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The effect of high temperature on color and residual compressive strength of concrete

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ABSTRACT: When exposed to high temperature like in a fire, a concrete structure sees its compressive strength and elasticity degraded, accompanying with a crack, a spalling and a change in color. The purpose of this study is to identify the relationship between temperature change and a change in color and a decrease in compressive strength in a heat exposed concrete structure. For this study, we manufactured a concrete specimen and heated it until it hit the variable temperatures of 100, 200, 300, 400, 500, 600, 700, and 800℃, whereupon the color change and the residual compressive strength were measured for analysis. The result of the study shows that color change and residual compressive strength in a concrete structure exposed to high temperature have a consistent relationship, therefore, it may be possible to know how much compressive strength of the concrete reduces by measuring color changes and estimating heating temperature.

1 INTRODUCTION

To evaluate damage to concrete exposed to high temperature such as in a fire, we first observe a change in color, a crack and a burst with naked eyes. The color of concrete tends to change to red at the temperature between 300℃ and 600℃, to whitish grey between 600℃-900℃, and buff between 900℃ and 1000℃.

Particularly, the color change into red is most prominent in the concrete made with siliceous aggregate, and least prominent in calcareous aggregate. The reason why the color changes into red is that iron in the aggregate dehydrates or oxidizes due to the high temperature. And the color change is related to reduction in concrete strength, and this could be very useful information to evaluate damages.

In addition, as the color turns into red within a certain temperature range as the temperature changes, this will enable to improve the existing subjective method of evaluating damage to concrete due to high temperature and to create a new quantitative method by quantifying a change in color accordance with a change in temperature.

The purpose of this study is to identify the quantitative relationship of a change in color and a decrease in compressive strength of concrete, when exposed to high temperature, with the temperature change.

2 COLOR ANALYSIS

2.1 *Color indicators*

The color changes can be quantified and expressed by each factor on color space coordinates, and a particular color can be indicated on HSI coordinates with hue, saturation, and lightness values.

A color on a HSI coordinates means a kind of colors such as red, yellow or green, and is measured

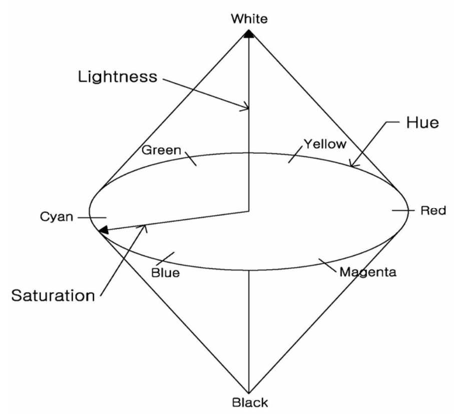

Figure 1. HSI Coordinates.

by wavelength. A hue of a color is indicated by the location on a horizontal circle. Zero (0) value on the circle defines pure red and the hue is quantified by angles.

Saturation indicates an amount of white color mixed in a pure color. Bright and deep red which is not mixed with white at all has a high saturation level, and on a HSI coordinates the circumference means 100% of saturation and the center of the circle means 0%.

Lightness indicates an amount of light that a material reflects, which is relative brightness and darkness. On a HSI coordinates, it is indicated on a vertical axis of the circle plane.

2.2 *Color measurement method*

Generally, a spectral color measurement system is used to measure a color quantitatively, especially in industries such as dying, stamping or construction interior to control colors.

In this study as well, the spectral color measurement was used to quantify color values and analyze them on the color coordinates.

When a visible ray with the wavelength of 380㎚ - 780㎚ reflects from or is penetrated into an item due to chemicals on the surface of the item, it changes spectral power distribution which means, it changes distribution of light speed of an original wave. Then, a different light is reached on the retina, producing stimulus which is conveyed to the brain through the optic nerve, and that's how we can distinguish different colors.

In this study, Spectrophotometer CM-2500d of Japanese MINOLTA was used for shade analysis, and as an analyzing program, SpectraWorks of Dong-san Machinery, a Korean measuring instruments producer, was used.

3 EXPERIMENT PLAN

3.1 *Concrete mixing and test samples production*

The cement used in this study is the ordinary Portland Cement, as a coarse aggregate crushed granite with maximum size limited to 20~25mm was used and as a fine aggregate, filer sand with blend ratio of 2.8 and absorption ratio of 0.6%. As an admixture, fly ash was used and set to have 10% of replacement ratio toward water-to-cement ratio.

The water-to-cement ratio of the cement specimen was planned at 0.45. The targeted slump of the combination was set to 15cm and the targeted air capacity was set to 5.0% (with an error tolerance of 1.5%). Refer the table 1.

We followed "Method of making and curing concrete specimens" of Korean Industry Standard (KS F 2403) when manufacturing the concrete specimens. The size of the concrete specimens was set to Φ100x200, and K type thermocouples were inserted in the center of the specimens in the depth of 3cm, 6cm, 9cm, 12cm, and 15cm from the surface in order to measure temperature inside. The specimens were capped after 24 hours following KS F 2403, de-molded after another 24 hours and cured in water for 28 days in a thermal water bath of 20℃.

Table 1. Concrete mix proportions.

W/C	S/a (%)	Binder (kg/m^3)	water (kg/m^3)	Mix proportions (kg/m^3)			
				G	S	C	FA
0.45	48.5	338	152	939	878	304	34

* G:Coarse aggregate, S:fine aggregate, C: cement, FA: Admixture (fly ash)

3.2 *Test methods*

In this study, we manufactured concrete specimens of Φ100x200 with variables of heating temperatures, heated them in an electric oven to measure color values and compressive strength, analyzed the result comparing that of the controlled concrete specimen, to identify the relationship between temperatures at which the concretes were exposed and color changes and residual compressive strength.

We also manufactured an electric oven with width x length x depth of 87cm x 80cm x 150cm to heat the concrete specimens, and installed a control box that controls temperature and heating speed. The targeted temperatures inside the electric oven were set between 100℃~800℃ and the oven was set to get heated at the speed of 13.33℃/min until it got to each targeted temperature and to remain for an hour in order for the temperature inside to reach targeted temperature evenly.

4 RESULT AND DISCUSSION

4.1 *Crack and color changes*

When seen with naked eyes, as at the room temperature, no change in any of specimen was found at the temperature between 100℃~200℃.

The color of the cement paste started to change at 300℃ into red, and as the temperature rose, the change became worse up until 600℃. Especially at 600℃, the color of the aggregate changed into red. And the overall color of the specimen started to change into grey at 700℃ or above.

In terms of crack, no crack was detected between 100℃~500℃ with naked eyes. At the temperature above 600℃, a crack started to be detected with naked eyes and as the temperature rose, the crack became wider from 0.2mm to 1.0mm.

4.2 *Changes in hue, saturation and lightness values*

Three factors on the color coordinates, which are lightness, saturation and hue, quantify changes in color of the heat-exposed-concrete. These properties were measured at the surfaces of the two specimens, and we got all 6 values of each temperature and their average value.

Figure 2 shows changes in the hue of the specimen at each temperature.

As shown in the figure, there was only little difference in the heated specimen below 200℃ with the unheated specimen, but the changes got severe between 300℃~600℃. And at the temperature above 700℃, it showed irregularity in changing pattern.

It is known that the reason why concrete exposed to high temperature of 300℃~600℃ sees its color change into red is because of iron contained in the fine aggregate or the coarse aggregate, and the hydrate starts to dissolve and the iron starts to get oxidized at this temperature.

Figure 3 shows changes in the lightness of the specimen at each temperature.

As shown in the figure, the lightness saw no significant change until 300℃, and started to decrease at 400℃~600℃ and bounced back at 700℃ and above.

The overall lightness started to decrease as hue changed at 300℃ and above and reversed at 700℃~800℃, but the variable breadth was not significant.

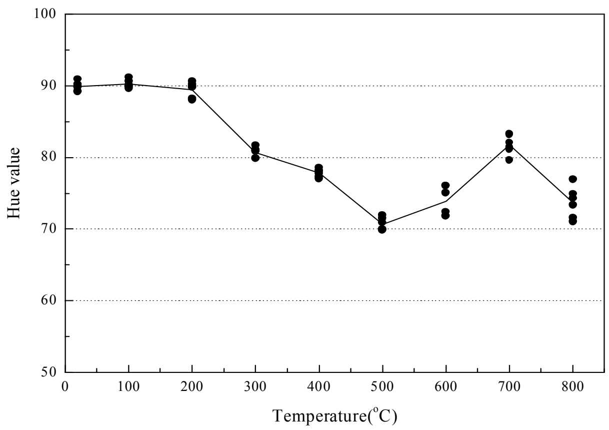

Figure 2. Change in Hue Value by Temperature.

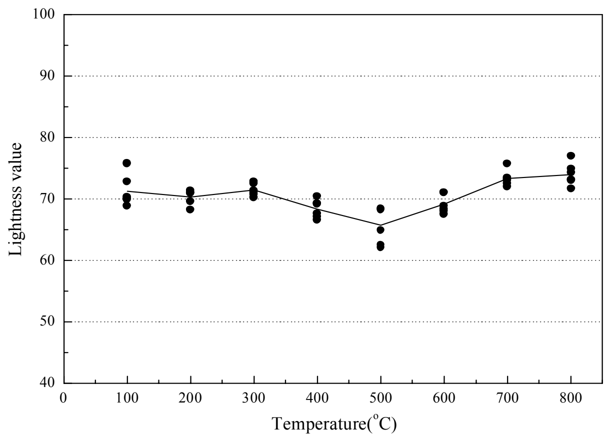

Figure 3. Change in Lightness Value by Temperature.

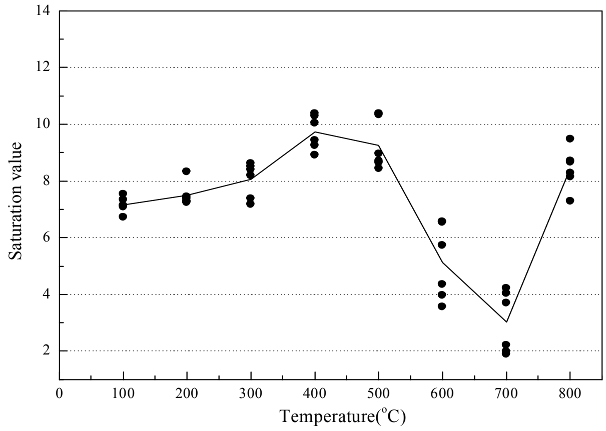

Figure 4. Change in Saturation Value by Temperature.

Figure 4 shows changes in the saturation of the specimen at each temperature.

As shown in the figure, the saturation value increased as the temperature rose and exceeded that of the controlled specimen at 300℃~500℃, where hue decreased and red color was detected. However, the saturation value plunged as the temperature hit 700℃ and hue changed.

In a nut shell, between the temperature of 300℃ and 600℃, where the red color is detected, the hue value decreases as temperature rises, the lightness shows no significant difference and saturation value exceeds that of the controlled specimen. At the temperature above 700℃, the hue and the lightness values bounce back while the saturation plunges. Therefore, it seems to be possible to estimate a heating temperature the concrete is exposed more accurately by comparing the hue value and the saturation value.

4.3 *Relative hue ratio and residual compressive strength by temperature*

In order to figure out the relative hue ratio and the residual compressive strength ratio at each temperature, we measured the relative hue ratio and residual compressive strength of the specimen with 0.45 of water-to-cement ratio, at 9 different temperatures from room temperature to 800℃, and the table 2 shows the result.

The relative hue ratio indicates ratio of the hue value of the heated concrete specimen to that of the controlled specimen, and the residual compressive strength ratio indicates the ratio of heated specimen's compressive strength to that of controlled specimen.

The table shows that the subject hue ratio gets accelerated above 300℃ and decelerated at 600℃. And the residual compressive strength decreases as the temperature rises, and at the temperature of 800℃, the residual strength is dropped to less than 10% level of the controlled strength at the room temperature.

Table 2. Relatve hue and residual strength ratio by temperature.

Temp. (℃)	Relative Hue Ratio	Compressive Strength(MPa)	Residual Strength Ratio
20	1.00	59.21	1.00
100	1.00	49.42	0.83
200	0.99	48.32	0.82
300	0.88	50.30	0.85
400	0.85	36.86	0.62
500	0.77	31.59	0.53
600	0.80	18.83	0.32
700	0.90	6.86	0.12
800	0.80	4.40	0.07

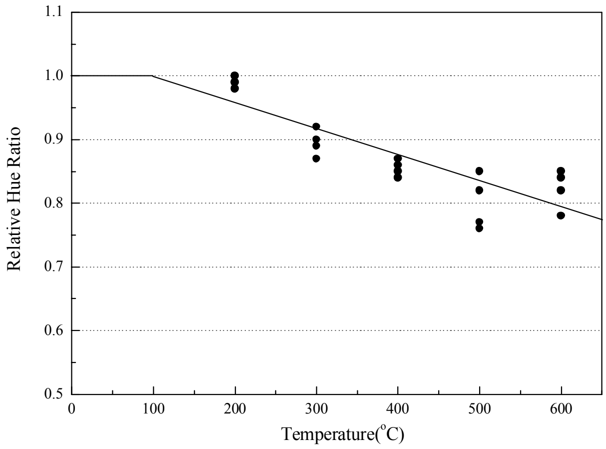

Figure 5. Temperature and Relative Hue Ratio.

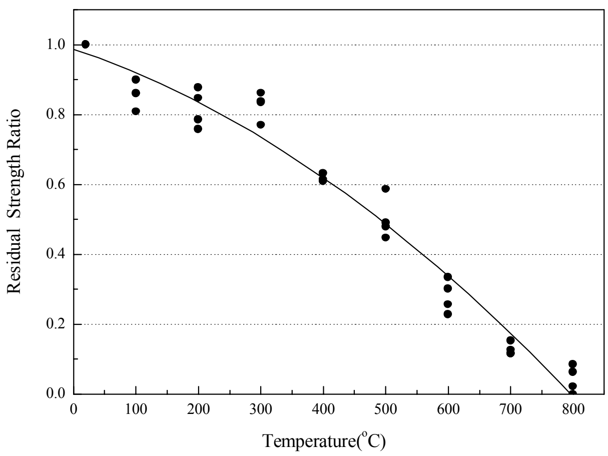

Figure 6. Temperature and Residual Compressive Strength.

The figure 5 shows the relationship between temperature and relative hue ratio, and is expressed with a linear equation with a constant, R of 0.84. No change in the hue value is detected up until 100℃ and the hue starts to change at 200℃. The hue value changes from 92% to 79% at 300℃~600℃, and as the temperature rises, the change in the hue continues to change.

The figure 6 indicates the change of the residual compressive strength as the temperature increases. The residual compressive strength can be expressed with a quadratic equation with R^2, a constant of 0.97. The residual compressive strength decreases as the temperature rises, from 92% to 0% at 100℃~800℃.

5 CONCLUSION

In this study, we observed the specimen with naked eyes and measured the change in color and residual compressive strength at different temperatures in order to figure out the relationship between temperature change of the concrete exposed to high heat and changes in its color and residual compressive strength, and we got the conclusion as below.

(1) As the result of observing the concrete exposed to high heat with naked eyes, red color starts to be detected at 300℃ and above and continues changing until 600℃, and at the temperature of 700℃, the color changes to light grey. The crack on the specimen starts to be detected at 600℃ and gets wider at 800℃.

(2) As the result of analyzing hue, the hue value sees larger change as the temperature rises, and especially the change gets severe at the temperature between 300℃~600℃,

(3) The residual compressive strength tends to decrease as the temperature rises, plunges to 60% at 400℃ and remain below 10% at 800℃.

(4) Between 100℃~600℃, the relative hue change and the residual compressive strength consistently decrease as the temperature rises, enabling to estimate the heating temperature that the concrete is exposed to and the decrease in compressive strength by measuring the hue change of the concrete exposed to high heat.

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