The Micro Crack Growth Behavior on the Post-Fire Reinforced Concrete Beam

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Abstract— The micro crack growth behaviour on the post-fire concrete reinforced concrete (RC) beams is investigated. The present study found that the burning temperature affects the micro crack width behaviour on the post-fire concrete. The burning temperature of 400°C increases the strength of the post-fire concrete in comparison to the strength of the unburned concrete as indicated by the increasing of the load required to advance the micro crack width. As the burning temperature is increase, the load required to advance the crack is decrease, even when the burning temperature reaches as high as 800°C, the effect of the burning temperature is profound to reduce the concrete strength. The increasing and decreasing of the post-fire concrete associates with the microstructure and the chemical compound of cement.

Keyword- Crack width, Concrete microstructure, High temperature, RC beam

I. INTRODUCTION

An emergence of phenomenon of fire on a building efforts of safety consideration of reinforced concrete exposed by high temperature. It has been well known than under some certain conditions a concrete may be resistance to high temperature, such as fire [1]-[3] , and a concrete of a structure has experienced to be exposed in high temperature may be still used after being assessed to determine the residual strength of the concrete [1]-[5]. Although the concrete has a characteristic to be resistant to high temperature, and there are many efforts to improve the mechanical properties, especially to increase its compressive strength more than 70 MPa. categorized as the high strength concrete [3],[4], however there are several factors influencing the strength relating to the microstructure of the concrete, thus more confirmations by investigations are needed to be conducted to know the mechanical properties of the concrete under certain condition, such as on fire [2].

The heat resistance of a concrete under fire is not only affected by the microstructure, but also the concrete cover which has a role to protect part of steel reinforcement. The cover is the outer part receiving the effect of high temperature [6]. The concrete cover is a factor that must be considered for a concrete design so that a concrete structure can be built to have enough fire proof. This will make the structure to be able to survive longer.

The watering treatment in cooling process on concrete after being exposed in a high temperature may recover and increase the strength. It is due to the fact that water absorption in concrete makes the possibility of additional chemical reaction of unreacted cement in the concrete. The exposing of the concrete in this high temperature may form other compounds leading to strengthen the concrete, but if the burning process persists in longer duration, and thus increasing the temperature of the concrete. This condition causes to decrease the possibility of the concrete to be recovered after experiencing in that high temperature conditions [5].In the previous work found that the watering treatment on burned reinforced concrete (RC) beam minimizes crack width under bending load [7]. In this work also shows that water/cement (W/C) ratio in concrete mixture determines the concrete quality, and it influences concrete porosity. The decomposition and releasing of water bond cause the significant changing in microstructure, especially chemical bonding, cohesive, and size of pore. For those reasons, the concrete in high temperature will loss the weight and the change of porosity leading to reduction of the concrete elasticity and quality. However, in another effort found that the best W/C ratio is 0.48, and at the heating temperature is up to 400°C do not decrease significantly the post-fire concrete strength if the W/C ratio is accurate [8].

The microscope investigation gives more clarification of change of the concrete characteristic associating with the high temperature especially the change due to chemical reaction. In the temperature between 400°C to 600°C leads to chemical reaction in cement pasta due to drying process and being followed by decomposition of materials concrete [1]-[3]. Some testing reports of a concrete of a building after being burned shown that the damage of concrete structure element due to fire will be fatal if there is a spall of concrete cover [2]. At 100°C some of water and calcium silicate (CaSi) as a hydrated desiccation in cement paste will be disappeared and being followed by decreasing the concrete strength. The increasing of vapour pressure in the concrete pores due to explosive spalling occurs in temperature between 300^{o}C to 600^{o}C, and at the temperature in the range 600^{o}C to 900^{o}Cthe cracked formation emerges in a concrete, hence, it makes the concrete become weak and brittle [9].

The RC beam has been used widely as main members of a structure, and it is very possible that the kind of the beam has an experience to be exposed in the high temperature such as when a building is on fire. To know the integrity of the fired building, thus, it is very important to assess the strength of the concrete structure of the building because the fire can alter and damage the concrete microstructure. Due to the micro cracks can be formed in the concrete after being exposed in high temperature, and the micro cracks influence the strength of the beam, hence to know the behaviour of the micro crack growth on post-fire concrete upon being loaded is of important to be understood, and this understanding may enhance an accuracy of the assessment result on the concrete after being exposed to the high temperature. Therefore in the present study, the micro crack growth behaviour on the post-fire concrete is investigated.

II. EXPERIMENT

The materials used in this experiment were natural sand including silicate rock, crushed stone with maximum diameter of 20mm and the commercial portland cement. The W/C ratio was 0.48, and the concrete slump test was 100-300 mm. The mix design calculation of the concrete was following the Indonesian Standart (SNI T.15-1990-03) in which cement : sand : gravel weight ratio is 1 :1.97 : 2.94, and the expectation of the compressive strength of the concrete up to 35 MPa might be obtained The steel used was reinforcing steel with 8mm diameter [10].

The type of the sample was 36 RC beams, and the sample dimension was 150 x 150 x 750 mm^3. The thicknesses of the concrete covers were 1.5 cm, 2.0 cm, and 2.5 cm, respectively with 28-day-old. The samples were burned in a furnace, and the temperature in the furnace was maintained in 400^{o}C, 600^{o}C, 800^{o}C for every sample for half hours. Following to the burning process, the samples were cooled by watering. The reinforced concrete beams testing was conducted in accordance with the ASTM standard [11] by flexure testing as depicted in the Fig. 1. The testing was carried out for each burning condition of the sample with three recurrences. The test was carried out also on samples which were not burned as a comparison. The load, P, was subjected to the samples obtained from a hydraulic universal testing machine with capacity 50 kN.

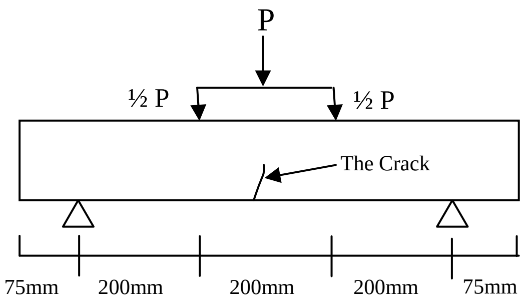

Fig. 1. Arrangement of the bending test

The micro crack width is depicted schematically in the Fig. 1. The observation and the measurement of crack width was carried out on every loading step controlled manually, and the measurement of the crack based on the maximum crack width on every load step using a travelling microscope with the accuracy 0.005 mm placed above the surface of the sample on which the crack was measured.

Because the mechanical properties of the concrete is affected by the microstructure [3], thus the change of the concrete microstructure due to high temperature was observed by aid of XRD, EDAX analysis and SEM. In the present study, the test and the observation for the micro crack width behavior together with the changes of the concrete microstructure were carried out also to the samples without being exposed to the high temperature as comparison.

III. RESULTS AND DISCUSSION

Fig. 2, 3 and 4 present the average crack behaviour of RC beam samples with concrete cover thickness 15 mm, 20 mm and 25 mm, respectively. From these figures can be seen that the samples after being exposed in fire with the temperature as high as 800^{o}C, the lower load is needed to advance the crack in comparison to the other. In the other hand in the case of exposing burning temperature is 400^{o}C, the higher load is required to advance the crack in comparison to the sample without being burned after the crack grows in some distances. To advance the crack on the samples with the exposing temperature 600^{o}C needs lower load than that on unburned samples. The crack growth behaviour taking place on the every sample relates to the change of microstructure of the concrete after being exposed in high temperature.

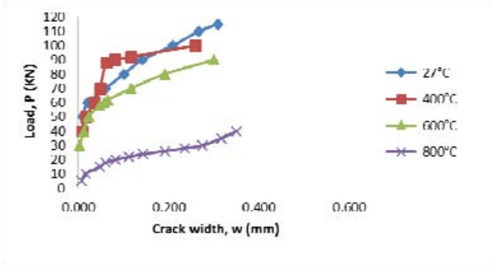

Fig. 2. The relation of crack width and load on difference temperature with 1.5 cm thickness of concrete cover.

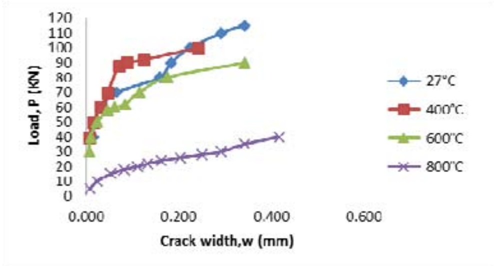

Fig. 3. The relation of crack width and load on difference temperature with 2.0 cm thickness of concrete cover.

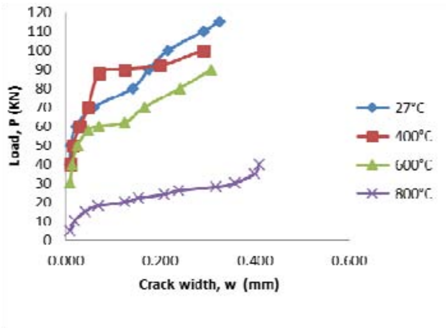

Fig. 4. The relation of crack width and load on difference temperature with 2.5 cm thickness of concrete cover.

Fig.5 shows the example of the effect of the cover thickness of the micro crack growth behavior when the burning temperature is 400^{o}C. The figure indicates that the cover thickness has less effect to the crack behavior, and the phenomenon is similar to the other burning temperatures. Therefore, in the present study the influence of the cover of the concrete will not be discussed, and the discussion will focus on the change of the microstructure and the chemical compound of the concrete after being burned.

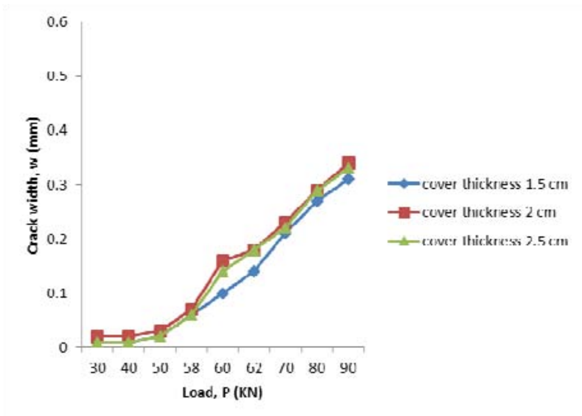

Fig. 5. The comparison of the effect cover thickness of the micro crack on concrete after being burned in 400^{o}C.

Fig. 6 shows the fracture surface of unburned sample, and the Fig. 7 to the Fig 9 show for samples with the exposing temperature 400 ^{o}C, 600 ^{o}C and 800 ^{o}C, respectively. Those figures show the change of the microstructure. In the case of unburned sample as shown in the Fig. 6, the small grain can be observed, and the shape of the grain closes to the spherical. The small grain and the spherical shape cannot be observed on the fracture surface of the sample after being burned in temperature 400 ^{o}C, however, in this case it is plausible that the individual small grain coalesces each other, hence, the spherical shape disappears as shown in the Fig.7, and it lead to the behavior crack width being difference in which the higher load is needed to advance the crack width. The coalescence of the grain also can be seen on the fracture surface when the burning temperature is 600 ^{o}C as shown in the Fig.8. The result of the coalescence of the grain is smaller than that to the former burning temperature condition, and the sharp irregular shape is observed. This may a possibility causing the load needed to advance the crack width is little bit lower than that of the unburned sample. Although the result of the massive coalescence can be seen in the Fig. 9 in which the sample had undergone burning treatment with temperature as high as 800^{o}C, however, the micro cracks appear within the coalescence grain as pointed by the white arrows. Therefore, these micro cracks lower the load to advance the crack width.

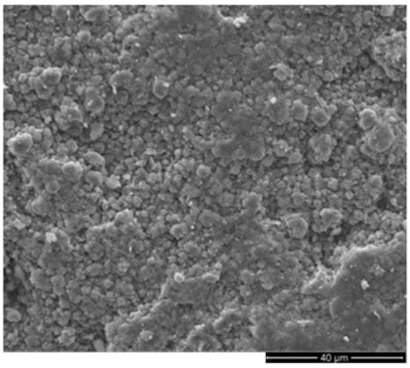

Fig. 6. The SEM Image of normal concrete sample at room temperature (27 ^{o}C).

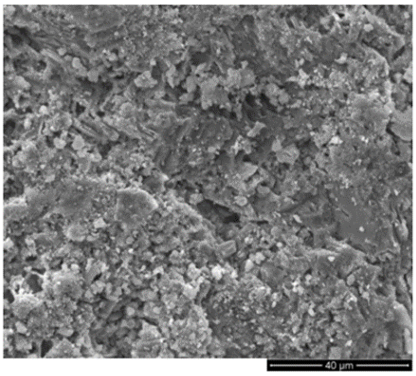

Fig. 7. The SEM Image of concrete sample burned at 400^{o}C.

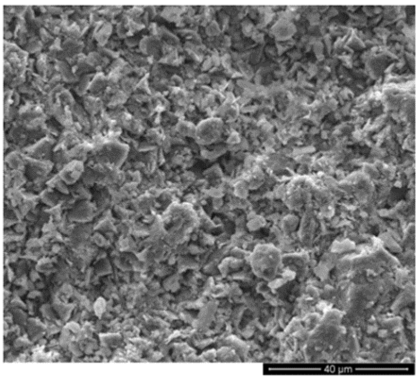

Fig. 8. The SEM Image of concrete sample burned at 600^{o}C.

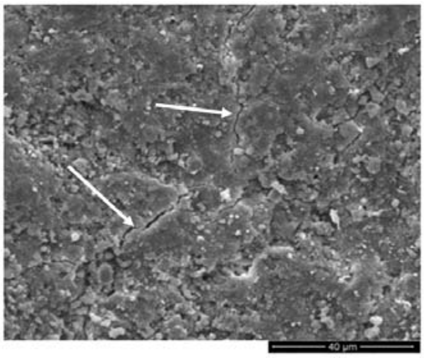

Fig. 9. The SEM Image of concrete sample burned in 800°C.

Fig.10 shows the result of XRD test for the intensity of portlandite phase as compound of $Ca(OH)_2$as indicates by the triangle, and the star indicates the intensity of SiO_2. From the figure can be observed that the intensity of the portlandite is the highest on the unburned sample (27°), however, this intensity gradually decreases as the burning temperature increases, and finally the portlandite intensity is disappear when the burning temperature is 800^0C. The intensity of SiO_2 compound reach the highest intensity after the concrete was burned under temperature as high as 400^0C, even, the intensity is higher than that of unburned concrete. When the concrete was burned under temperature being higher than 400 ^{0}C, the intensity of SiO_2 decreased. In addition, the summary of EDAX test confirmed that the element content of Si is the highest after the concrete was burned in 400^0C as depicted in the Fig.11, and the other element to form the portlandite such as Ca and O changes after the concrete is burned.

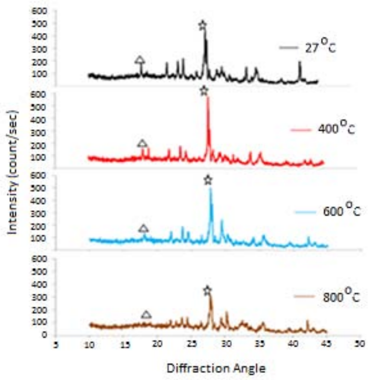

Fig. 10. The XRD profile of concrete samples.

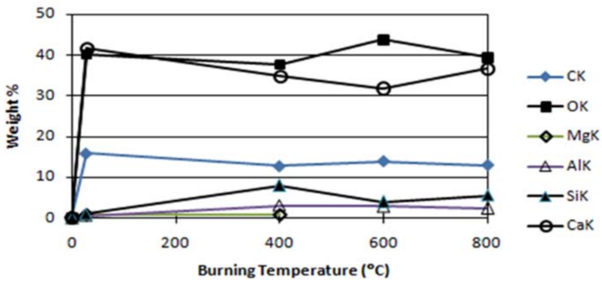

Fig. 11. The summary of EDAX results as relationship of burning temperature and percentage of weight.

The XRD and EDAX test reveals that the burning temperature affects the chemical compound condition, those are $Ca(OH)_2$or portlandite and SiO_2 or silica, consequently the mechanical properties of the concrete changes also. Because the portlandite acts as fastener materials involved in the mixture of the concrete, thus, the decreasing of the portlandite is responsible to strength of the concrete. In the present study, it is shown by the phenomenon in which the loading needed to advance the crack width is lower when the burning temperature of the concrete was higher than 400°C. It is well known that the present of the SiO_2 is very important in the concrete in which this compound has function as a filler material. Besides that, the compound can increase compressive strength and permeability of the concrete because of the pore filling ability [12]-[14]. Because the SiO_2 content is the highest after the concrete was burned in 400°C, hence, the load required to advance the crack width is higher than others.

Although in the present study, the effect temperature on the mechanical properties of the steel was not confirmed, however, it is widely known that if the steel is exposed in the temperature as high as 800^{o}C, depending to the cooling rate, it will affect the mechanical properties. Because the steel is in the concrete, thus, during the watering process after being burned, the steel did not contact directly to the water, and the cooling rate of the steel could be considered to be slow. Therefore the hardness and the strength of the steel are decreased by such treatment [6]-[8], [15]. This mechanical behavior of the steel is believed to contribute to the decreasing of the strength of the concrete, which is shown by the decreasing of the load needed to advance the crack on the sample after being burned in 800^{o}C.

The present study demonstrates that the burning temperature affects the micro crack behavior of the concrete. There are four factors influencing the micro crack width behavior associating with the burning temperature. The first is the grain of the cement paste condition after being exposed to the high temperature followed by the watering. In the high temperature the grain is coalescence, but during watering the micro cracks is formed if the burning temperature is high enough, i.e., 800 ^{o}C. This weakens the concrete strength. The second has an association with the chemical condition of the concrete, such as the portlandite and the silica content. Because those substances have key role as binder to the concrete materials, the decreasing of those reduce the strength of the concrete. The decreasing of the concrete strength may come from the steel, which is weakened during the burning and watering process. Finally, the micro cracks, the decreasing of the portlandite and silica together with the weakened steel may be responsible to the loss of composite effect of the materials involved in the concrete, if so, the strength of the concrete will decrease. Therefore, the decreasing of the concrete strength affects to the behavior of the crack width under certain loading or in another words, it can be stated that the behavior of the micro crack width on the post-fire crack indicates the strength of the concrete.

IV. CONCLUSION

1. The burning temperature affects the micro crack width behaviour on the post-fire concrete.

2. The burning temperature of 400^{o}C increases the strength of the post-fire concrete in comparison to the strength of the unburned concrete as indicated by the increasing of the load required to advance the micro crack width.

3. As the burning temperature is increase, the load required to advance the crack is decrease, even when the burning temperature reaches as high as 800^{o}C, the effect of the burning temperature is profound to reduce the concrete strength.

4. The increasing and decreasing of the post-fire concrete associates with the microstructure and the chemical compound of cement. All paragraphs must be indented. All paragraphs must be justified, i.e. both left-justified and right-justified.

REFERENCES

[1] Wei Ming Lin , TD. Lin, L J Powers Couched, ACI Material Journal, 93-M22 (1996) 199-205.
[2] Kodur,Venkatesh KR ,Dwaikat,MB , ACI Material Journals ,Comments, Business Publication, (2008).
[3] Min Li,Chun Xiang Qian , Wei Sun , Cement and Concrete Research 34 (2004) 1001-1005, Perganon,Elsevier Ltd.2004
[4] K .Sakr, E.EL-Hakim , Effect of high temperature or fire on heavy weight concrete properties,Cemen and Concrete Research 35(2005) 590-596.
[5] Krishna M V , Rao P , KhumaRatish and Khan Azhar, Architecture and Civil Engineering , Vol. 8 (2010) 23- 34
[6] Tan, T.H., Tan, K.H., GuoZhenhai,, ASCE Journal of Structural Engineering (United States),vol.130,no.8 (2004) 1225-1232.
[7] Setyowati E W, Soehadjono A, Journal of Basic and Applied, India.,vol.3,no.2 ,(2013) 922-927
[8] Shi Xudong, Tan, T.H., Tan, K.H., GuoZhenhai, ASCE Journal of Structural Engineering (United States),vol.128 , no.3 ,(2002) 365-373.
[9] Adam Levesque, Fire Performance of Reinforced Concrete Slabs.Thesis, Worcester Polytechnic Institute, 2006
[10] SNI 03-2834-2002. Tatacara Pembuatan Rencana Campuran Beton Normal. Indonesia: BSN, Indonesia.
[11] ASTM C78/C78M -10e1. Standard Test Method for Flexural Strength of Concrete , ASTM International , USA
[12] VermaAjai, Chandak Rajeev, Yadav R K, Research Journal Of Engineering Sciences, Vol . 1, (2012) 1-4.
[13] Ahmed M., MuhannadIsmeik&Khaled Z R , Global Journal Of Researches In Engineering Vol. 12 .(2012) 27-31.
[14] Suraya H A ,Ismail A R , Lee Y L , International Journal of Sustainable Construction Engineering & Technology, Vol.1 No.2 (2010)
[15] Tan, K.H., Yuan Weifeng, Pan, T.C, Modeling concrete structure under fire effect, First International Conference on Design and Analysis of Protective Structures against Impact/Impulsive/Shock Loads, Japan. 2003.