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Effect of Different Cooling Method to the Crack Width of Reinforced Concrete Beam Burned in High Temperature

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ABSTRACT

Fire disaster on building structure at some big cities that still happened due to fire is one of high risk failure of structure. Fire can become thermal burden which did not wanted and not hoped to be happened on building structure. On fire disaster, the temperature has tendency to increasing so high in a short time. There is an influence from fast hot and cooling cycle that will cause the concrete structure to become cracked and become wider until finally the concrete structure will collapse. This study discussed about the power of concrete structure especially the comparison of wide crack of reinforced concrete beam and natural concrete beam due to higher temperature of fire with the difference cooling process and watering. The methodology consisted of experiment using cooling process as normal process (or cooling without watering) and cooling by watering. This experiment was carried out by three kinds of temperature, 200°C, 400°C, and 600°C with factor of cement water was steady in 28 days and then carried out watering process at the burner which burned until 1000°C with dimension of 1m x 1m x 1m. The next step was cooling without and with watering for the beam with the dimension of 75 cm x 15 cm x 15 cm. Crack Detector Microscope was used to detect crack width in every burden of LCD adding. Results showed that there was significant difference concrete crack width at every higher temperature. Cooling process could recover the concrete beam.
Keywords: crack width, temperature, cooling, concrete beam, after burning.

INTRODUCTION

Nowadays, fire disaster has been a common phenomenon in big cities. On fire disasters, the common fire control technique is by spraying water to the burning part of the building. This practice could result in a more lost. Fire can act as thermal burdens which give influence to the properties of the structure. The increasing temperature in a short time will make the concrete swell, and sudden cooling due to water spraying will yield the crack, and finally the structure will collapse. To minimize the lost, many studies have been done to improve the technique for controlling fire disaster.

Concrete is a composite materials that consist of cement, gravel or aggregate and water. Due to the increase of temperature in fire disasters, there will be a deformation of the concrete. The easiest symptom observed from concrete that been burned in fire disaster is a change in concrete color. Another deformation type that can be observed is the crack formation, flaking and void, or a composite of these 3 types deformation. According Hansen [1] heating the concrete up to temperature 200° – 300° C will increase tension strength of the concrete. However, the tension strength of the concrete will decrease if the temperature increases. The heating at temperature of 400° C make the strength only 80% of the initial strength, and at temperature of 700° C. The strength is only 30% of the initial strength. This phenomenon can be explain by Riley in Gani [2] suggestion which explain that at temperature 300° C the cracks occurs only at surrounding aggregate particle, whereas at the temperature of 300 – 500° C the cracks occur inside the cement paste as well as at the surrounding aggregate particle [3].

During fire disaster, the heating condition outside of the concrete is different with the heating condition inside of the concrete. Therefore, at low temperature heating, it is often observed that the crack, usually with micro size, occur only at the surface of the concrete. In such case, it is suggested that this concrete, with any treatment, can be reused. Partowiyatno [4] developed a technique to repair the damaged concrete due to fire by watering the damaged concrete. It is expected that watering of damaged concrete will make water, which permeated into the concrete, react with C_2S and C_3S on cement particle or with β C_2S at burned cement to form CSH and $Ca(OH)_2$. Watering was doing until saturated condition, and there are 3 methods of watering of damaged concrete, i.e.: 1) by using wet gunny sack to cover the concrete column, 2) by hollowed hose irrigated with water which then wrapped to concrete column, and 3) by sprinkler water application. According to Triwiyono [5], if the technique was done properly, the recovery of the strength of damaged concrete could approach the initial strength.

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There are two factors which will influence the recovery of the strength of damaged concrete, namely: concrete quality which is determined by water/cement (W/C) ratio, and the duration of the concrete expose to fire. The high W/C ratio indicate that there are a lot of cement that has not yet react with other constituent, and hence the recovery of its strength will get higher. The longer on the exposed time of the concrete to fire, the lower the recovery strength [6]. Effect of fire on concrete beams causes evaporation of free moisture in the concrete, with a continued exposure to fire, the temperature inside the beam increases and the strength of concrete decreases, it may be to reduction in concrete compressive strength [7]. Effect of fire on concrete beam also making the residual bearing capacities.[8].The residual shear strengths and ratios provided by concrete and shear reinforcement have predicted by models.

The experiment that described here was aimed to study about the effect of different cooling method to the crack width of reinforced concrete beam burned in high ttemperature. The data found in this experiment could be used as the base information wether the concrete structure that experienced fire disaster can still be used or not.

MATERIALS AND METHODS

The samples (concrete) preparation and data measurements were done in the Material Laboratory of Brawijaya University, Malang, Indonesia and the combustion was done at Ceramic factory at Dinoyo, Malang, Indonesia.

The sample of 150 cm x 150 cm x 750 cm was made from mixed of cement, gravel (aggregate), with 3 iron reinforcement of 8 mm diameter. The cement used was obtained from PT Cement Gresik, East, Java, Indonesia, and the aggregate obtained from Pandaan aggregate factory at Pandaan, East Java, Indonesia. The concrete used had a grade of fc = 25 MPa, slump = 12 cm and FAS= 0.5.

To determine the length of curing time of the concrete, the tensile test was performed at 7, 14, 21, and 28 days. Tensile strength was measured with Universal Testing Machine, and the tensile strength was considered as the tension stress at the initial failure. The result show that the strength increase with increasing curing time and reach a constant value of about 28 Mpa at 28 days curing. Therefore, the concrete was cured by wrapping it with wet cloth for 28 days. The sample was then combusted in furnace combustion at temperature of: (a) 200°C, (b) 400°C, and (c) 600°C. for :(a)35 minutes,(b) 152 minutes and (c) 195minutes, after which the concrete was cooled to temperature of 27°C with: (a) watering and (b) No watering. Thus there were 6 combination treatments, and as control, we have concrete sample (without combustion) that was stored at a room temperature of 27°C. These 7 treatments were arranged in a complete randomized concrete beam design with 3 replications. The sample was weighted before and after combusting.

The data collected include the change of colour, crack width, crack pattern, and compression strength. Crack width was measured with "*crack detector microscope"* and the width of the crack was measured for the maximum width soon before failure.

The data was analysed with two ways Analysis of Variant, and if there was any significant differences, then a further Least Significant Different (LSD) will be performed

RESULTS AND DISCUSSION

Time of combustion

The length of combustion time to reach the desired temperature is given in Figure 1. The higher on the desired temperature causes the longer on the time length of combustion. In order to reach the combustion temperature of 200° C, it required 35 minutes, and for reaching 600° C the time of combustion increased to about 240 minute. For comparison, in Figure 1 is also presented the theoretical combustion time (according to ASTM standard, literature 4) for the desired temperature

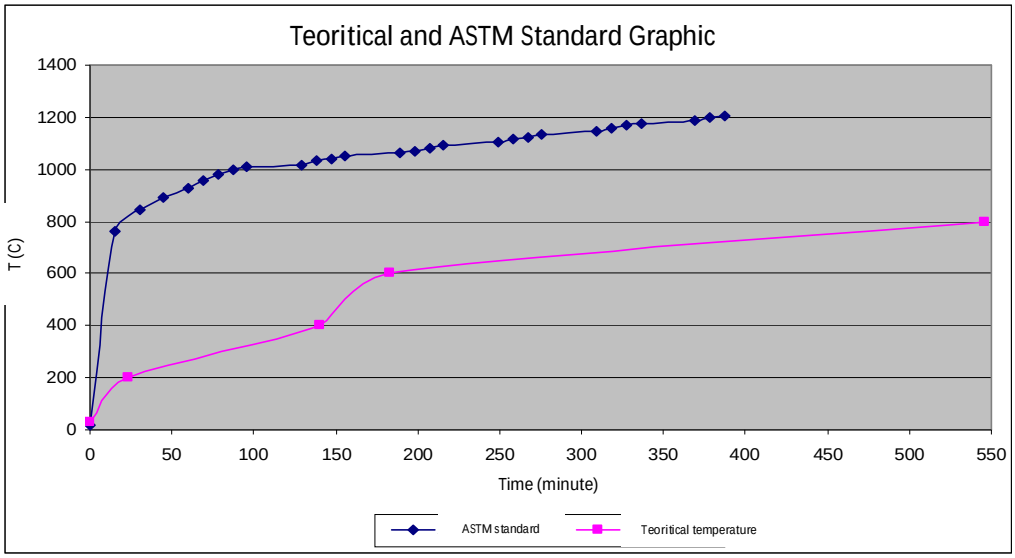

Figure 1. The length of combustion time to reach the desired temperature.

Compared to ASTM standard, the length of combustion time observed in this experiment was much longer. To reach 600° C temperature, for example, according to ASTM standard only required about 30 minutes, whereas the required time observed in the experiment was 240 minutes. This was merely due to the difference of the furnace used.

Lost of weight

The result presented in Table 2 shows that at 200° C combustion, there was no changes sample weight. Furthermore, the higher on the combustion temperature causes the higher the lost of weight of the sample. This is reasonable because, at high temperature of combustion, the lost of water due to evaporation would be more, and therefore the weight will be lower.

Table 1 the lost of weight due to different combustion and methods of cooling

Cooling Method	Combustion Temperature (°C)	Initial Weight (Kg)	Lost of Weight (%)
Control	Room temperature	41.98	-
Watering	200	41.10	0.24
	400	41.70	2.19
	600	40.60	3.65
Without Watering	200	41.02	0.45
	400	41.60	2.76
	600	41.20	6.20

The strength AFTER COMBUSTION AND COOLING

The correlation between variables with compressive strength on concrete will be shown on this table below, including graphic and explanation. The table and graphic below will present the relation between concrete's compressive strength on temperature 200°C, 400°C, 600°C, and 800°C at the cooling process, whether its normal cooling or cooling with watering.

Table 2. The Compressive strength for the sample no watering.

Cooling Method	Temperature	sample	Compressive Strength (MPa)
-	Room Temperature (No burn)	1	21.931
		2	20.200
		3	17.314
Without Watering	200°C	1	16.160
		2	12.120
		3	11.543
	400°C	1	7.791
		2	7.503
		3	8.081
	600°C	1	2.308
		2	3.463
		3	2.885
	800°C	1	2.308
		2	2.020
		3	2.597

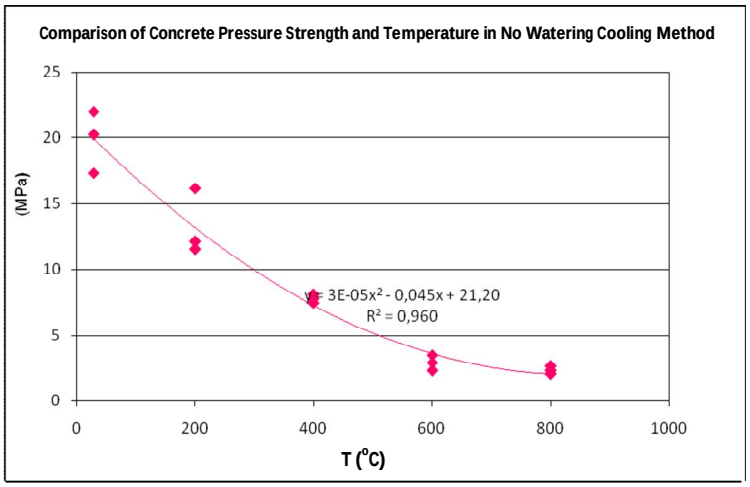

Figure 2 the Correlation between Concrete Pressure Strength and No Watering Cooling Method in Sample 1, Sample 2, and Sample 3

Table :3 The Correlation between Concrete Pressure Strength and Watering Cooling Method

Cooling Method	Temperature	sample	Compressive Strength (MPa)
Watering	200^{0}C	1	20.776
		2	17.891
		3	12.697
	400^{0}C	1	9.234
		2	6.926
		3	8.080
	600^{0}C	1	3,557-
		2	3.463
		3	4.617
	800°C	1	2.886
		2	2.308
		3	3.751

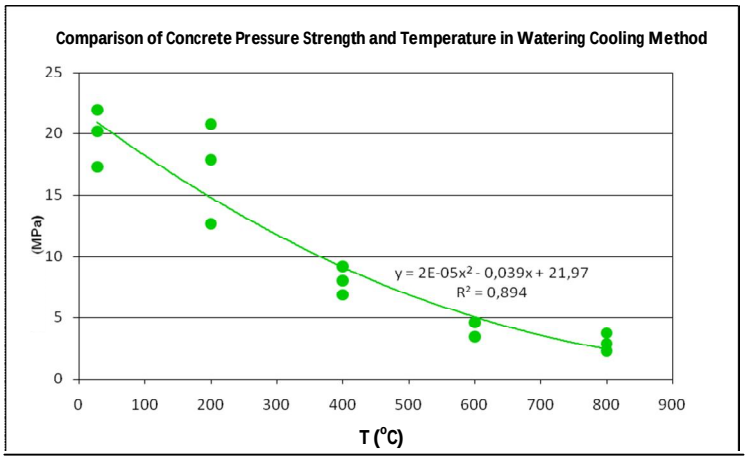

Figure :3 The Correlation between Concrete Pressure Strength and Watering Cooling Method in Sample 1, Sample 2, Sample 3

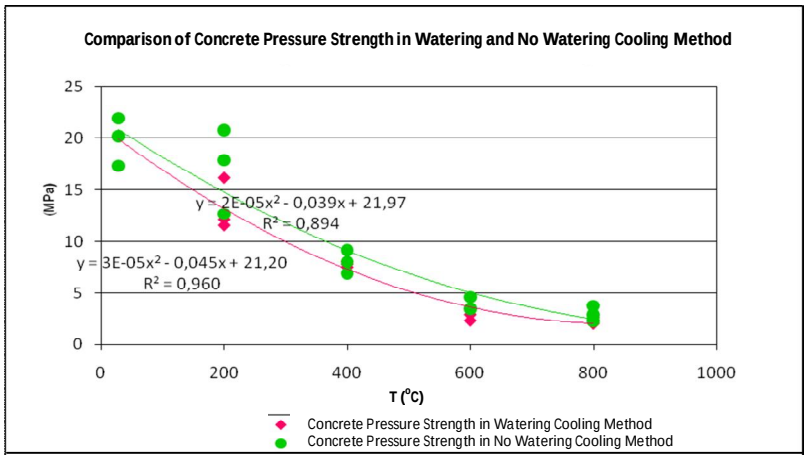

Figure :4 The Correlation between Concrete Pressure Strength in Watering and No Watering Cooling Method in Sample 1, 2 and 3,

Crack formation and crack width

It was observed that beam has flexure shear crack with the crack direction is almost straight ahead with block wick. Then flexure shear crack is a slanting crack as the continuation from flexure shear crack before. On all of beams test, crack begins in the first burdening on the middle of unfolded due to a bigger burden moment (it is the center of interval burden). The crack's form soft vertical crack which is caused by bent and when burden is regularly added, then the crack will move to the neutral line. Then close to the falling down burden, the diagonal pull crack from center direction to burden center, and followed by burden adding, the crack becomes wider and longer until reaches the upper tight and under block without signing, diagonal pull falls down in brittle and suddenly from center burden in the direction to the center one. It is shown on spread one (spread one means between center and soot's tool is spread the load) moved and bent in the same way while middle spread is only load only the bent because moving power to the spread is the same with zero.

The analysis shows that temperature of combustion and methods of cooling influence the crack width and crack pattern (Table 2). In general, crack width increase with increasing combustion temperature. There was a tendency that cooling with watering method yielded a narrower crack. At high combustion temperature (600° C), there was different crack pattern observed for different method of cooling. The result of cooling without watering is the concrete fail in the form of crack and peeling, but the result of cooling using watering methods there was a peeling only.

Table 4 Effect of combustion temperature and cooling method on crack width and crack pattern

Methods of cooling	Temperature	Crack width (mm)	Crack pattern
No watering	200^{0}C	0.31	hair crack
	400^{0}C	0.44	hair and big crack
	600^{0}C	0.48	crack and peeling
Watering	200^{0}C	0.22	hair crack
	400^{0}C	0.28	hair and big crack
	600^{0}C	0.40	Peeling

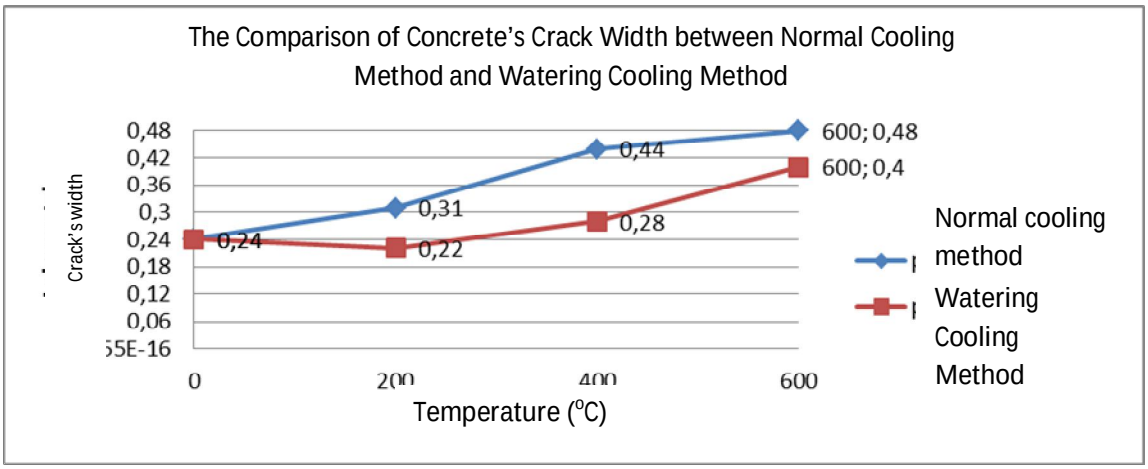

Figure 5 the Comparison of Concrete's Crack Width Between Watering and No Watering Cooling Method

CONCLUSION

Based on analysis as above, it is concluded that

1. The greater difference of temperature will affect the crack width of concrete beam that occur on pressured.
2. The difference of cooling method (normal cooling and watering cooling) for the concrete beam after burning will make differences of crack's width of the concrete beam that occur on pressured.
3. The process of concrete beams cooling (normal cooling and watering cooling) indicated that cooling time and burning concrete temperature is influencing the crack width when being burdened
4. The average crack's width of concrete beam on 200°C, 400°C and 600°C with cooling watering treatment will be smaller than crack's width of concrete beam in normal cooling.
5. Cooling treatment to the concrete with watering can increase the concrete recovery degree about 0.19 at temperature of 200°C; 0.30 at temperature of 400°C and 0.135 at temperature of 600°C

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