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Melting Effect on Fiber to Prevent Spalling on High Strength Concrete†

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In order to systematically examine the explosive spalling of high strength concrete, it was used small size specimen to evaluate explosive spalling property and temperature history according to ISO-834 fire curve. Also, optimizing condition of mixed fiber was confirmed by calculating the weight loss of fiber based on heat transfer analysis of inner concrete. Based on melting point of fiber, we used three fiber types [which were polyethylene (110 °C), polypropylene (165 °C), nylon fiber (225°C)]. Mixed fiber as 0.15, 0.25 % of concrete volume, test on spalling properties, TG-DTA of fiber and FEM analysis were performed.

Keywords: Explosive spalling, ISO-834 fire curve, Fiber, Melting point, FEM analysis.

INTRODUCTION

High strength concrete, there is high risk of explosive spalling in which covering is peeled off according to time exposed to fire, internal amount, temperature and others as it is tightly organized inside. As cross sectional loss for coverings of concrete occurs and temperature is transferred to the interior of structure rapidly by such explosive spalling, it is proposed that collapse of building may occur due to dramatic decrease in resisting force of reinforced steel. Causes of such explosively spalling of high strength concrete are reported to be dramatic increase in temperature, high moisture content, low water to cement ratio, difference in thermal expansion strain of aggregate and cement paste and others[1]. Therefore, in order to prevent explosive spalling, such causes need to be removed but it is difficult due to the conditions of construction.

Due to above reasons, studies on technology to prevent explosive spalling of high strength concrete are conducted by many scholars and method to mix fiber without change in cross section and size of concrete member and discharge vapor pressure [2]. Method to mix fiber into concrete is most economic and effective construction method to reduce explosive spalling of concrete and mixing of (polypropylene) fiber is reported to be most effective for prevention of explosive spalling[3]. But application of fire resistance performance design according to fiber mixing method developed based on previous studies may lack reliability and systematic and quantitative fire resistance performance evaluation should be conducted based on its cause[4].

This study was aimed to design of fire resistance performance through systematic and quantitative evaluation based on fiber mixing conditions, comparative analysis was conducted through objective tests with the utilization as its purpose.

EXPERIMENTAL

Fibers: Physical properties of polyethylene fiber, polypropylene fiber, nylon fiber and steel fiber mixed in order to prevent explosive spalling of high strength concrete and enhance the performance as a plan to enhance fire resistance performance of fiber are showed in Table-1.

TABLE –1
PHYSICAL PROPERTIES OF FIBER

Physical properties	Polyethylene	Polypropylene	Nylon
Diameter (µm)	12	20	20
Length (mm)	12	12	12
Density (g/cm^3)	0.91	0.91	1.1
Tensile strength (MPa)	25-700	30-750	75-900
Elasticity (GPa)	1.4-2.2	1.4-2.2	3.9-5.9
Melting point (°C)	100	165	225

Concrete: The properties of the materials are summarized as follows. The specific surface area of the cement used was 3,200 m^2/g and its specific gravity 3.15. The chemical agent

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used was polycarboxylate. Granite aggregate had a specific gravity of 2.70, a maximum size of 13 mm and an absorption rate of 0.9 %. For the fine aggregate, washing sand of density 2.65 g/cm^3 and absorption rate of 1.0 % was used.

Mass loss of fiber: It is reported in these studies that maximum pressure of vapor is influenced by the melting point of fiber. Therefore, in order to prevent explosive spalling of fiber, accurate understanding on melting point of fiber is necessary thus melting point of fiber utilized to prevent explosive spalling was analyzed using differential thermal analysis (DTA) based on change in condition of fiber.

Spalling test: In regards to the heating of specimen, unstressed test was conducted for 50 min (maximum temperature 886 °C) based on ISO-834 standard heating curve. For the purpose of fixing the specimen, heating test was conducted in this study after imposing the load of 2 kN to evaluate explosive spalling.

Analysis on temperature distribution: Finite element analysis program Midas FEA was used for the heat transfer analysis of specimen and the value of EN 1992-1-2:2004(E) was utilized as thermal constant value of material in heat transfer analysis.

Fig. 1 shows the comparison between test value measured through temperature sensor buried inside the concrete and temperature analysis value. Although analysis result is little different from test value, based on temperature distribution analysis between 5-30 min at which explosive spalling occurs.

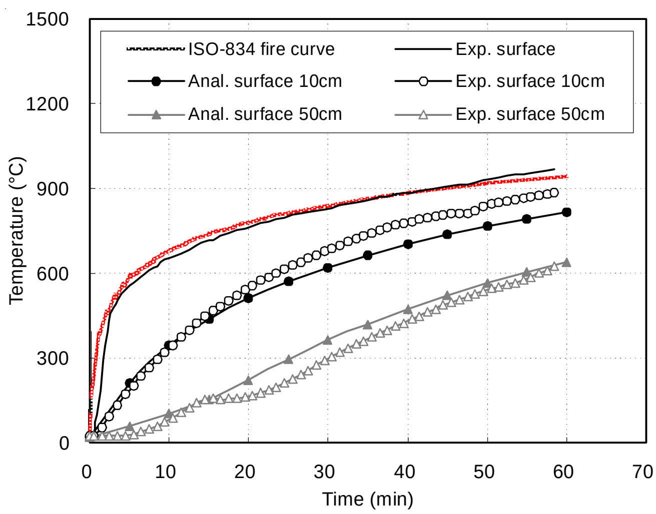

Fig. 1. Comparison of temperature history

Following hypothesis was premised in order to calculate melting amount of fiber based on temperature distribution during the heating:

(1) The temperature distribution of actual specimen is same as analysis condition.

(2) Fiber is distributed equally within specimen.

(3) Evaporation amount of fiber was calculated with formula (Fig. 4).

Also, in order to analyze the influence of explosive spalling lowering followed by melting and evaporation of fiber, it was set as 10, 30 and 50 mm deep from the surface as showed in Fig. 2.

Area rate for temperature distribution of inner concrete based on each time period is shown in Fig. 3. Also, fiber

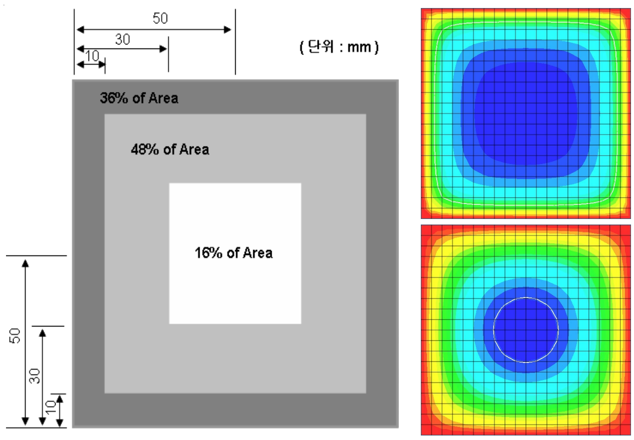

Fig. 2. Calculation of temperature distribution

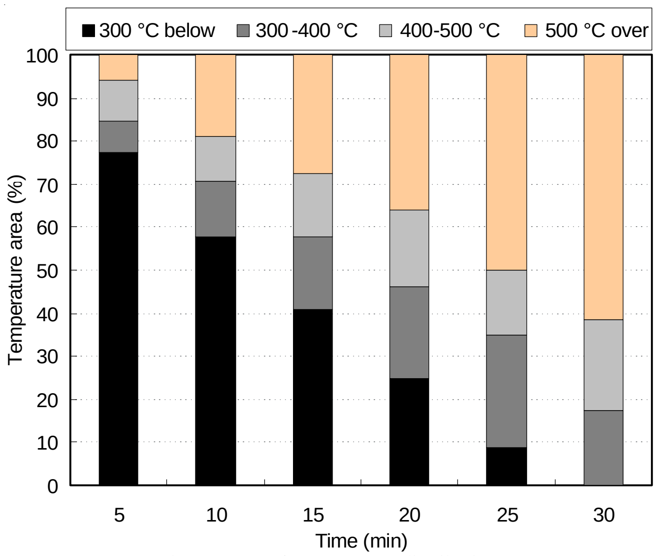

Fig. 3. Area of temperature distribution

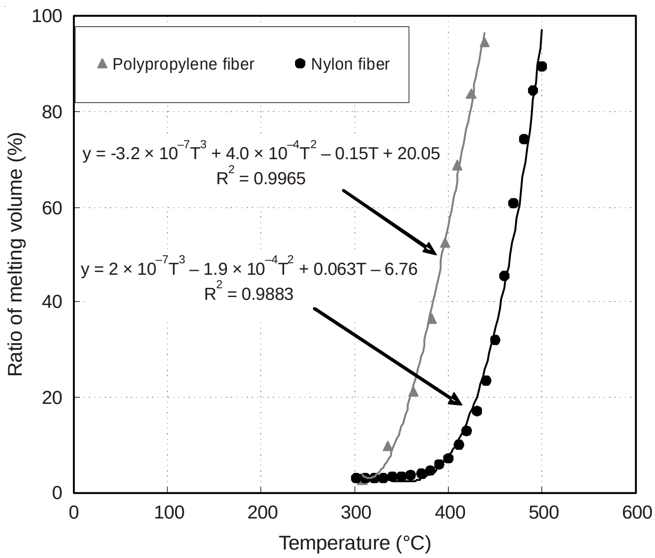

Fig. 4. Equations of mass loss at temperature

evaporation rate based on time in regards to set area was calculated by the formula (1).

$$R_P = F_r \times A_r \times F_m \times (A_{300\text{-}400} + A_{400\text{-}500} + A_{500}) \qquad (1)$$

where, R_p: Fiber loss within surface distance (vol %); F_r: Overall fiber mixing rate (vol %); Ar: Area rate within surface distance (%); F_m: Min. fiber melting rate within surface distance (%); $A_{300\text{-}400}$: Area rate at 300-400 °C (%); $A_{400\text{-}500}$: Area rate at 400-500 °C (%); A_{500}: Area rate at over 500 °C (%).

RESULTS AND DISCUSSION

Mass loss of fiber by heating: The weight loss of each fiber based on the location inside the concrete was showed in Fig. 5. In regards to the concrete weight loss at inner 10 mm location, polypropylene fiber showed dramatic weight loss after 300 °C and polyethylene fiber showed dramatic weight loss after 450 °C after it was started at 300 °C.

However, nylon fiber is determined to have effect of alleviating initial pressure as it maintains some weight loss from 50 to 400 °C at which dramatic weight loss occurs. Also, it was revealed to be most effective in actual explosive spalling resistance performance evaluation.

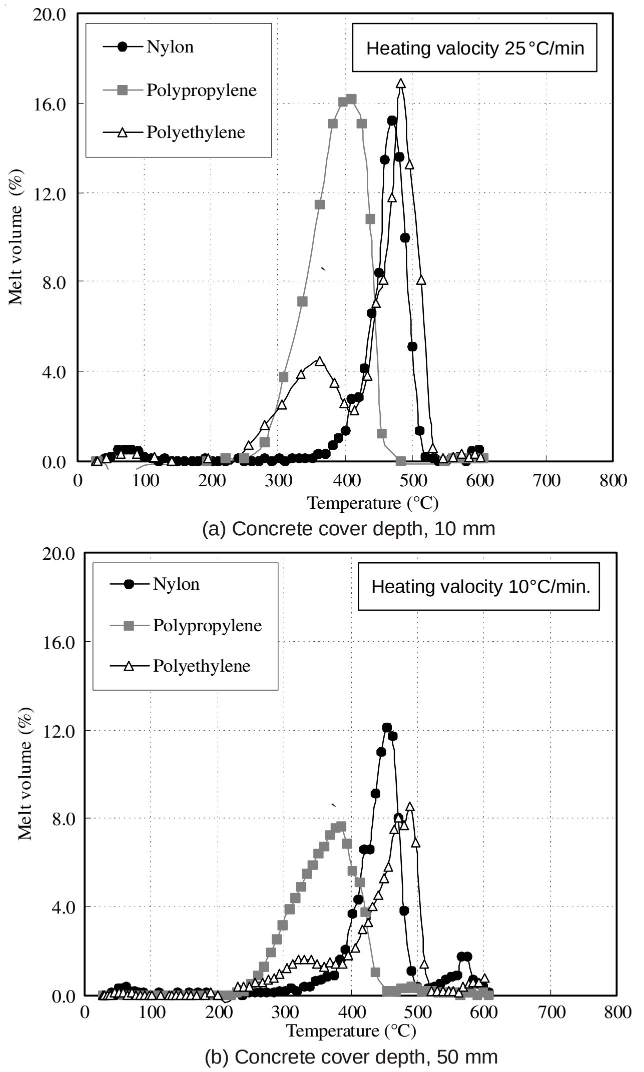

Fig. 5. Mass loss of each fiber based on the location inside the concrete

Result of spalling test: Generally, pore is formed at low temperature and initial pressure can be alleviated with lower melting point thus it reported to be effective in prevention of explosive spalling. However, in regards to the explosive spalling test conducted in this study, explosive spalling control performance of each fiber was reported to be as nylon > polypropylene > polyethylene fiber. Thus it showed different result compared to general theory. In regards to the melting point, although it was lowest for polyethylene fiber and highest for nylon fiber, it was revealed that temperature at which pore is actually formed with weight loss rather than melting is the evaporation point as a result of weight analysis.

Mass loss of fiber in concrete: Fig. 6 shows mass loss of each fiber based on the location inside the concrete. Until surface distance 10 mm, melting amount of fiber in nylon fiber reinforced concrete at initial stage of 5-10 min. is large compared to polypropylene fiber reinforced concrete and its value was determined to be over 0.012 vol. %. At 10-20 min it is small compared to polypropylene fiber reinforced concrete but it was revealed to present similar behaviour at after 20 min.

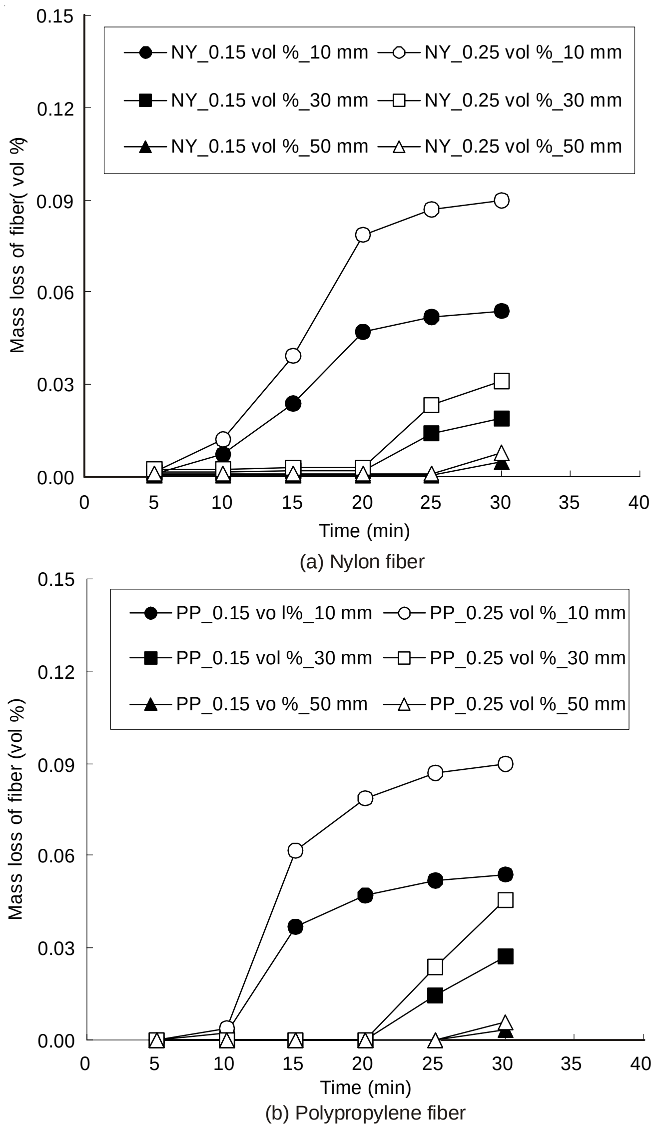

Fig. 6. Mass loss of fiber with fiber mixed volume

Also, the difference in such tendency increased with the increase in mixing rate and it was confirmed that difference of fiber loss followed by fiber melting and evaporation of surface distance 10 mm was presented to be large compared to value at surface difference 30 and 50 mm with the increase in mixing rate. Also, since the loss amount of total fiber is at least over 60 % of total fiber at temperature which was reached after 30 min. It was determined that vapor pressure was maintained due to the formation of sufficient pore where vapor pressure can be discharged and moved at higher temperature. Therefore, when explosive spalling test result, relation of pore pressure and result value from analysis on melting amount of fiber are summarized, difference in loss amount followed by initial evaporation was presented to have effect of lowering explosive spalling in ultra high strength concrete. Although concrete which is heated quickly presents difference in melting point of fiber followed by dramatic increase in temperature.

Conclusions

• The prevention of initial explosive spalling may be difficult even when mixing rate is increased due to closure of pore with the increase in fiber weight at temperature between 100-300 °C. In regards to nylon fiber, however, it was revealed to be effective in preventing explosive spalling compared to other fibers due to pore formed at early stage which occupies 3 % of total fiber content at temperature between 100-400 °C.

• As a result of analyzing mass loss of fiber based on inner temperature distribution of concrete, nylon ultra high strength fiber reinforced concrete had advantage in preventing initial explosive spalling since its fiber melting amount was greater in early stage of 5-10 min. compared to polypropylene fiber reinforced concrete until the surface distance of 10 mm.

• Since dramatic increase in fiber loss at temperature of over 300 °C occurs inside the concrete just like polypropylene fiber, it is determined to be effective in alleviation of vapor pressure in middle and long-term. Also, increase in mixing rate, it was analyzed to be very effective in preventing explosive spalling when it is reinforced together with nylon fiber presenting same value as the test value.

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