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Mechanism of Change in Splitting Tensile Strength of Concrete during Heating or Drying up to 90 °C

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Abstract

Changes in temperature and relative humidity affect splitting tensile strength of concrete but the mechanisms are left unknown. This study aimed to clarify the mechanism through experiments using control mortar specimen and concrete specimens with two types of coarse aggregate of different shrinkage behavior mixed with the control mortar. Specimens were shaped in a thin plate for a faster equilibrium with the ambient drying conditions. Drying of different temperatures or relative humidities were maintained till the mass of specimens become constant. Then length changes, mass changes and splitting tensile strength were determined.

It was shown that changes in strength of control mortar became more significant as drying conditions became severer while the change was not always monotonic. Compared with existing studies on shrinkage of cement pastes, the shrinkage of mortar specimens was supposed to be affected by the changes in strength of cement paste and by increase in strength as a result of multiple crack formation that occur due to fine aggregates.

Changes in strength of concretes were affected by the change in mortar strength particularly at a relative humidity ranging from 0.80 to 0.43, where effects of fine cracks due to restraint of aggregate were imposed and strength reduction became more significant when coarse aggregate with a lower shrinkage was used. The restraining effect of coarse aggregate was confirmed also during heating higher than 40°C resulting in reduction of strength. It was concluded that the changes in strength of concrete during drying were mainly affected by both changes in mortar strength and restraint of coarse aggregate.

1. Introduction

The establishment of performance assessment methods that examine the current state of concrete properties, and the establishment of predictive performance assessment methods are both essential to enable the long-term use of reinforced concrete structures. Changes in compressive strength of concrete during drying or heating up to 90 °C have previously been reported by Maruyama *et al.* (2014a). That research demonstrated that concrete strength does not decrease uniformly with drying. Specifically, the compressive strength of concrete is influenced by the physical properties of the cement paste and the damage caused by volumetric change during drying of the paste and aggregate, and further cement paste, which combines porous and colloidal characteristics (Maruyama *et al.* 2014b), exhibits various strength levels under drying conditions. Concrete with a W/C of 0.55 was found to have its lowest compressive strength at 40% RH. Under severer drying conditions, strength

showed a tendency to increase, demonstrating strength development during drying.

Considering such a multi-factor strength determination mechanism, it is quite unlikely that a high correlation between the compressive strength and tensile strength of concrete can be found as in the case of concrete of young age that is undergoing hydration (Comité Euro-International du Béton 1993, Japan Concrete Institute 2008). Therefore, we decided to investigate the influences of drying and humidity on splitting tensile strength.

A previous study pointed out that splitting tensile strength of ordinary concrete is greatest in the vicinity of 60% RH during drying at room temperature (Hansen 1968). Further, Kishitani *et al.* (1982) reported that when exposed to a high temperature environment for 1000 days, the splitting tensile strength of concrete declined almost linearly with temperature in the range up to 100 °C. Based on the results of a comparison of micro-damage and exposure to high temperature, Kanda *et al.* (2007) also reported a high correlation between damage and strength. A study by Naus *et al.* (2010) observed also that tensile strength tends to decline monotonically in relation to temperature during long-term drying, but they found tensile strength to be extremely low in the range up to 100 °C when the period of exposure to high temperatures is short. However, according to the experimental results by Kishitani *et al.* (1982), in order to clearly demonstrate the problems posed by the drying effect, it is important to perform testing in a state

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of full equilibrium where there is no water movement in the test specimens. This is because the differences in internal and external water distribution causes self-stress in the test specimens and has an impact as an error factor during measurement.

In order to assess the impact of micro-damage around aggregate during drying while keeping this in mind, we decided to investigate also the influence of aggregate size by comparing concrete with a limestone aggregate, which is characterized by little shrinkage, and concrete with a sandstone aggregate, which is characterized by large shrinkage.

2. Experimental overview

2.1. Materials and mix proportions

The materials used in the experiments are listed in **Table 1**. The chemical composition and mineral composition of the cement are shown in **Tables 2** and **3**. The mix proportions of the mortar and concrete and the results of the fresh property test are shown in **Table 4**.

As the coarse aggregate for the concrete, crushed limestone aggregate (GLS), which has small drying shrinkage strain, and large crushed hard sandstone (GSS), which has large drying shrinkage strain, were used. Three orthogonal specimens each measuring 3x3x8 mm were cut from both types of aggregate, and the results of

length change isotherm measurement using humidity-controlled thermomechanical analysis (TMA, **Fig.1**) are shown in **Fig. 2**. The temperature was controlled within 20 ± 0.1 °C.

Because aggregate size affects length change and damage around aggregate during drying (Maruyama *et al.* 2014a, Maruyama and Sugie 2014), coarse aggregate with grain sizes of 5-10 mm, 10-15 mm and 15-20 mm was used in equal parts by mass. The concrete specimens are designated as LS-Mix for concrete using crushed

Fig.1 Schematic of a system for measurement of length change isotherm of aggregates.

Fig. 2 Relationship between drying shrinkage strain of coarse aggregate and relative humidity.

Table 1 Properties and characteristics of materials for experiments.

Cement	Notation	Properties and characteristics
Cement	C	Ordinary Portland cement, Density: 3.16g/cm ³ , Blaine value: 3230cm ² /g
Fine aggregate	S	Land sand, Saturated and surface-dry density: 2.58 g/cm ³ , Adsorption ratio: 2.08%
Coarse aggregate	GLS	Limestone, Saturated and surface-dry density: 2.64 g/cm ³ , Adsorption ratio: 0.36%
	GSS	Sandstone, Saturated and surface-dry density: 2.59 g/cm ³ , Adsorption ratio: 0.89%
AE agent	AE	Complex of denatured lignin sulfonic acid compound and poly-carboxylic acid compound
Viscosity improver	AS	Cellulosic water-soluble polymer

Table 2 Chemical composition of cement.

LOI (%)	Chemical composition (mass%)								
	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	SO ₃	Na ₂ O	K ₂ O	Cl ⁻
2.3	20.04	5.21	2.87	64.9	1.46	2.21	0.14	0.34	0.019

Table 3 Mineral composition determined by X-ray/Rietveld analysis.

Mineral composition (mass%)							
C ₃ S	C ₂ S	C ₃ A	C ₄ AF	CC	CS ₂ H	CS ₂ ·0.5H	M
58.3±1.5	17.5±1.2	5.7±0.7	10.5±0.7	4.9±0.5	1.1±0.3	1.2±0.3	0.8±0.2

Table 4 Mixture proportions of concretes and properties of concretes at fresh state.

	Mixture proportions									Slump (cm)	Air (%)	Temp. (°C)
	W/C(%)	s/a (%)	Unit mass (kg/m³)									
			W	C	S	GLS	GSS	AE	AS			
Mortar	55	—	271	492	1432	—	—	4.9	2	23	4.9	21
LS-S	55	51.8	177	322	940	909	—	3.2	1.3	6.5	2.9	21
LS-M										8.5	2.9	21
LS-L										11.5	2.8	21
LS-Mix										10.0	3.0	21
SS-S	55	51.8	177	322	940	—	892	3.2	1.3	6.5	2.6	20
SS-M										8.5	2.6	21
SS-L										9.5	2.5	21
SS-Mix										9.0	2.6	21

limestone aggregate, and SS-Mix for concrete using crushed hard sandstone.

Further, to assess the effect of aggregate size on drying, testing of concrete using exclusively GLS of either 5-10 mm, 10-15 mm, or 15-20 mm grain size was also conducted. These concretes were named LS-S, LS-M, and LS-L, respectively. Concrete using similarly graded GSS was named SS-S, SS-M, and SS-L, respectively.

In terms of mix proportions, the same volumetric proportions of coarse aggregate, water, cement, and fine aggregate were used for all concrete batches. Therefore, slump and air content were not adjusted. However, viscosity agent was used to suppress bleeding.

Batches of 80 L were produced by mixing each type in a 100 L pan type mixer for 3 minutes in a thermostatic chamber at 20 ± 1 °C.

The two types of concrete and mortar using different types of coarse aggregate were placed in $\phi 100 \times 200$ mm lightweight molds and the cylinders were demolded after two days. Standard water curing was performed up to the

age of 1 year under the constant temperature of 20 ± 1 °C in a saturated aqueous solution of calcium hydroxide. The choice of a saturated aqueous solution of calcium hydroxide was to prevent leaching of calcium from the specimens

The $\phi 100 \times 200$ mm mortar and concrete cylinders were then cut with a diamond cutter to a thickness of 9 mm to produce $\phi 100 \times 9$ mm specimens.

The specimens were dried at the constant temperature of 20 °C and humidity of 95% RH, 80% RH, 60% RH, 43% RH, and 20% RH, and were also heated in a constant-temperature furnace at 40 °C, 65 °C, and 90 °C. Drying by saturated salt solutions was performed under the constant temperature of 20 °C, and air circulation was performed in the chamber. To eliminate the effects of carbonation on the specimens under heating, heating was performed in a closed system in equilibrium with a saturated sodium hydroxide solution at room temperature. The schematic of the drying process is shown in Fig. 3. Both the inflow and outflow air around the specimens

Fig. 3 Schematic of drying systems. Carbonation was prevented by CO₂ adsorbent or closed air circuit.

passed through a gas scrubbing bottle to eliminate the influence of carbon dioxide.

2.2 Size-dependence experiments

For faster drying, $\phi 100 \times 9$ mm disc-shaped specimens obtained by sawing $\phi 100 \times 200$ mm specimens were used in this study. Thereupon, the authors decided to investigate the influence of specimen size on experimental results.

Many studies have been conducted on the influence of specimen size on concrete strength, including assessment in terms of fracture mechanics (Bažant 1984) and assessment in terms of aggregate size (Tanigawa and Yamada 1977).

With regard to the influence of size in splitting tensile tests, Hasegawa *et al.* reported that no size effect on specimen length was observed (Hasegawa *et al.* 1985). Further, Tanaka *et al.* reported that in the case of specimens with a diameter of 500 mm or greater, a size effect caused by the non-homogeneity of the material was observed, and that in the case of specimens with a diameter of up to 200 mm, a size effect caused by fracture energy exists (Tanaka and den Uijl 2008). As described above, with regard to splitting tensile strength, a diameter size effect is recognized, but there is no agreement about the effect of length size. Therefore, in order to evaluate the size effect when using specimens of $\phi 100 \times 9$ mm, splitting tensile tests on specimens of four different sizes, i.e. $\phi 100 \times 150$ mm, $\phi 100 \times 100$ mm, and $\phi 100 \times 50$ mm in addition to $\phi 100 \times 9$ mm, were conducted. The mix of the specimens was the LS-L type whose large and single sized coarse aggregate would show the size dependence of defects more clearly.

2.3 Influence of aggregate shrinkage

The effect of aggregate shrinkage was investigated for mortar, LS-Mix, and SS-Mix samples.

After cutting, the specimens were again subjected to standard water curing. Prior to the measurement, the specimens were wiped with a clean rag, and measurement of length and mass was performed in a water-saturated state. They were then placed under the specified drying or heating conditions, and the specimens were considered to have reached equilibrium when the change in mass of the specimens over 24 hours declined to 0.03% or less. After high-temperature drying, the specimens were sealed in aluminum bags and placed in a temperature-controlled room at 20 °C for three hours, and subjected to measurement of length and mass changes. Then the specimens promptly underwent splitting tensile strength testing with a universal testing machine.

Heated drying of the specimens was done using a hot-air circulation type heating chamber. To avoid carbonation, care was taken to supply CO₂ free air from a gas scrubbing bottle with a CO₂ absorbent as it is shown in Fig. 3. The drying period, which was longest for the humidity level of 43% RH, was 32 days for mortar and

Fig. 4 Schematic of a measurement system for length of specimen.

36 days for concrete.

Change in the length of the specimens before and after drying was measured with a laser displacement meter (1/2000 mm accuracy). The schematic of measurement process is shown in Fig. 4. The specimen temperature at drying shrinkage strain measurement was 20 °C. Stainless steel (SUS304) of a known length was provided and the length of each specimen was determined based on the length difference between the stainless steel and the specimen, and the drying shrinkage strain was calculated accordingly. It should be noted that the length of the stainless steel changes with temperature, the indoor temperature during measurement was also measured, and the necessary correction was performed using the thermal expansion coefficient of stainless steel of $17.0 \times 10^{-6}/^{\circ}\text{C}$. In addition, the diameter was measured in three places for each specimen, and the obtained values were averaged as the length of the specimen. Based on the change in length before and after drying, the shrinkage strain was calculated, using the pre-drying length as the base length.

The mass immediately after drying was measured using a precision balance (resolution: 0.0001 g). Following mass measurement, the samples were dried for 48 hours at 105 °C in a nitrogen flow until they reached equilibrium mass, and their water content was calculated from the change in mass before and after drying.

2.4 Effect of aggregate size

The effect of aggregate size was investigated through tests on LS-L, LS-M, and LS-S specimens and SS-L, SS-M, and SS-S specimens, comparing the LS-Mix and SS-Mix described in section 2.3. Specimen drying and water content measurement were performed using the same procedures as those described in section 2.4. After drying and the attainment of mass equilibrium, the splitting tensile strength was performed.

3. Results and discussion

3.1 Size effect

The splitting tensile test results for the various specimen sizes are shown in Fig. 5. On the whole, specimen size shows no correlation with splitting tensile strength and standard deviation of strength, while the smaller the specimen size, the smaller the standard deviation is. It was concluded that splitting tensile strength can be assessable even for $\phi 100 \times 9$ mm specimens.

3.2 Influence of aggregate shrinkage on splitting tensile strength

3.2.1 Drying shrinkage strain and water content

Figure 6 shows the relationship between the equilibrium drying shrinkage strain and the drying conditions of the LS-Mix, SS-Mix, and mortar specimens. In each drying condition, the drying shrinkage strain of SS-Mix was greater than that of LS-Mix. Error bars of 1-sigma of measured variation are shown also in this figure, but they are all within the marker size. As shown in Fig. 2, the drying shrinkage strain at each relative humidity level is greater for SS-Mix using coarse aggregate. The fact that the drying shrinkage strain of coarse aggregate influences the drying shrinkage strain of concrete agrees with the existing research data and confirmed that shrinkage of mortar is constrained by coarse aggregate (Fujiwara 2008). Figure 7 shows the evaporable water content of each concrete specimen. In the LS-Mix and SS-Mix specimens, differences in evaporable water content were observed in the RH range between 95% and 20%. This is considered to be the effect of dehydration of the clay minerals contained in SS-Mix.

3.2.2 Strength

(1) Influence of the cement paste matrix

Figure 8 shows the relationship between the splitting tensile strength and drying conditions of each test specimen. For mortar, the splitting tensile strength increases from saturation to 60% RH, then decreases from 60% RH to 43% RH, then increases again from 43% RH to 20% RH, and reaches its highest value at 20% RH. In the case of drying by heating, strength declined gradually. Thus in the case of mortar, there is a non-monotonic relation between splitting tensile strength and drying conditions. Since such behavior has already been confirmed for cement paste, we checked the behavior trends of mortar against those of cement paste. Figure 9 compares the relationship between the normalized strength and drying conditions of mortar and cement paste. In that figure, normalized strength is the ratio of the average value of the splitting tensile strength of the specimens for each drying condition to the average value of the splitting tensile strength of specimens in the saturated state. The data from bending tests was used for cement paste.

An examination of the results in accordance with the drying process from the saturated state indicate that the paste showed an increase in strength in the range up to

Fig. 5 Length size effect on splitting tensile strength. The samples were LS-L.

Fig. 6 Relationship between drying shrinkage strain and heating or drying condition. Error bars of 1-sigma of measured variation are shown but they are within the size of each marker.

Fig. 7 Relationship between evaporable water content and heating or drying condition. Error bars of 1-sigma of measured variation are shown but they are within the size of each marker, except for LS-Mix 20% RH condition.

80% RH, and that after reaching the maximum value, the strength declined until 40% RH. On the other hand, in the

Fig. 8 Splitting tensile strength of mortar, LS-Mix, and SS-Mix as a function of heating or drying condition.

case of mortar, the strength increased until 60% RH. Two things can be considered to be at work here, namely (1) the multiplication of crack development paths during fracture owing to the role of fine aggregate, which causes an increase in strength as the result of increased energy consumption during fracture, and (2) the fact that the alteration process of the paste in the mortar may not have fully run its course due to the limited drying period of about 30 days. However, as regards the phenomenon of the strength value reaching its maximum value once through drying from the saturated state, the influences of the strength increase behavior of cement paste arising from the precipitation of hydrates associated with drying and physical and chemical bonding among hydrates are considered to be dominant (Maruyama *et al.* 2014b).

This influence of the incorporation of fine aggregate agrees with the fact that almost no strength reduction due to drying after the maximum strength value is reached can be seen in mortar. In the case of cement paste, the minimum strength value is reached at 40% RH (in the case of mortar in this study, 43% RH), and the amount of decrease of splitting strength of mortar is extremely small. This is assumed to be due to the increase in apparent strength caused by the formation of some cracks around the fine aggregate, which makes it easy for multiple cracks to appear under loading.

Strength of cement paste tends to increase under drying conditions more stringent than 40% RH (Maruyama *et al.* 2014b). This is due to the fact that calcium silicate hydrate interlayer distance becomes shorter, C-S-H densifies, and the strength of solids increases. The strength of mortar tends to be almost similar to that of cement paste.

The gradual decline of strength after it reaches its maximum value is caused by the expansion of crack width as the result of the increased shrinkage of the paste, and dehydration and decomposition of the aluminate hydrate in the paste at temperatures of 65 °C or higher (Maruyama *et al.* 2014b).

Fig. 9 Normalized strength of mortar and hardened cement paste as a function of drying or heating condition. (Paste data is cited from Maruyama *et al.* 2014b. Datum of paste at 65 °C is calculated as an average data of 60 and 70 °C. And Datum of paste at 43% is assumed to be same as that at 40% RH.).

(2) Influence of aggregate shrinkage

Figure 10 shows the relationship between normalized strength and drying for LS-Mix, SS-Mix, and mortar specimens. In the case of both LS-Mix and SS-Mix, splitting tensile strength increases from saturation to 80% RH, then declines until 43RH%, and from 43% RH to 20% RH, it increases slightly. While this behavior is largely similar to that of cement paste, it differs slightly from that of mortar. The behavior from saturation to 80% RH is similar to that of mortar, and the rate of strength increase is also the same. Thus the strength increase trend of SS-Mix and LS-Mix in this region can be said to be due to the influence of the mortar. However, the trend from 80% RH to 43% RH differs among mortar, SS-Mix, and LS-Mix. In other words, the restraining effect of coarse aggregate in that range is considered to be large. In fact, as can be seen in **Fig. 6**, in that humidity range, large differences in drying shrinkage strain of concrete appear, and differences in restraint dependent on aggregate shrinkage, in other words, the influence of damage

Fig. 10 Normalized strength of mortar, LS-Mix, and SS-Mix as a function of heating or drying condition.

around the aggregate, are considered to dominate (Maruyama *et al.* 2014a).

The strength increase in the range from 43% RH to 20% RH follows the same trend for mortar, SS-Mix, and LS-Mix, but the fact that the rate of increase is smaller for concrete than for mortar is due to the smaller amount of mortar that is effectively working in the load transfer path contributing to strength increase through the damage that has already occurred around the aggregate (Maruyama *et al.* 2014a).

In the drying range from 20% RH to 90 °C, the rate of strength decrease of LS-Mix is larger than that of SS-Mix, and that amount is either comparable to that of mortar or slightly smaller. In any case, the strength reduction behavior of mortar dominates that of concrete.

Looking these behaviors from the perspective of the damage that accumulates in concrete, a clear differences in strain can be seen between concrete and mortar as shown shrinkage strain graph in Fig. 6. Because the strain of mortar with the same mix proportions as that of the mortar used in the concrete is shown, this significant difference in strain between concrete and mortar is believed to be caused by the restraining effect of aggregate. On the other hand, taking into account the fact that this is

strain at the equilibrium state, the strain of the mortar in concrete has to be the same as the strain of the mortar specimen. Because the tensile strength of mortar is on the order of several MPa, a large number of cracks can be assumed to occur in mortar restrained by aggregate. That is to say, many cracks occur in mortar under the restraining effect of the aggregate in concrete, which results in the creation of voids. If the elastic tensile strain of the mortar is ignored, the amount of voids ought to be in a linear relationship between the strain differences between concrete and mortar. Based on this concept, the strain difference between mortar and concrete has been defined in a previous report as gap strain, which is a measure of the amount of damage (Maruyama *et al.* 2014a). The gap strain in this study is indicated in Fig. 11. As shown in that figure, in the range from saturation to 80% RH there is virtually no difference in the damage to the mortar portion of the concrete for LS-Mix and SS-Mix, and in the range from 80% RH to 43% RH, that difference expands, and in the drying range from 43% RH to 20% RH, the increase in the amount of damage is almost the same, and further, in the drying range from 40 °C to 90 °C, the amount of damage increases for LS-Mix.

These results correspond to the large increase in normalized strength for LS-Mix and SS-Mix in the range from 80% RH to 43% RH, and the growing decline in strength for LS-Mix in that same range.

Further, the fact that strength reduction in the range of 40 °C to 90 °C is greater for LS-Mix than for SS-Mix can be interpreted as being caused by expansion of damage.

3.3 Influence of aggregate size on splitting tensile strength

Figure 12 shows the water content under different heating or drying conditions, where the differences in water content between the concretes using LS, as well as using SS, were not large.

Figure 13 shows the splitting tensile strength results. The splitting tensile strength in the saturated state was largely the same for LS and SS, on the order of 3.5 MPa. Overall, mortar strength displayed similar trends to those of LS-Mix and SS-Mix. In other words, strength in-

Fig. 11 Gap strain, which is defined by the difference between mortar and concrete drying shrinkage strain, and drying or heating condition.

Fig. 12 Evaporable water content of LS-S, LS-M, and LS-L (a), and SS-S, SS-M, and SS-L (b) under different heating or drying conditions.

Fig. 13 Splitting tensile strength of LS-S, LS-M, and LS-L (a), and SS-S, SS-M, and SS-L (b) under different heating or drying conditions.

creased in the range from saturation to 80% RH, then declined until 43% RH, and increased slightly at 20% RH. After that, strength declined along with the rise in temperature in the heated drying range of 40 °C on up.

Now looking at the LS series, the strength of LS-L at 80% RH was about 0.5 MPa lower compared with LS-Mix, LS-S, and LS-M. This is thought to be due to the fact that LS-L has already developed cracks around the aggregate by the time it undergoes drying, because in the case of large aggregate, the effect of the transition zone surrounding the aggregate being relatively small, cracks may easily occur even at moderate dryness (Maruyama and Sugie 2014). This is thought to be why the strength of LS-L became smaller at 80% RH. The relationship between drying and strength after that was equivalent between LS-M and LS-Mix, and as discussed in section 3.2, the number of cracks that occurred during drying being determined over the humidity range especially from 80% RH to 60% RH, it became clear that the cracks that occur in the high humidity range have a greater influence on the strength behavior during drying. In the case of LS-L as well, the strength declined below the value at saturation during drying at 65 °C and higher.

On the other hand, looking at the SS series, the strength was highest for LS-Mix at 80% RH. LS-S, LS-M, and LS-L all had strength about 0.5 MPa lower at that humidity level. Although the reason for this is unknown, it might be that distribution of cracks occurs to a greater extent for continuously graded aggregate, which might have prevented a marked decline in strength. Looking at drying at 60% RH, only LS-L showed lower strength by about 0.5 MPa, and similarly to the LS series, only LS-L continued to consistently show lower strength in the subsequent drying.

Comparing the SS series and the LS series, we see that the SS series exhibited greater strength increase at 80% RH, and that after that the strength decline trend was almost the same for both series. As a result, the strength of the SS series during drying up to 90 °C did not fall below the strength at saturation.

As described above, the size of aggregated used in concrete does not have a significant effect on strength at saturation, but it does affect strength during subsequent drying. This effect is particularly pronounced in the range from saturation to 60% RH due to the restraining effect of mortar shrinkage, and the strength at 80% RH varies depending on aggregate size. Even during drying at humidity below 60% RH or heated drying, the strength reduction amount was found to be slightly greater for large aggregate.

3.4 Notes on strength assessment for aging management

The splitting tensile strength of concrete, used as the cracking strength as well as to assess shear cracking strength, is one of the important parameters for aging control. As a design strength, splitting tensile strength is often expressed as a function of compressive strength. Because this relationship is valid at saturated conditions, these design formulas are not necessarily appropriate for the evaluation of concrete performance after drying.

Moreover, the obtainment of this property value through core sampling from existing buildings and subsequent loading test is anticipated as a direct method. However, because most core sampling is carried out using the wet core sampling method, attention should be paid that the strength data acquisition is done under conditions that differ from the ordinary strength conditions in the building. Particular attention is in order when acquiring data in a high-temperature drying environment.

Separate consideration of the core sampling acquisition method and how the obtained data is to be interpreted is necessary. Further analytical studies of these questions are planned in the future.

4. Summary

This study has discussed the splitting tensile strength change mechanism for mortar with a water-cement ratio of 0.55 and concretes using aggregate with different

amounts of shrinkage under various drying conditions.

In the case of mortar, the strength changed along with drying, but the trend was not uniform. In a 20 °C environment, the strength reaches its highest value at 60% RH, while in the range from 43% RH to 20% RH, there was a slight increase in strength. This trend was strongly influenced by the strength change of the cement paste, and was also attributed to the effect of an increase in apparent strength due to multiple cracks in the presence of fine aggregate.

Besides being affected by changes in mortar strength, concrete is influenced also by fine cracks caused by coarse aggregate restraint. The decline in strength due to the fine cracks formation as the result of the restraining effect of coarse aggregate on cement paste was particularly pronounced in the range from 80% RH to 43% RH. The impact of the restraining effect of aggregate was also seen in the range from 40 °C to 90 °C. In the case of aggregate prone to high shrinkage with shrinkage behavior similar to that of mortar, the damage was lesser, and thus the decline in strength was smaller in the range from 80% RH to 43% RH. On the other hand, in the case of aggregate with low shrinkage, the decline in strength was higher in that range. As a result, under the drying condition of 90 °C, which produced a decline in strength, the strength value was lower than that at saturation. Further, in the case of large aggregate size too, the restraining effect of such aggregate affected changes in splitting tensile strength during drying. As a result, tensile strength at 90 °C was likely to be smaller than that at saturated condition.

The splitting tensile strength of concrete changes during drying, but in the range up to 65 °C, the splitting tensile strength does not fall below the value at saturation and remains high regardless of the drying condition.

Assuming that the wet method is used for core sampling for the purpose of strength assessment during maintenance, how the test results should be positioned is a question that warrants discussion.

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