Estimation of Fire Damage in High-Strength Mortar Mixed Polypropylene Fibers by Ultrasonic Tomography

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1. GENERAL INSTRUCTIONS

Concrete causes spalling explosively when exposed to high temperatures. In structural members, loss of cross section caused by spalling can result in a loss of structural functions, and can lead to collapse at the frame level [1]. Many researchers have been studying explosive concrete spalling caused by heat generated in fires for many years, and have cited factors such as water content, thermal stress from rising temperatures, water vapor pressure, mineral composition of aggregate, and concrete mixture [2-3]. Methods for preventing explosive concrete spalling include the application of fire resistant sheaths and the mixing of fibers into concrete. The mixing of short polypropylene(PP) fibers, or PP fibers, is a widely used method particularly in reinforced concrete construction with high-strength concrete, because this method offers economic advantages and results in a smaller finished cross section of members. However, there has been limited research to further understanding of the mechanical characteristics or internal behavior of concrete mixed with PP fibers [4].

The ultrasonic method used in the present research is a technique that has been used from the beginning of non-destructive testing, and, to date, has been used to estimate properties of concrete such as compressive strength, Young's modulus and crack width. Moreover, the tomography method has been developed in recent years as a method for estimating the internal quality of concrete. However, research on the applicability of this method to the estimation of fire damage of concrete has not yet been reported [5-7].

The authors report here the results of experiments that were conducted to determine fire damage of mortar specimens and to investigate the applicability of ultrasonic tomography method as a non-destructive method for gaining information on the internal behavior of mortar subjected to fire damage.

Mortar specimens mixed with PP fibers were placed in a furnace and heated from four sides to investigate the effect that the addition of PP fibers has on the mechanical characteristics of fire damage behavior inside the mortar and the applicability of ultrasonic tomography in fire damage estimation.

2. EXPERIMENTAL METHOD

2.1 Manufacture of specimens

Mortar cubic specimens of 300 × 300 × 300mm were applied in the experiment. Ordinary Portland cement (density:3.60g/cm^3) and river sand (density in saturated surface-dry condition : 2.60g/cm^3) were used.

The water-cement ratio (W/C) was varied in 3 levels of 0.25, 0.3, and 0.4. One cubic specimen and six cylinders of ϕ 100 × 200mm were prepared for each water-cement ratio. *Table 1* shows the mix proportions of mortar.

Table 1 Mix proportions of mortar

W/C	S/C	W	C	S	PP	HAE
0.25	1.13	232	971	1,098	0.2	10.68
0.3	1.28	249	858	1098	0.2	8.58
0.4	1.25	335	835	1047	0.2	0

[Notes] W/C : Water-cement ratio, S/C : Sand-cement ratio, W : water(kg/cm^3),
C : Cement(kg/cm^3), S: Sand(kg/cm^3), pp : Polypropylene(vol%),
HAE : High-range reducing AE agent

All specimens were demolded after one week, and the fire experiment was carried out at the age of eight weeks after curing in air for seven weeks.

2.2 Fire experiment

The fire experiment of mortar specimens was carried in the Fire Science Laboratory of Tokyo University of Science. The heating process was followed by the standard heading curve by ISO 834 [8].

$$T = 345\log_{10}(8t+1) + T_0$$

Where,

T_0 : Initial temperature,
t : Time (minutes)

Twenty-five thermocouples were set in each cubic specimen to examine the temperature distribution in the specimen. The arrangement is shown in *Figure 1*. Each specimen was heated from 4 sides.

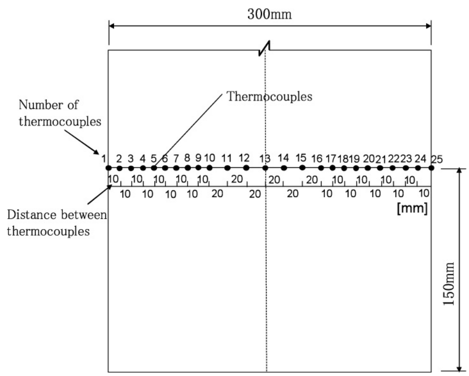


Figure 1 Location of thermocouples in specimen

2.3 Experiment of small size cores

Compressive test of small size mortar cores of 23mm in diameter was carried out for examining the internal properties of specimen after fire. *Figure 2* shows the location for drilling out small size cores.

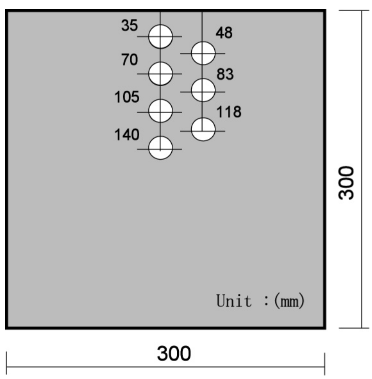


Figure 2 Location for drilling small size cores

2.4 Ultrasonic tomography method

2.4.1 Outline of experiment

The tomography method was applied by using measured ultrasonic pulse velocities. In this study, a target section was divided into 900 blocks in each 10mm internal.

As shown in *Figure 3*, in the case that the portion with low velocity exists in the specimen, the estimated pulse velocity of the blocks represented by one side hatch becomes low. In this study, therefore, analyses in X and Y directions were carried out separately, and higher values of pulse velocity in each block were used as estimated pulse velocity.

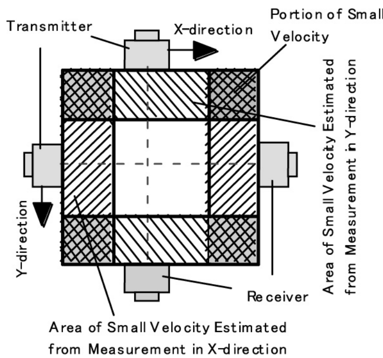


Figure 3 Measuring method of ultrasonic pulse velocity

2.4.2 Measuring method of pulse velocity

A transmitter with the frequency of 50kHz was used for measuring the transmitting time of ultrasonic pulse. *Figure 4* shows the position where the ultrasonic pulse velocity is measured. As shown in the figure, transmitting times were measured at 20mm internal in both X and Y directions, and the measurement between 450 points was done in one section of each specimen.

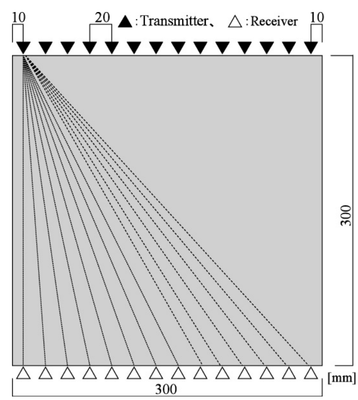


Figure 4 Schematic diagram of measuring method for ultrasonic pulse velocity (Y-direction)

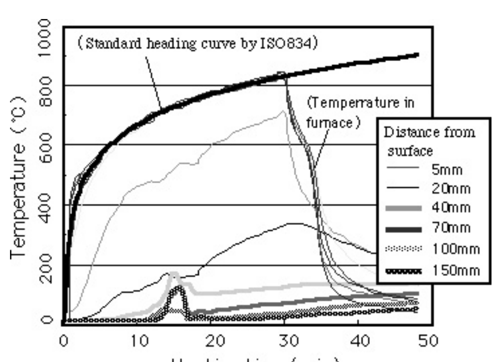


Figure 5 Temperature-heating time curves of specimen heated during 30 min.

3. EXPERIMENTAL RESULTS AND DISCUSSION

3.1 Temperature change in fire-resistant furnace and specimen

Figure 5 is an example of the temperature change in the specimen after heating for 30 minutes based on the standard heading curve by ISO 834. It is shown in the figure that each temperature around specimen rises along the standard heating curve. A high temperature is shown near the heated surface, and the temperature at the portion of 70mm from the surface is about 100˚C.

3.2 Analytical results of ultrasonic tomography

Figures 6(a) and *(b)* show the examples of the distribution of ultrasonic pulse velocity before heating obtained by the tomography method of X-direction analysis. The pulse velocity in the specimen in PP fibers mixed *(a)* is not different between *(b)*.

Figure 7 shows the examples of the distribution of ultrasonic pulse velocity after heating obtained by the tomography method of one-direction analysis. The pulse velocity in the outside is low and that in the central portion is high. And mixing the PP fibers(a) and (c) hardly influences internal temperature distribution and ultrasonic pulse velocity after heating.

Figure 8 shows the distribution of Young's modulus calculated from ultrasonic pulse velocity at 30 minutes heating. The Young's modulus ratio obtained by tomography shows the similar tendency with that by small cores shown in *Figure 12*. The pulse velocity from heating surface is not remarkably different between PP mixed and the one of no mixing.

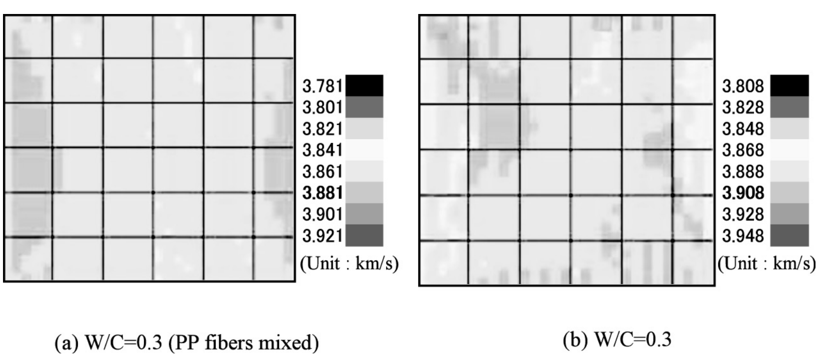
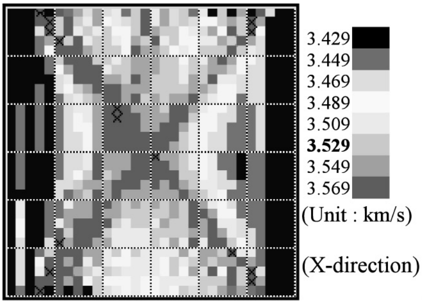
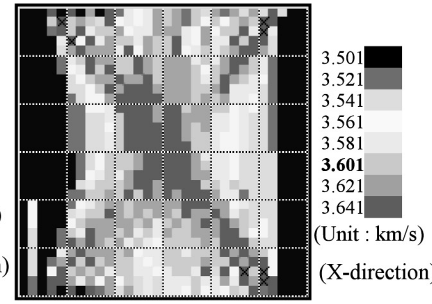


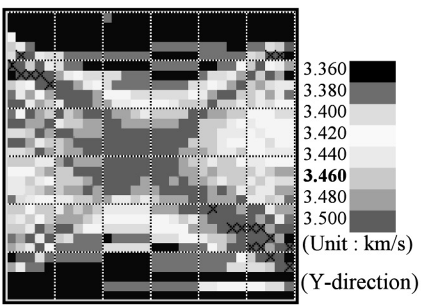
Figure 6 Distribution of ultrasonic pulse velocity before heating obtained by tomography (X-direction)



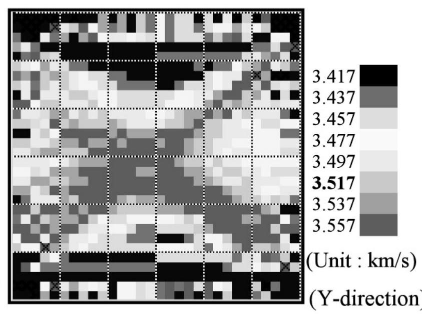
(a) W/C=0.3 (PP fibers mixed)



(b) W/C=0.3

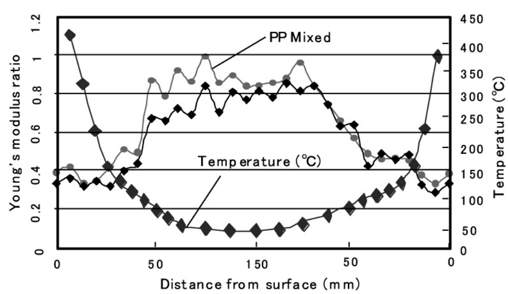


(c) W/C=0.4 (PP fibers mixed)



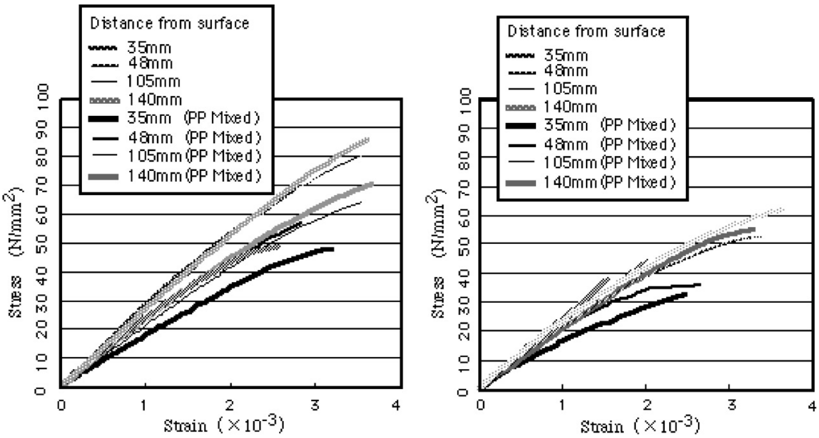
(d) W/C=0.4

Figure 7 Distribution of ultrasonic pulse velocity after heating obtained by Tomography



X-direction (W/C=0.3)

Figure 8 Relationships between Young's modulus ratio and distance from surface



(a) W/C=0.3 (b) W/C=0.4

Figure 9 Stress-strain curves of small size cores

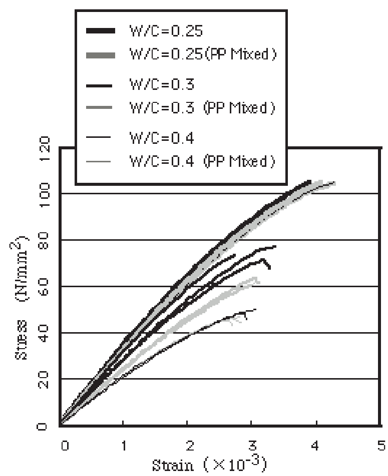


Figure 10 Stress-strain curves of standard cylinder under no heat

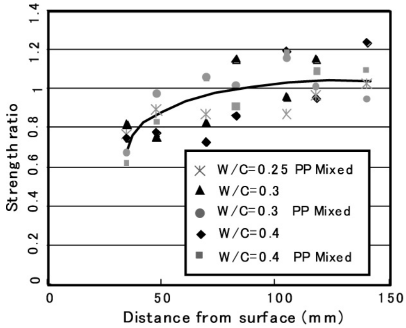


Figure 11 Relationship between strength ratio and distance from surface

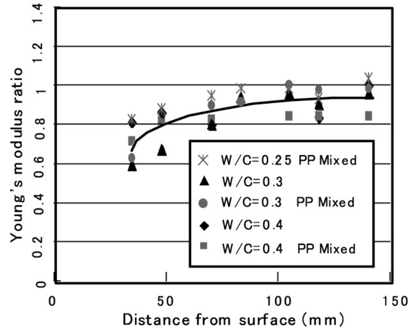


Figure 12 Relationship between Young's modulus and distance from surface

Figures 9(a) and *(b)* show stress-strain curves of small size cores drilled from the cubic specimens. As shown in these figures, the strength decreases in the decrease of the distance from heating surface and is hardly affected by water-cement ratio in the specimens drilled from the neighborhood of surface. And, stress-strain curves of standard cylinders of ϕ 100×200 under no heat are shown in *Figure 10*.

Figure 11 shows the relationship between compressive strength ratio and distance from surface, where strength ratio represents the ratio of compressive strength of small size core to that of standard cylinder. The strength ratio decreases in the decrease of the distance from surface within 80mm.

Figure 12 shows the ratio of Young's modulus of small size core to that of standard cylinder, and the Young's modulus ratio decreases as the distance from surface is decreased.

4. CONCLUSIONS

The results obtained in this paper are summarized as follows:

1) The fire damage is remarkable in the neighborhood of heated surface, but, the portion further than 70mm is hardly affected by heating.
2) Detailed distribution of ultrasonic pulse velocity of specimen damaged by fire can be obtained by the tomography method.
3) The changes in fire damage behavior inside mortar mixed with PP fibers could be observed using ultrasonic tomography method.

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