

# Water Permeability of Concrete after Exposed to High Temperatures

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**Abstract.** *The water permeability of fly ash concrete after exposed to high temperatures was investigated in this research. The fly ash samples were represented as the fire building and the deterioration of concrete as evaluated in terms of compressive strength and water permeability were tested and measured. High fineness fly ash was used to replace Portland cement Type I at 10, 20 and 30% by weight of binder. The 90-day concrete samples were heated at 200, 300 and 400 degrees Celsius for each test in the electric chamber for 60 minutes. Suddenly, the concrete samples were rapid cool down in water bath. Compressive strength and water permeability were processed. The experimental results showed that the compressive strength of fly ash concrete with the replacement up to 30% was higher than the ordinary concrete. The compressive strength was reduced when the exposure temperature was increased. For the water permeability, the unheated samples of fly ash concrete gave the lower value than the ordinary concrete. However, when temperature increased, the fly ash concrete had more permeation than the ordinary concrete sample; even the compressive strength was higher.*

## Keywords:

fly ash, concrete, high temperature, compressive strength, water permeability

## 1. Introduction

Most of fire buildings have been fired hydrant by water. The concrete after fired will be loss of their loss bearing capacity. Apart from many effects as cracking and spalling, there can be a permanent loss of strength in the remaining material and thermal expansion may cause damage in parts of the building not directly affected by the fire. When exposed to high temperature, the chemical composition and physical structure of the concrete change considerably. Its mechanical properties such as strength, modulus of elasticity and volume deformation decrease remarkably and this results in structural quality deterioration of concrete [1]–[3].

The evaluation of building after fired generally is nondestructive testing such as rebound hammer testing or ultrasonic pulse velocity testing. From the compressive strength of concrete is observed and use to determine the deterioration. The effects from void or cracking in the micro-structure of concrete are not included to concern. However, this damage would be important due to the long term properties of concrete. Therefore, any substance such as liquid or gases easily flow pass through inside concrete and could be induced the iron oxide. The evaluation of concrete permeation will be a significant parameter to determine the deterioration of concrete after fired.

Fly ash recognized as pozzolan has been extensively used in concrete work. It is used for increasing the durability of concrete through pore refinement and reduction in calcium hydroxide of cement paste matrix [4]. Properties of concrete are affected by quality and quantity of fly ash. It is generally agreed that fine fly ash is more reactive. This improves the properties of concrete which compared to as received coarse fly ash. [5], [6]. Nowadays, the amount of using fly ash in concrete is more than 2 million tons each year and daily increase due to the growth of construction. Therefore, many buildings are constructed by using the fly ash concrete.

As mention above, it would be useful to clarify the deterioration of fly ash concrete after fired. The result of this research could be indicated the long term properties or durability of fly ash concrete.

## 2. Methodology

### 2.1 Material and Method

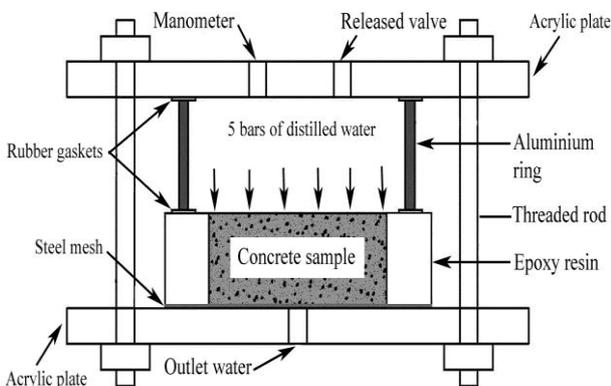
The materials used in this study were Portland cement type I, river sand, crushed limestone with maximum nominal size of 20 mm, lignite fly ash from the Mae Moh power plant in the North of Thailand. Fly ash was grounded until their particle size retained on a sieve No. 325, was less than 5 percent by weight. The concrete mixtures are presented in Table 1.

**Table 1:** Concrete mixture proportions (kg/m<sup>3</sup>)

Mixes	CT	FA10	FA20	FA30
Cement (kg)	381	343	305	267
Fly ash (kg)	-	38	76	114
Sand (kg)	703	675	662	651
Aggregate (kg)	1050	1050	1050	1050
Water (kg)	210	210	210	210
W/B	0.55	0.55	0.55	0.55
Slump (mm)	105	120	115	110

The cylinders specimens (100 x 200 mm in size) for compressive strength testing were demoulded 24 hours after casting and curing in a water tank. Superplasticizer was prepared to maintain the slump of fresh concrete between 50-100 mm. Concrete cylinders of 100 mm in diameter and 200 mm in height were cast and then cured in the water until the testing age. At 60 days of curing, the concrete specimens were taken up from curing tank and then were placed in the electric furnace chamber. The temperatures of testing were set at 200, 300 and 400 °C. The concrete samples were exposed in the high temperature chamber for 60 minutes. Then, they were rapidly cooled down by submerged the samples in a water tank for 10 minutes. Compressive strength and water permeability were tested and measured after the concrete samples were cooled to an ambient temperature (25 °C).

The tests of water permeability of the concrete samples after exposed to high temperature were conducted by using a permeability cell as suggested by khatri and Sirivivatnanon [7] as shown in Fig.1. The steady flow method was used to test the permeability of concrete in this study. The coefficient of water permeability was determined by measuring the amount of water passing through the concrete specimens. The water permeability is calculated by based on Darcy's law and the equation of continuity.



**Fig. 1:** Water permeability apparatus

Concrete cylinder specimens of 100 mm in diameter and 40 mm in thickness. Each sample slice was casted with 25 mm thick of non-shrinkage epoxy resin to prevent the water leakage. The pressure of 0.5 MPa (5 bars) recommended by concrete society [8] was employed. Report results are averages of three samples. Flow rate was monitored. The steady flow rate was used to calculate the value of permeability using equation (1).

$$K = \frac{\rho l g Q}{PA} \tag{1}$$

Where

- K – coefficient of permeability (m/sec)
- ρ – density of water, 1,000 (kg/m<sup>3</sup>)
- l – thickness of concrete sample (m)
- g – gravity acceleration (9.81 m/sec<sup>2</sup>)
- Q – flow rate (m<sup>3</sup>/sec )
- P – absolute water pressure (Pascal)
- A – cross sectional area of sample (m<sup>2</sup>)

### 3. Results

#### 3.1 Compressive strength

The compressive strengths of all concrete samples are shown in Table 2 and Fig.2. For Controlled concrete (CON), the compressive strength of unheated samples was 29.7 MPa; where the values tended to reduce as the increase progress of temperature. The residual compressive strength of CT concrete which exposed to 200, 300 and 400 °C was 26.2, 23.4 and 20.6 MPa or about 88, 79 and 69% of unheated samples, respectively.

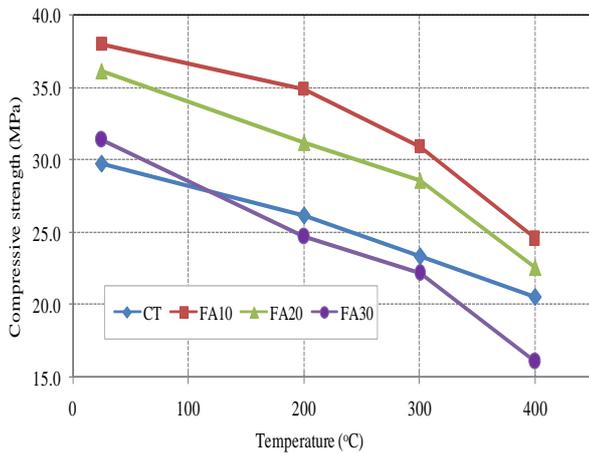
For unheated FA concrete, the results showed that the using of high fineness fly ash could assist the compressive strength of concrete. The compressive strength of FA10 concrete was 38.0 MPa, which was the highest. The more amount of replacement by fly ash also had the compressive strength higher than the CT concrete. Therefore, the compressive strengths of FA20 and FA30 were 36.1 and 31.4 MPa, respectively. The results agreed with the previous reports in [9], [10]. This phenomenon was due to the pozzolanic reaction and the packing effect from fly ash [11]. The fly ash in this research was very high fineness, thus that the effect from the pozzolanic reaction also started at the early age of samples.

After exposed to the high temperature, the compressive strength of all FA concretes reduced as the same CT concrete. FA10 concrete exhibited the decreasing compressive strength, there were 34.9, 30.9 and 24.6 MPa at 200, 300 and 400 °C, respectively. The effects of temperatures on the FA20 and FA30 concretes acted in a similar manner as the FA10 concrete. The levels of residual compressive strength of the FA20 were 31.2, 28.6 and 22.6 MPa, respectively. The strength of the FA20 still higher than the control samples and were slightly lower than FA10 at the same temperature. While the values were 24.7, 22.2

and 16.1 MPa for the strength of FA30 concrete. However, the residual strength of the FA30 after exposure to those temperatures was less than the control samples

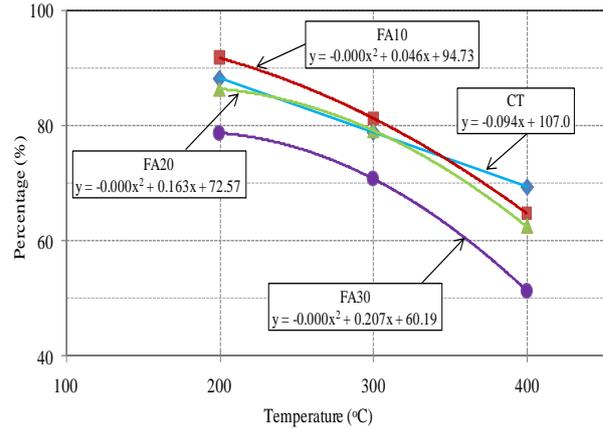
**Table 2:** Compressive strength of concretes and the percentage after exposure to high temperature

Temp. (°c)	Com. Str. (%)	Concrete mixtures			
		CT	FA10	FA20	FA30
Room (25)	MPa	29.7	38.0	36.1	31.4
	(%)	100	100	100	100
200	MPa	26.2	34.9	31.2	24.7
	(%)	88	92	86	79
300	MPa	23.4	30.9	28.6	22.2
	(%)	79	81	79	71
400	MPa	20.6	24.6	22.6	16.1
	(%)	69	65	63	51



**Fig.2:** Compressive strength of concretes exposed to various temperatures

The relationship between normalized or the percentage of compressive strength and the temperature of all concretes are shown in Fig. 3. It revealed that the rate of reducing in compressive strength of FA concretes was slightly lower than the CT concrete. The normalized of FA30 was lowest at all temperature of heating. The normalized of FA30 concrete was about only 51% at 400 °C. This result is the important information to concern about the amount of replacement by fly ash especially for fire resistance feature. The normalized of FA10 and FA20 concrete were greater than the CT concrete at 200 and 300 °C. The opposite result was occurred at 400 °C, which those two concretes had the normalized lower than the CT concrete. Also, from the results, this could be concluded that the responding of fly ash concrete exposed the high temperature exceed 400 °C was rather worse as compare the CT concrete.



**Fig. 3:** Percentage of compressive strength of concretes

### 3.2 Water permeability

The coefficient of water permeability of all concrete is shown in Table 3. The value of water permeability of unheated CT concrete was  $3 \times 10^{-11}$  m/s and its value increased at the evaluated temperature. Fig. 4 shows the trend of water permeability, which the CT concrete had the value of water permeability lower than FA10 concrete since the samples were exposed to the high temperature. The values of water permeability of CT increased to  $0.08 \times 10^{-9}$ ,  $0.35 \times 10^{-9}$  and  $56 \times 10^{-9}$  m/s at 200, 300 and 400 °C, respectively. The normalized of water permeability ( $k_{300}/k_{25}$ ) of CT concrete rapidly increased from 12 to 1,867 when the exposed temperature was increased from 300 °C to 400 °C.

**Table 3:** Water permeability of concretes and the percentage after exposure to the high temperatures

Temp. (°c)	Permeability, k*	Concrete mixtures			
		CT	FA10	FA20	FA30
Room (25)	$k_{25}$	0.03	0.01	0.04	0.25
	$k_{25}/k_{25}$	1	1	1	1
200	$k_{200}$	0.08	0.48	2.55	9.65
	$k_{200}/k_{25}$	3	48	64	39
300	$k_{300}$	0.35	4.19	17.5	55
	$k_{300}/k_{25}$	12	419	438	220
400	$k_{400}$	56	214	266	309
	$k_{25}/k_{25}$	1867	21400	6650	1236

\* Coefficient of water permeability, k =  $\times 10^{-9}$  (m/sec)

For FA concretes, the values of water permeability were in the same trend by increasing as the increasing rate of the exposed temperature. The water permeability of unheated FA10 specimens gave the lower permeability than unheated CT concrete. However water permeability of the

FA10 specimens after exposure to high temperatures was higher than the CT concrete at all exposed temperature. The water permeability of FA20 and FA30 had a high value of water permeability and higher than CT at all temperatures.

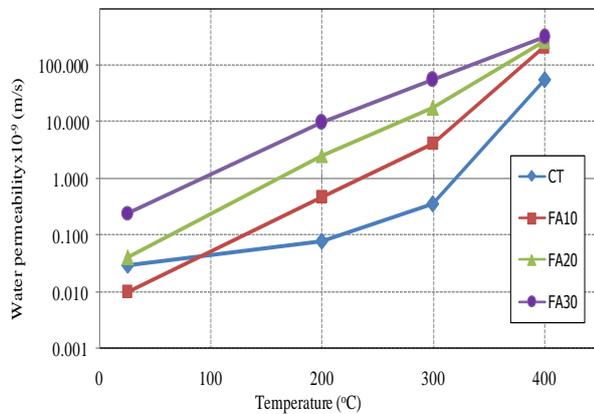


Fig. 4: Water permeability concretes exposed to various temperatures

Consider the normalized of fly ash concrete, it is found that the water permeability of those fly ash concretes rapidly increased since the samples exposed to 300 °C. At this state, the result suggested that the amount of void or cracking in the micro structure of concrete must be increased, thus the water can pass into concrete matter easily. Moreover, the normalized of fly ash concretes exposed to 400 °C were extremely increased to 21,400, 6,650 and 1,236 for FA10, FA20 and FA30, respectively.

#### 4. Conclusion

From this research the following conclusions could be noted:

1. The strength and water permeability were inversely change with the increasing temperatures and tended to decrease with the increasing percentage of replacement of Portland cement Type I by fly ash.

2. At the temperature of 200 and 300°C the strength of fly ash concrete slight decreased from initial strength for all level of replacement. When the temperature reached 400°C the highest strength losses was FA30 and it was only 51% of its initial strength.

3. The replacing Portland cement by fly ash level of 10% resulted in highest strength and lowest of water permeability for unheated samples.

4. The deterioration of fly ash concretes after exposed to the high temperature may be worse as compare to the normal concrete.

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