# Some Experiments to Improve the Aesthetic Appearance and Performance of Concrete*

Hiroshi SAKURAI,** Koichi AYUTA,** Kaneyoshi OKADA,** Norito SAKO,*** and Yoshio FUJITA****

**Key words** Efflorescence, Curing, Ratio of efflorescence-affected area, Coefficient of moisture, Water-cement ratio

**Abstract**

Performance improvements have become an imperative in concrete engineering these days. We have investigated early-stage curing methods in order to clarify the relationship between concrete appearance (efflorescence) and improvements to the quality of the surface concrete. The purpose of the study was to experimentally test which curing factors had an effect on the concrete. Experiments were carried out on specimens with varying mix conditions cured under different conditions.

The experimental data were analyzed to determine the relationship between certain concrete characteristics and the ratio of efflorescence-affected area. The factor having greatest influence was the coefficient of moisture content. Next was the water-cement ratio. The appearance of efflorescence was also affected by the movement of water in concrete; efflorescence was most pronounced when the pore volume was of the size $10^4 \sim 10^5$ Å. This pore size allows the greatest movement of water in the concrete. Curing control at the earliest stage was critical to improvements in such performance measures as the strength of the concrete.

## 1. INTRODUCTION

Improving the performance of concrete has become a critical issue in the world of concrete engineering. Many studies of high-performance concrete and developing agents are being carried out these days, but there has been little investigation of curing methods.

We have investigated early-stage curing methods with the aim of correlating the appearance of concrete[1]—the development of efflorescence—with improvements in concrete quality. Experiments were carried out on specimens under various curing conditions and with different internal characteristics. Other experiments included in the study were tests and analysis of the effects of capillary pores on performance.

* Part of this report was presented at JCA Conference, 1994.

** Department of Civil Engineering, Faculty of Technology, Kitami Institute of Technology.
*** Graduate School, Kitami Institute of Technology.
****Guest Professor, Kitami: Institute of Technology.

# 2. METHOD

## 2.1 Experimental method

### 2.1.1 Experiment on efflorescence

The experimental flow used in this study of improving concrete performance by curing condition is shown in Fig. 2.1. The size of the specimens, their water-cement ratios, unit cement weight, and curing conditions are shown in Table 2.1.1. The mix proportion was varied, according to the unit cement weight and water-cement ratio, so as to maintain an air content of 4.5 ± 1%. Slump data were recorded for reference. The specimens were of colored concrete ; after mixing, a coloring admixture was added to the fresh base concrete to give it color. Specimens were moved to the curing room, where the relative humidity was 80%. After a day, the weight and surface moisture ratio of the specimens were measured. In order to record the initial conditions of the surface, photographs were taken. The specimens were cured until seven days of age under several curing conditions. At 7 days, efflorescence occurring test on the specimens were started. At 28 and 91 days, the specimens were set up in an efflorescence-measuring instrument. The area affected by efflorescence

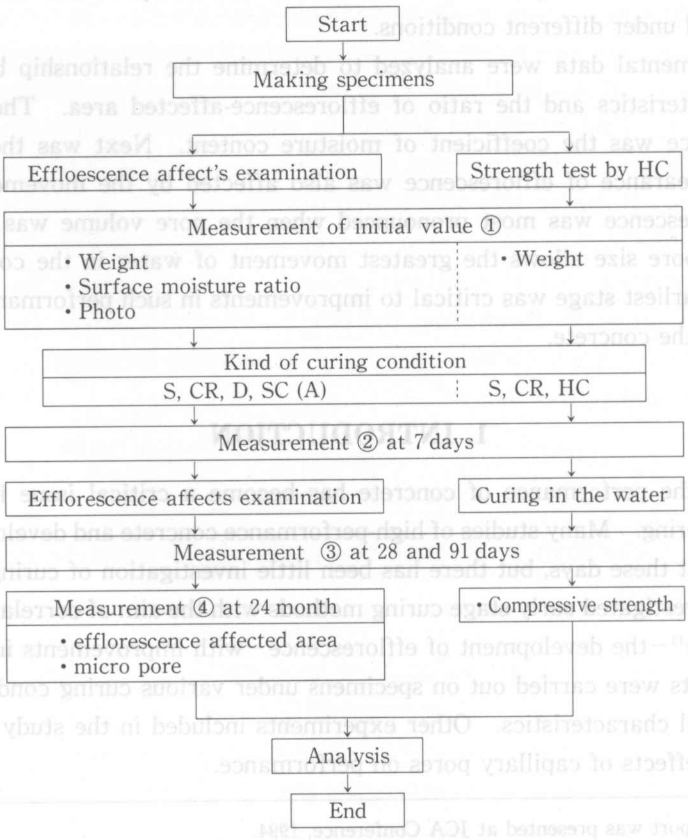


**Fig. 2.1** Flow of examination

was measured on each face of the specimen, and the ratio of efflorescence-affected area was calculated by dividing this by the total surface area of the specimen. Capillary pores, both at the surface and within the specimens, were measured at 24 months. The results of these observations were correlated against each unit cement weight, curing condition, water-cement ratio, and other factors.

### 2.1.2 Experiment on the relationship between strength and early-stage curing conditions

The following is the procedure used to check the relationship between strength and early-stage curing conditions. After mixing, the specimens were moved to a room with a relative humidity of nearly 100%. After a day, the initial condition of the concrete was recorded by measuring the weight of the specimens. Each specimen was cured until 28 or 91 days of age under standard curing conditions in water after high-humidity curing (HC) for a day, as described in Section 2.2.

**Table 2.1.1** Details of specimens

| Specimens | I | II |
|---|---|---|
| purpose of examination | Efflorescence affect's examination | Strength test by HC |
| Size of specimens (cm) | 10x10x20 | $\phi$10x20 |
| Water-cement ratio (%) | 40, 55, 70 | 25, 40, 55 |
| Unit cement weight (kg/m³) | 250, 350, 450 | 227,313,500 |
| Curing condition | S, SC (A), CR, D | S, CR, HC |

**Table 2.1.2** Types of admixture

| Chemical admixture | sign |
|---|---|
| ① air entraining agent | AE |
| ② air entraining water reducing agent | PO |
| ② foam reducing agent | PA |

Note;
① Use for examination for Appearance
② Use for examination for Strength

**Table 2.1.3** Mix proportion, properties and strength of concrete

| case | Mix Proportion | | | | | | Kind of chemical admixture | | | Property | | 28 day's compressive strength | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | W/C (%) | S/a (%) | Unit weight | | | | AE (%/C) | PA (%/C) | PO (ℓ/C) | slump (cm) | AIR (cm) | S (kgf/cm²) | CR (kgf/cm²) |
| | | | W | C | S | G | | | | | | | |
| A | 40 | 30 | 100 | 250 | 613 | 1140 | 0.006 | — | — | 0.1 | 9.3 | 316 | 245 |
| B | 55 | 30 | 138 | 250 | 584 | 1374 | 0.019 | — | — | 1.1 | 4.2 | 336 | 216 |
| C | 70 | 55 | 175 | 250 | 923 | 931 | 0.010 | — | — | 6.6 | 5.6 | 212 | 163 |
| D | 40 | 30 | 140 | 350 | 555 | 1311 | 0.088 | — | — | 1.0 | 3.8 | 322 | 284 |
| E | 55 | 60 | 193 | 350 | 1028 | 693 | 0.042 | — | — | 8.6 | 4.8 | 319 | 251 |
| F | 70 | 70 | 245 | 350 | 1102 | 479 | 0.053 | — | — | 24.1 | 4.6 | 201 | 171 |
| G | 40 | 60 | 180 | 450 | 784 | 891 | 0.144 | — | — | 8.0 | 5.2 | 360 | 288 |
| H | 55 | 47 | 248 | 450 | 892 | 602 | 0.324 | — | — | 24.4 | 5.3 | 285 | 219 |
| I | 70 | 70 | 315 | 450 | 918 | 396 | 0.302 | — | — | — | 4.4 | 212 | 188 |
| 1-25-X | 25 | 42 | 125 | 500 | 792 | 1194 | — | 2.0 | 0.009 | 0.4 | 0.4 | | |
| 1-40-X | 40 | 42 | 125 | 313 | 875 | 1292 | — | 2.0 | 0.009 | 0.1 | 1.1 | | |
| 1-55-X | 55 | 42 | 125 | 227 | 886 | 1337 | — | 2.0 | 0.009 | 0.4 | 1.3 | | |
| 2-55-X | 25 | 42 | 125 | 500 | 792 | 1194 | — | 2.3 | 0.009 | 1.3 | 0.6 | | |
| 3-25-X | 25 | 42 | 125 | 500 | 792 | 1194 | — | 2.3 | 0.009 | 1.5 | 0.3 | | |

One face of each specimen was made smooth with a shaving machine in preparation for loading tests. At 28 and 91 days, the specimens were set up to test for compressive strength, and their Poisson's ratio was measured.

The various admixtures are shown in Table 2.1.2. The mix proportions, properties, and strengths of the concrete were as shown in Table 2.1.3.

## 2.2 CURING METHODS

The specimens were cured until seven days of age under standard curing conditions, in the curing room (R.H. 80%), the dry room, and the special curing room as shown in Table 2. 2.1. The process of curing is shown in Fig. 2.2.

The appearance of efflorescence is affected by humidity and $CO_2$ density, so special A curing (SC(A)) was carried out at a higher humidity and $CO_2$ density.

Compressive strength is affected by moisture at the early stage, so high-humidity curing (HC) was carried out to ensure that the specimens did not dry up. HC were started from 0. 0, 0.5, 1.0, 2.0, 2.5, 3.0, 3.5, and 4.0 hours after placing concrete as sown in Fig. 2.2.1

Moisture evaluations are shown in Table 2.2.2. The coefficient of moisture (CM) of the specimens was calculated using Equations (2.2.1) and (2.2.2) below.

$$CM = 1/M \times 100 \quad \cdots\cdots \text{Eq. (2.2.1)}$$

where M is the linear regression of Table 2.2.2 and the following equation:

$$M = -0.03333EC + 4.333 \quad \cdots\cdots \text{Eq. (2.2.2)}$$

where EC is environmental condition which is a factor in calculating creep.[3]

**Table 2.2.1** Curing conditions

| Curing | Curing condition | Sign | CM |
|---|---|---|---|
| Standard | In the water at temperature 20°C | S | 125 |
| Curing room | Temperature 20°C, R. H. 85% | CR | 67 |
| Dry room | Temperature 45°C, R. H. 10% | D | 25 |
| Special A | Temperature 20°C, R. H. 95% kept blowing $CO_2$ always | SC(A) | 94 |
| High humid | Temperature 20°C, R. H. 95% in the water after 7days | HC | $\alpha$•125 |

Note: $\alpha$ in special caring condition within 24 hours,

**Table 2.2 2** Moisture coefficient

| Environmental condition | M* |
|---|---|
| in the water | 0.8 |
| R. H. 90% | 1.3 |
| R. H. 70% | 2.0 |
| R. H. 40% | 3.0 |

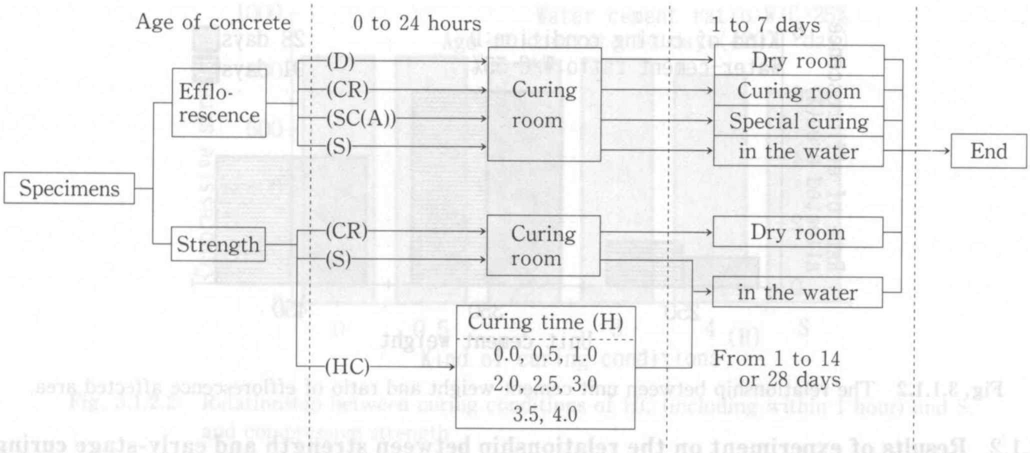


**Fig. 2.2.1** Curing process

## 3. Results of observations and discussion

### 3.1 Results

### 3.1.1 Results of experiment on efflorescence-affected area

The relationships between ratio of efflorescence-affected area and the coefficient of moisture and water-cement ratio are shown in Fig. 3.1.1.1. With increasing coefficient of moisture and water-cement ratio, there was a fall in the ratio of efflorescence-affected area.

The relationship between the ratio of efflorescence-affected area and the unit weight of cement is shown in Fig. 3.1.1.2. It is clear that unit cement weight has little influence on the amount of efflorescence.

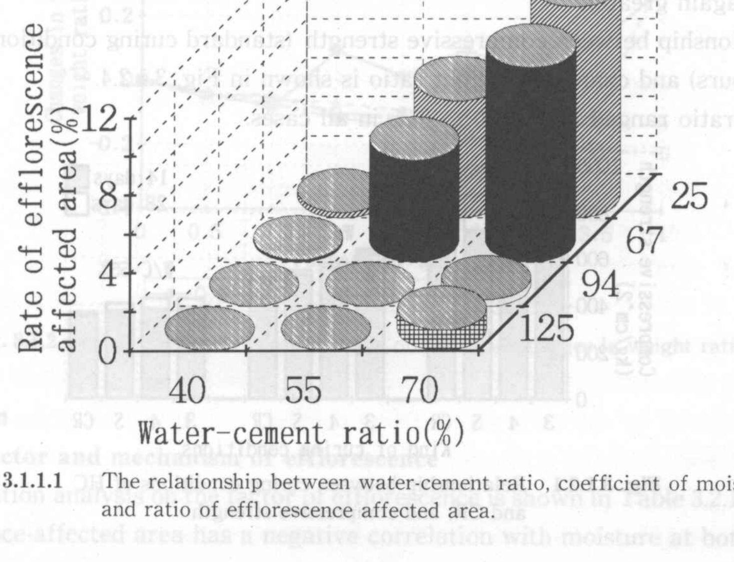


**Fig. 3.1.1.1** The relationship between water-cement ratio, coefficient of moisture and ratio of efflorescence affected area.

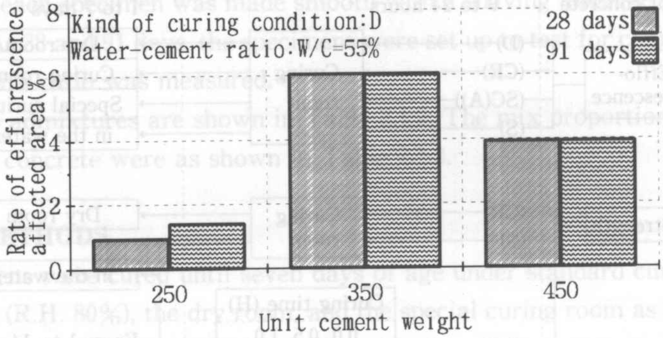


**Fig. 3.1.1.2** The relationship between unit cement weight and ratio of efflorescence affected area.

### 3.1.2 Results of experiment on the relationship between strength and early-stage curing condition

The relationship between 14- and 28-day compressive strength and curing conditions of several HC and CR is shown in Fig. 3.1.2.1. The compressive strength of concrete cured under high humidity was greater than that of standard-cured concrete for all water-cement ratios. With earlier initiation of high-humidity curing, the compressive strength increased.

The relationship between compressive strength and curing conditions of HC (including within 1 hour) and S is shown in Fig. 3.1.2.2. These compressive strength data were obtained after accelerated curing at 55°C(420°C•day is equivalent in age of concrete 14 days with standard curing). With earlier initiation of high-humidity curing, the compressive strength was greater.

The relationship between compressive strength and curing conditions of HC within 4 hours by 0.5 hour increments) is shown in Fig. 3.1.2.3. These compressive strength data were obtained by standard curing at 20 ±3°C (840°C•day is equivalent in age of concrete 28 days with standard curing). With earlier initiation of high-humidity curing, the compressive strength was again greater.

The relationship between compressive strength (standard curing conditions for 0.5, 2.0, 3.5, and 4.0 hours) and change in weight ratio is shown in Fig. 3.1.2.4.

Poisson's ratio ranged from 0.20 to 0.25 in all cases.

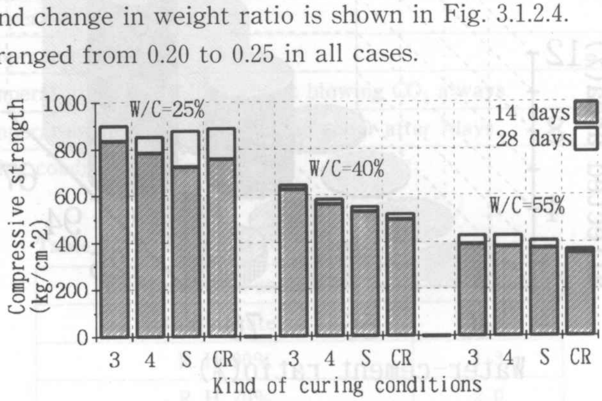


**Fig. 3.1.2.1** Relationship between curing conditions of HC and CR, and compressive strength

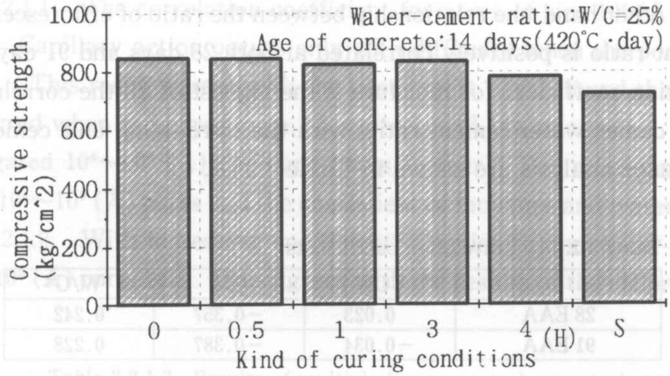


**Fig. 3.1.2.2** Relationship between curing conditions of HC (including within 1 hour) and S, and compressive strength

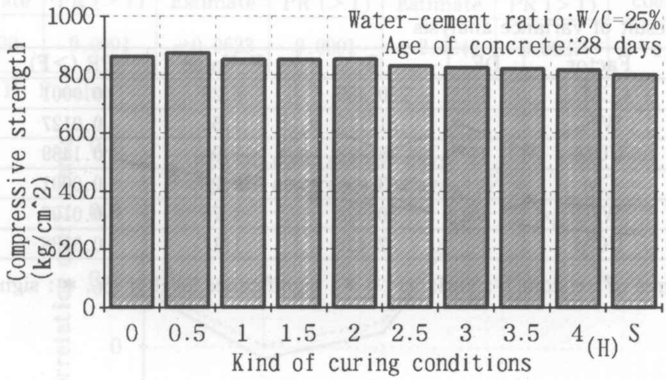


**Fig. 3.1.2.3** The relationship between curing conditions of HC (within 4 ours by 0.5 hour increments) and S, and compressive strength6

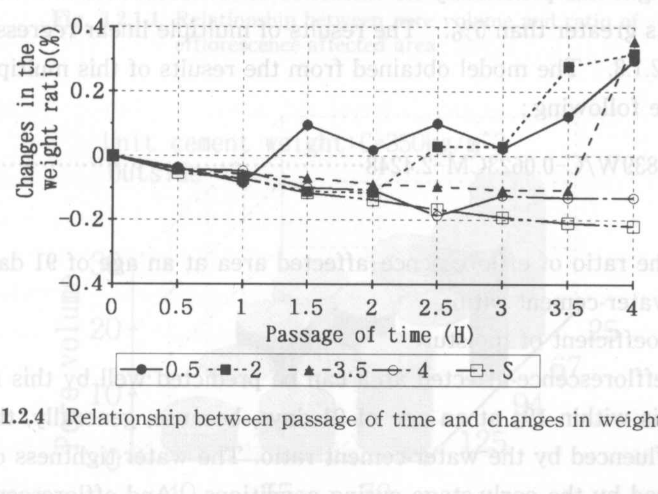


**Fig. 3.1.2.4** Relationship between passage of time and changes in weight ratio

## 3.2 Discussion

### 3.2.1 The factor and mechanism of efflorescence

A correlation analysis on the factor of efflorescence is shown in Table 3.2.1.1. The ratio of efflorescence-affected area has a negative correlation with moisture at both 28 days and

91 days. On the other hand, the relationship between the ratio of efflorescence-affected area and water-cement ratio is positively correlated at both 28 days and 91 days.

The correlation coefficient for moisture is the highest of all the correlation coefficients measured; next comes water-cement ratio, with the third being unit cement weight. The results of a variance analysis are shown in Table 3.2.1.2.

**Table 3.2.1.1** Correlation coefficients

| | UCW | CM | W/C |
|---|---|---|---|
| 28 EAA | 0.023 | −0.357 | 0.242 |
| 91 EAA | −0.034 | −0.387 | 0.228 |

Note: 28 EAA: Ratio of eflorescence affected area at 28 days.
91 EAA: Ratio of efflorescence affected area at 91 days.
UCW: Unit cement weight

**Table 3.2.1.2** Result of variance analysis

| Item | Factor | DF | S | F-Value | PR (>F) | Decision |
|---|---|---|---|---|---|---|
| 28EAA | CM | 3 | 220.459 | 8.20 | 0.0001 | * * |
| | W/C | 2 | 81.715 | 4.56 | 0.0127 | * |
| | UCM | 2 | 35.422 | 1.98 | 0.1439 | |
| 91EAA | CM | 3 | 263.955 | 9.20 | 0.0001 | * * |
| | W/C | 2 | 90.928 | 4.75 | 0.0107 | * |
| | UCM | 2 | 22.426 | 1.17 | 0.3138 | |

Note DF: Degree of freedom, S: variance, * *: significance level of 1%, *: significance level of 5%

The coefficient of moisture has a great influence on efflorescence, and the significance level is 1%. The second greatest influence is water-cement ratio, with a significance level of 5%.

Unit cement weight has practically no influence on efflorescence-affected area, and the significance level is greater than 5%. The results of multiple linear regression analysis are shown in Table 3.2.1.3. The model obtained from the results of this multiple linear regression analysis is the following:

$$91EAA = 0.1839W/C - 0.0623CM - 2.4248 \quad \text{Eq. (3.2.1)}$$

where,

91EAA: the ratio of efflorescence-affected area at an age of 91 days
W/C: water-cement ratio
CM: coefficient of moisture

The ratio of efflorescence-affected area can be predicted well by this model, since the significance level is within 1% at an age of 91 days, because, generally, the coefficient of permeability is influenced by the water-cement ratio. The water-tightness of the concrete's surface is influenced by the early-stage curing conditions. And efflorescence is caused by movements of water in the concrete. Thus, we investigated the capillary pores in the concrete.

The relationship between ratio of efflorescence-affected area and capillary pore size is shown in Fig. 3.2.1.1. The correlation coefficient for pores of size $10^4$ (Å) is the highest of those analyzed. Capillary action occurs only with difficulty when the pores are smaller or larger than this. This result agrees with the past report which found that capillary action frequently occurred when the pores were $1.3\times10^4\sim10^5$ (Å) in size.

We investigated $10^4\sim10^5$ (Å) capillary pores further. The relationships between the total volume of $10^4\sim10^5$ (Å) pores and the coefficient of moisture and water-cement ratio are shown in Fig. 3.2.1.2. With increasing coefficient of moisture and water-cement ratio, the volume of $10^4\sim10^5$ (Å) pores fell. This agrees with the results of the efflorescence examination.

**Table 3.2.1.3** Results of multiple linear-regression analysis

| Objective variable | Independent variable | | | | | | Multiple correlation coefficient | PR (>F) |
|---|---|---|---|---|---|---|---|---|
| | W/C | | CM | | Intercept | | | |
| | Estimate | PR (>T) | Estimate | PR (>T) | Estimate | PR (>T) | | |
| 91EAA | 0.1839 | 0.0001 | −0.0623 | 0.0001 | −2.4248 | 0.3037 | 0.7733 | 0.0001 |

Note: T: T vale, F: F value

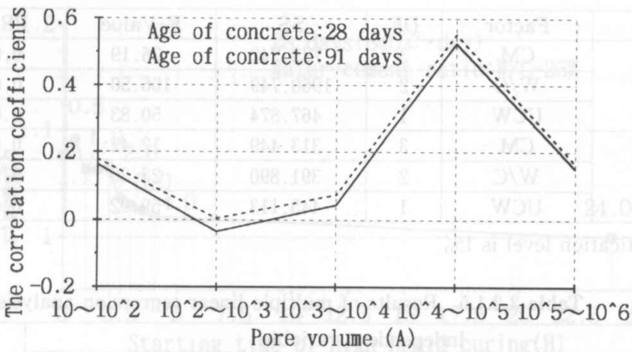


**Fig. 3.2.1.1** Relationship between pore volume and ratio of efflorescence-affected area

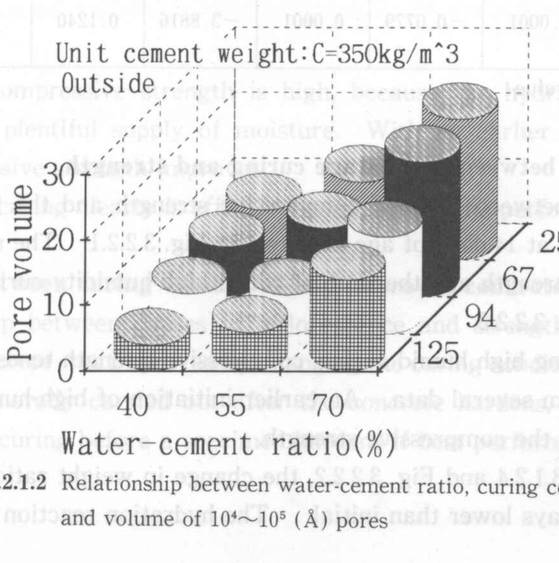


**Fig. 3.2.1.2** Relationship between water-cement ratio, curing conditions, and volume of $10^4\sim10^5$ (Å) pores

The results of a variance analysis are shown in Table 3.2.1.4. All factors influence the generation of capillary pores of size $10^4 \sim 10^5$ (Å). The significance level is 1%. Here, though, we select coefficient of moisture and water-cement ratio as factors in the multiple linear regression analysis, since these have a great influence on efflorescence, with significance levels of 1% and 5%. The results of multiple linear regression analysis are shown in Table 3.2.1.5.

The model obtained from this multiple linear regressive analysis is the following:

$$V = 0.4258W/C - 0.0779CM - 3.8816 \quad \text{Eq. (3.2.2)}$$

where,

V: volume of $10^4$ (Å) pores (at specimen surface)

W/C: water-cement ratio

CM: coefficient of moisture

The volume of $10^4 \sim 10^5$ (Å) pores should be predicted well by this model, since the significance level is within 1%.

**Table 3.2.1.4** Results of variance analysis

| Item | Factor | DF | SS | F-Value | PR:>F | Decision |
|---|---|---|---|---|---|---|
| Proe volume $10^4$Å~$10^5$Å at surface | CM | 3 | 723.242 | 26.19 | 0.0001 | ** |
| | W/C | 2 | 1960.749 | 106.50 | 0.0001 | ** |
| | UCW | 1 | 467.874 | 50.83 | 0.0001 | ** |
| Proe volume $10^4$Å~$10^5$Å at center | CM | 3 | 313.449 | 12.42 | 0.0001 | ** |
| | W/C | 2 | 391.890 | 23.30 | 0.0001 | ** |
| | UCW | 1 | 445.113 | 59.92 | 0.0001 | ** |

Note: ** : Signification level is 1%

**Table 3.2.1.5** Results of multiple linear regression analysis

| Objective variable | Independent variable | | | | | | Multiple correlation coefficient | PR (>F) |
|---|---|---|---|---|---|---|---|---|
| | W/C | | CM | | Intercept | | | |
| | Estimate | PR (>T) | Estimate | PR (>T) | Estimate | PR (>T) | | |
| Pre volume $10^4$Å~$10^5$Å at surface | 0.4258 | 0.0001 | −0.0779 | 0.0001 | −3.8816 | 0.1240 | 0.8241 | 0.0001 |

Note: T: T value, F: F value

### 3.2.2 The relationship between early-stage curing and strength

The relationship between ratio of compressive strength and the time at which high-humidity curing begins at 14 days of age is shown in Fig. 3.2.2.1. The relationship between ratio of compressive strength and the time at which high-humidity curing begins at 28 days of age is shown in Fig. 3.2.2.2.

With earlier starting high humid curing, compressive strength tends to be strong, which had been expected from several data. An earlier initiation of high-humidity curing before setting time influences the compressive strength.

Comsidering Fig. 3.1.2.4 and Fig. 3.2.2.2, the change in weight ratio after the ordinarly standard curing is always lower than initial. The hydration reaction does not proceed to completion due to a shortage of moisture. However, change in the weight ratio after high-humidity curing were nearly always greater than initial.

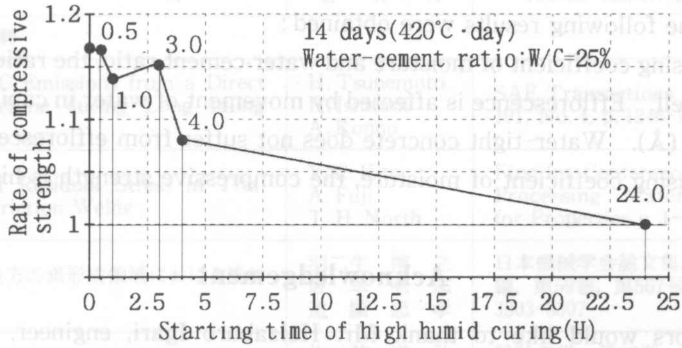


**Fig. 3.2.2.1** Relationship between initiation of curing and compressive strength ratio at 14 days of age

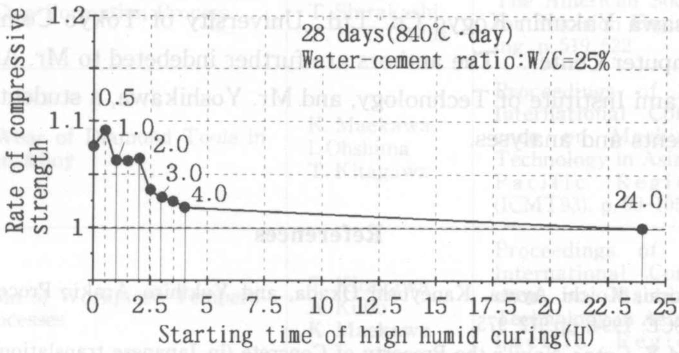


**Fig. 3.2.2.2** Relationship between initiation of curing and compressive strength ratio at 28 days of age

In this case, the compressive strength is high, because the hydration reaction goes to completion with a plentiful supply of moisture. With an earlier start to high-humidity curing, the compressive strength improves.

High-humidity curing clearly is effective in improving the performance of concrete.

### 3.3 Relationship between curing conditions and improved concrete performance

The relationship between causes of efflorescence and strength was examined. The performance of concrete was improved by changing the curing conditions in the early stages.

Wet curing is generally carried out after the concrete hardens, but it is important to implement suitable curing before a specimen hardens if best performance is to be obtained.

# 4. CONCLUSION

In this study of improvements to the aesthetic appearance and performance of concrete, factors affecting the ratio of efflorescence-affected area and compressive strength were evaluated. The following results were obtained :

(1) With increasing coefficient of moisture and water-cement ratio, the ratio of efflorescence-affected area fell. Efflorescence is affected by movement of water in capillary pores of size about $10^4 \sim 10^5$ (Å). Water-tight concrete does not suffer from efflorescence.

(2) With increasing coefficient of moisture, the compressive strength is higher.

## Acknowledgement

The authors would like to thank Mr. Heizaburo Igari, engineer, and Dr. Makoto Hirabayashi, president of Kitami Institute of Technology, Mitsuo Soken Co., Ltd., Ikeda Concrete Co., Ltd., for their guidance and encouragements. The authors are also indebted to Shinei Saiseki Kogyo Co., Ltd., Yamagami Prestress Concrete Co., Ltd., Bayer Ltd., Kao Co., Ltd., Fujisawa Yakuhin Kogyo Co., Ltd., University of Tokyo Computer Center, and Hokkaido Computer Center. The authors are further indebeted to Mr. Araki, the graduate students of Kitami Institute of Technology, and Mr. Yoshikawa, a student, for their support in the experiments and analyses.

## References

1) Hiroshi Sakurai, Koichi Ayuta, Kaneyoshi Okada, and Yukihiro Araki : Proceedings of Hokkaido Branch of JSCE, 1994, pp.972-975.
2) Y. Osaka and Y. Goto : Navil's the Preperty of Concrete (in Japanese translation), Gihodo Press, p.29, 1980.
3) JSCE : Standard Specification of Concrete for Construction, pp.84-87, 1991.
4) Peter KRESSE : Phenomenon of Efflorescence on Concerte — the Mechanism and Possibility of Preventing, Report of Bayer Ltd.