Investigation of Polypropylene Fiber Reinforced Concrete After Elevated Temperature Using Color Quantification and Alkalinity Method

Ni Nyoman Kencanawati, Suryawan Murtiadi, and Zul Aida Nur

Abstract Concrete properties change when it is exposed to high temperature. Fire can reduce the strength and the stiffness of the concrete. Another visible thing is the change in the color of the concrete. Furthermore, a decrease in the alkaline degree of concrete can also occur at high temperatures. This study combines quantifying the value of the color change, quantifying the alkaline level, and evaluating the residual strength of post-fire concrete. Two concrete grades were prepared: 25 and 45 MPa and exposed to a high temperature of 300 and 700 °C. The amount of 1.8, 2 and 2.5 kg/m^3 of polypropylene fiber were added to the concrete. According to the temperature rise analysis, the farther the position from the concrete surface causes a decrease in temperature. The 2.5 kg/m^3 fiber content shows more excellent post-fire mechanical performance because it provides the pores needed by concrete when water vapor pressure occurs due to high temperature; therefore, cracks in the cement paste can be avoided. Visually, the color change between grade 25 and 45 MPa are the same in each temperature; however, they have different coordinates as observed by the color test. Furthermore, the addition of 2.5 kg/m^3 fiber to the concrete contributes a superior effect to prevent the decrease of the alkaline level during the fire.

Keywords Concrete color quantification · Concrete pH · Elevated temperature · Polypropylene fiber

1 Introduction

Concrete is often used as material construction worldwide because of many advantages. Concrete is relatively easy in terms of producing and maintenance and is more

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resistant to climate change. However, the quality of the ingredient materials determines the strength of concrete. Fiber is also often added to concrete mixtures to improve its properties [1, 2]. Polypropylene fiber is one of the most widely used fibers in concrete mixtures. These fibers are in the form of filaments that will spread into the mixture when mixed in the concrete mix. When the temperature increases, polypropylene fibers can increase permeability by forming pore cavities to release concrete moisture. The existence of this water vapor release path can reduce spalling in the concrete when a fire occurs. European standards require the addition of a minimum of 2 kg/m^3 polypropylene fibers to reduce spalling in fire-induced concrete [3, 4].

After being exposed to high temperatures, the concrete will change its properties depending on the fire's temperature. Fires can cause cracking or spalling of the concrete, which can reduce its compressive strength. Another visible thing is the change in the color of the concrete. In general, the concrete's color becomes slightly reddish when the temperature reaches 300 °C, turns greenish grey when the temperature becomes 600 °C and even turns yellow when the temperature increases to 1200 °C [5–8]. A decrease in the alkaline degree of concrete can also occur at high temperatures. A decrease in the concrete's pH is a sign that there is carbonation of the concrete due to a fire [9].

Assessment of post-fire concrete condition, primarily to determine the residual strength, is mostly done using non-destructive tools on the concrete. The hammer test and ultrasonic pulse velocity methods are often used to estimate the residual strength after a fire. The rebound number indicating the surface hardness of the concrete is related to the compressive strength of the existing concrete based on the conversion value or the tool's calibration graph. Likewise, the velocity of the ultrasonic wave propagation that is transmitted into the concrete body is collected by the receiver sensor. It enables us to describe the quality of the material in the concrete body, whether cracks have occurred or are still sound after being exposed to high temperatures. Research on the application and analysis of non-destructive testing on concrete at elevated temperatures has been well established [10–12].

During assessment after a fire, we also need to investigate the temperature that has been reached by the concrete. Visual assessment by evaluating the color change can lead to the demand. Various methods have been used to describe the color of post-fire concrete. Spectrophotometer method, polarization microscopy, colorimetry, and digital applied concepts have been studied. Samples are prepared either from a concrete surface, heated concrete powder, or image capture directly on the concrete surface. These methods are continually evolving to quantify post-fire concrete color [13–16].

Examination of the alkaline content of the concrete also benefits in the assessment. Concrete that has experienced a decrease in pH certainly indicates carbonation in the concrete and requires proper follow-up repair. To date, checking the concrete's pH has been done by spraying phenolphthalein on the surface of the concrete. If the concrete surface does not change color to magenta, carbonation has occurred in the concrete [9].

Table 1 Concrete mixture proportion

Grade (MPa)	Weight (kg/m^3)			
	Water	Cement	Fine aggregate	Coarse aggregate
25	205	410	694	1041
45	205	586	624	936

To the end, research has only emphasized each method on the behavior of post-burn concrete mainly the investigation on mechanical properties. This study enriches the investigation by applying the series methods of quantifying the value of the color change, the method of quantifying the alkaline level in concrete, and evaluating the residual strength value of post-fire concrete. Combining these methods is useful to assess concrete after a fire and to produce more detailed conclusions.

2 Methodology

2.1 Material

Two concrete grades were prepared, which were 25 and 45 MPa. The water-cement ratios were 0.46 and 0.35, respectively, for grade 25 and 45 MPa. Natural aggregate was utilized as fine aggregate with a maximum size of 4.75 mm. Meanwhile, crushed stone was used as coarse aggregate with a maximum size of 20 mm. The mixture proportion of each concrete grade is shown in Table 1.

The mixture proportion shown in Table 1 is regarding as the control mixture proportion without polypropylene fiber. Then the series of 1.8, 2 and 2.5 kg/m^3 of polypropylene fiber were added to each control mixture. The fiber length was 12 mm and the diameter was 0.006 mm. Specimens were cylinder concretes with a size of 150 mm in diameter and 300 in height.

2.2 Temperature Growth

After curing time for 60 days, the concrete was heated to 300 and 700 °C. Concrete subjected to elevated temperature can be carried out if the water content in the concrete pores has decreased significantly. When there is still excess water in the concrete pores, a water vapor pressure explosion will inevitably occur during exposed high temperatures. This explosion can cause cracks in the cement paste due to the high tensile stress. Therefore, exposure should be carried out at a concrete age of more than 28 days.

After reaching the intended temperatures, they were kept until one hour. The growth of temperature was according to ISO 834 standard furnace test [17] as shown

Fig. 1 Electric furnace

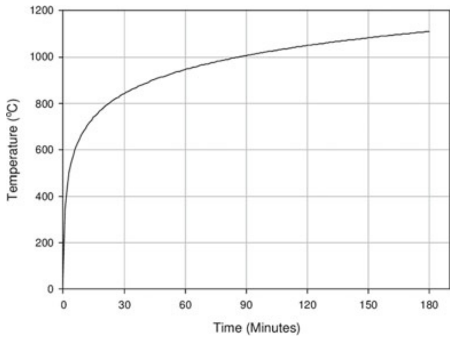


Fig. 2 Temperature growth [17]

in Eq. 10. The furnace was an electric furnace, as shown in Fig. 1 The maximum temperature capacity was 1200 °C. The relation between time and temperature from the standard furnace test is given in Eq. 1 and Fig. 2.

$$\theta_g = 20 + 345\log(8t + 1) \tag{1}$$

where t is time measured in minute.

2.3 Procedures of pH Level Measurement

The digital pH meter using the Ezdo brand was used to measure the alkaline content of concrete after the fire. This tool can measure the pH of the material from a range of 0–14. The pH testing process began with extracting concrete samples after the compression test with a thickness of approximately 2 cm from the surface. A sample of 30 g of concrete cement paste was crushed to a powder form and dissolved in 50 ml distilled water (Aquades).

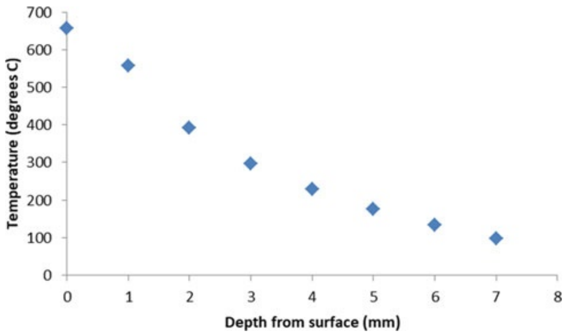


Fig. 3 Temperature rise in concrete for 700 °C exposed to fire

The solution is mixed with a stirrer to ensure homogeneity during measuring pH. At the same time, the pH measurement is carried out by inserting the sensor into the solution and the pH value was read on the display.

3 Result and Discussion

3.1 Temperature Rise

The temperature rise on the surface and some concrete depth using Wickstrom's method for a maximum temperature of 700 °C is given in Fig. 3. The temperature of the concrete surfaces approaches 657 °C; meanwhile, in the inner layer, the temperature is 82 °C. This temperature rise occurs in concrete, which has been exposed to the furnace test for one hour. The farther the position from the concrete surface causes a decrease in temperature.

3.2 Concrete Strength at Elevated Temperature

At ambient temperatures (20 °C), it appears that concrete with the addition of polypropylene fibers of 1.8 kg/m^3 reaches the highest compressive strength among other concrete with an additional proportion of other polypropylene fibers. This occurs either in the grade of 25 or 45 MPa. The addition of 1.8 kg/m^3 polypropylene fiber has a compressive strength greater as much as 1.4 times compared to that of control concrete without fiber, both on concrete grade 25 and 45 MPa.

However, when the temperature increased to both 300 and 700 °C, the concrete containing 2 kg/m^3 polypropylene fiber has the highest residual compressive strength compared to concrete with other fiber content either in grade 25 or 45 MPa. For grade 25 MPa, concrete with a content of 2.0 kg/m^3 only decreased by 30% from its initial strength when being exposed to a fire of 700 °C. For concrete with grade 45 MPa, it shows even better performance, which only decreases by 20%. Even at ambient temperatures, concrete with a fiber content of 1.8 kg/m^3 has the optimum strength, yet concrete with a fiber content of 2 kg/m^3 shows better performance when the temperature increases. When the temperature was high, the polypropylene fibers melted and provided more pores so that water subjected to vapor pressure due to high temperatures can pass and does not push the surrounding cement paste. This fiber content provides the pores needed by concrete when water vapour pressure occurs due to high temperature; therefore, cracks in the cement paste can be avoided. Thus, the concrete's performance with a fiber content of 2 kg/m^3 is better during the fire. Figure 4 and Fig. 5 present the concrete compressive strength at ambient and elevated temperature for concrete grade 25 MPa and 45 MPa respectively.

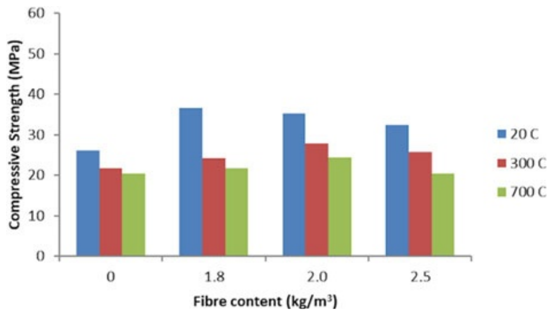


Fig. 4 Post-fire compressive strength of grade 25 MPa

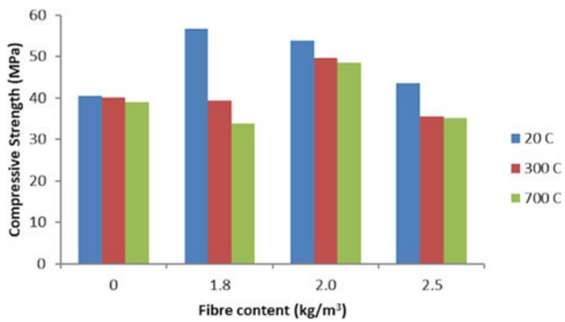


Fig. 5 Post-fire compressive strength of grade 45 MPa

3.3 Color Identification

The change of concrete surface color after exposed to 300 and 700 °C is presented in Fig. 6. The color test was carried out qualitatively and quantitatively. Qualitatively, the examination was conducted by visual inspection. Meanwhile, the quantitative test was performed using a spectrophotometer-based from the Color HunterLab tool. Color systems are represented by numbers in x, y, and z coordinates. L is a black to white color with a value range between black (0) and white (+100) and is located on the z-axis. The *a* value lies between the colors magenta (+100) and green (−100) and is located on the x-axis. The value of *b* is assigned between yellow (+100) and blue (−100) and lies on the y-axis. The color test results are presented in Table 2 and Table 3 for grade 25 MPa and 45 MPa respectively. Even though the color change between Grade 25 and 45 MPa are the same in each temperature visually, however they have different coordinates as observed by color test.

When the coordinates are plotted in a 3D curve (Figs. 7 and 8), the color pattern can be more understood clearly. The ambient temperature shows the color which lies mostly in the bottom, meanwhile due to exposed to the highest temperature, the concrete color is positioned more at top of the curve. This pattern is valid for

Ambient temperature 300°C 700°C

Fig. 6 Visualization of pre and post-fire concrete

Table 2 Color test for grade 25 MPa

Polypropylene (kg/m^3)	Visual examination			Color quantification								
	20 °C	300 °C	700 °C	20 °C			300 °C			700 °C		
				L	a	b	L	a	b	L	a	b
0	Grey	Brownish grey	Greyish white	34.83	0.17	3.98	62.71	0.70	5.22	68.50	0.07	3,29
1.8	Grey	Brownish grey	Greyish white	42.78	0.65	5.17	65.85	0.25	5.66	63.26	0.16	3,51
2	Grey	Brownish grey	Greyish white	43.45	0.28	6.41	64.33	0.17	3.24	66.61	0.24	3,43
2.5	Grey	Brownish grey	Greyish white	47.63	0.65	5.83	65.75	0.19	3.51	65.38	0.02	5,08

Table 3 Color test for grade 45 MPa

Polypropylene (kg/m³)	Visual examination			Color quantification								
	20 °C	300 °C	700 °C	20 °C			300 °C			700 °C		
				L	a	b	L	a	b	L	a	b
0	Grey	Brownish grey	Greyish white	37.42	0.86	4.32	54.56	1.06	5.10	56.14	0.13	3.37
1.8	Grey	Brownish grey	Greyish white	48.65	0.88	5.52	57.97	0.33	3.13	57.95	0.26	5.55
2	Grey	Brownish grey	Greyish white	42.72	0.57	4.87	57.76	0.73	3.13	58.98	0.19	4.97
2.5	Grey	Brownish grey	Greyish white	51.03	0.22	6.00	56.28	0.97	5.63	58.14	0.30	6.02

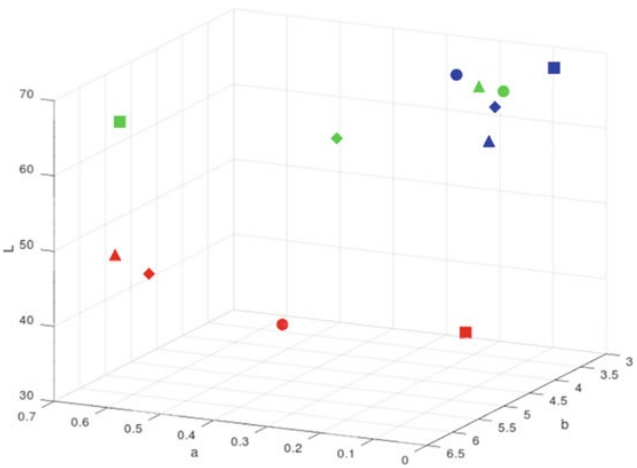


Fig. 7 Color visualization for grade 25 MPa

all concrete grades and each fiber contents. The color of red, green, and blue in in the figures refers to the temperature of 20 °C, 300 °C and 700 °C respectively. Meanwhile, the shape of square, diamond, circle, and triangle in the curves refers to the content of fiber of 0 kg/m³, 1.8 kg/m³, 2 kg/m³ and 2.5 kg/m³ respectively.

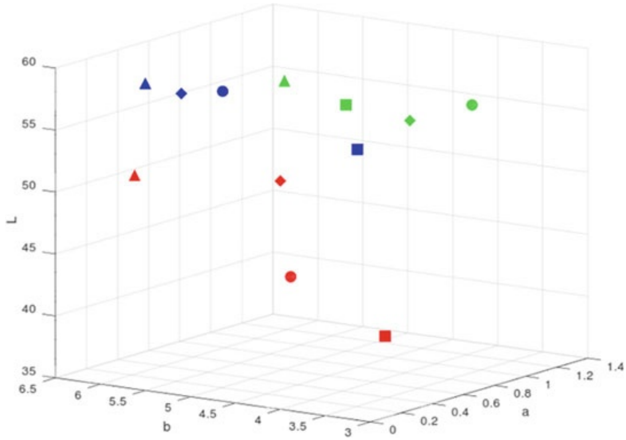


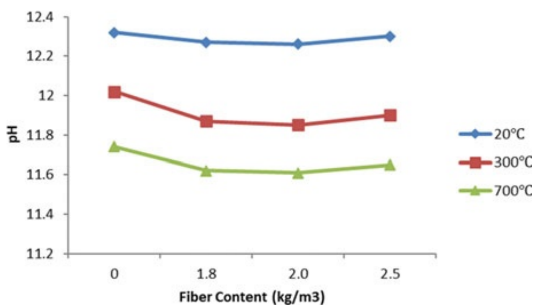
Fig. 8 Color visualization for grade 45 MPa

3.4 *Alkali Level Identification*

The alkaline level of concrete can be indicated by the pH value. The pH value is measured using a pH meter on concrete samples that have experienced high temperatures. The pH level of normal concrete was also measured as a control. The concrete alkalinity before and after fire is shown in Fig. 9 for grade 25 MPa and Fig. 10 for grade 45 MPa.

It appears that the properties of concrete are alkaline, with the top alkaline levels ranging from a pH of 12.3. However, with the increase in temperature, the concrete's alkaline content decreases due to the chemical process. Considering the polypropylene fiber content in concrete, the greatest the polypropylene content can be the best in maintaining the pH value at high temperatures compared to other polypropylene levels. It occurs either in grade 25 or 45 MPa. The addition of this fiber to the

Fig. 9 Alkaline level for concrete grade 25 MPa



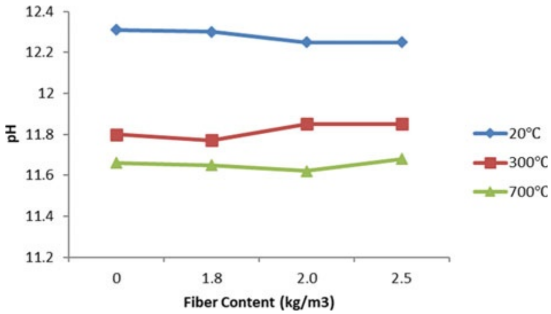


Fig. 10 Alkaline level for concrete grade 45 MPa

concrete is able to prevent the decrease of the alkaline level of the concrete because the polypropylene fiber is made of plastic; therefore, it does not affect the alkalinity level of the concrete during a fire. The alkalinity in concrete in concrete after a fire is very important property to provide passive protection to steel reinforcement continuously.

4 Conclusion

The 2 kg/m^3 fiber content shows greater performance because it provides the pores needed by concrete when water vapor pressure occurs due to high temperature; therefore, cracks in the cement paste can be avoided. Visually, the color change between grade 25 and 45 MPa are the same in each temperature; however, they have different coordinates as observed by color test. The addition of this fiber to the concrete is able to prevent the decrease of the alkaline level during the fire.

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