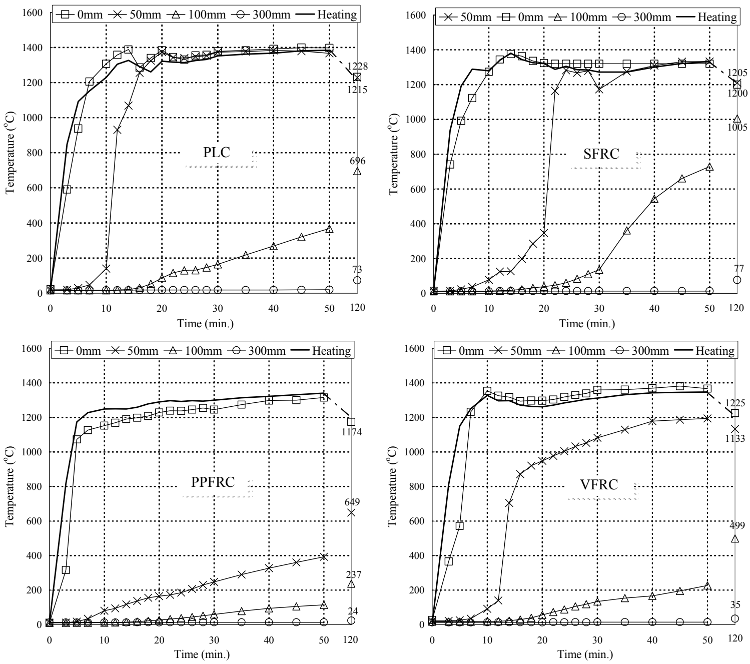


Figure 6: Inside temperature – exposed time to fire-heating

Here temperature of back-surface of each concrete were not as high as the melting temperature of waterproofing sheet. This experimental result represents that such concrete has no possibility to affect the sheet in case of fire accident.

Table 7 gives the weight of fiber in concrete after the heating test. This result was obtained from the investigation of cubic piece (50x50x50mm), which was cut from the heated concrete specimen. From the investigation, it was confirmed that the plastic fiber melted within 100 mm from the heated surface of concrete.

3.3 Gas analysis of plastic fiber

In the present study, gas from plastic fiber was analyzed to evaluate the influence on human body. These results had been obtained from the standard test provided in Japan Industrial Standard. Table 8 gives the analyzed gas of plastic fiber, i.e. PPF and VF. As

Table 7: Weight of fiber remaining in concrete after heating test

Depth (mm)	0~5	5~10	10~15	15~20	20~25	25~30
SF (g/cube)	---	5.53	5.32	6.07	5.55	4.21
PPF (g/cube)	---	melted	1.44	0.80	1.24	1.41
VF (g/cube)	---	melted	0.48	0.75	0.58	0.70

Table 8: Gas analysis of plastic fiber

	CO	CO_2	H_2S	HCl	Sox	Nox	HCN
PPF (mg/g)	67	780	---	---	---	---	---
VF (mg/g)	280	450	---	---	---	---	---

shown in Table 8, harmful gases were not detected from plastic fiber except for CO and CO_2. Here, CO detected from the gas analysis was not harmful level to human health. The gas analysis indicates that the plastic fiber reinforcing concrete has hardly influence on human body even if the fire accident happened in tunnel.

4. CONCLUSIONS

In this paper, the behaviour of concrete which simulate tunnel lining under fire accident was presented. Especially, characteristic of PFRC was investigated experimentally for evaluation of the applicability to lining concrete. The conclusions of present study are listed as follows:

- PF can soften the stem pressure and prevent the sudden collapse of lining concrete.
- PFRC has the higher resistance to explosion by fire than PLC or SFRC.
- PLC and SFRC rarely has possibility of waterproof-sheet melt even in fire accident.
- Combustion gas from PF has no influence on human even if the fire accident happened.

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