*- Technical Paper -*

# A STUDY ON THE CREEP AND SHRINKAGE OF HIGH PERFORMANCE LIGHTWEIGHT AGGREGATE CONCRETE

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ABSTRACT
The properties of creep and shrinkage are essential for appropriate evaluation of effective prestressing force of the prestressed concrete structures with consideration of the prestressing force loss caused by creep, shrinkage and relaxation. The experimental tests of creep and shrinkage for high performance light weight aggregate concrete with rapid hardening high strength cement have conducted and the results are discussed with comparison to the design codes to study such basic properties.
Keywords: high performance lightweight aggregate, creep, shrinkage, elastic modulus, compressive strength, delayed elastic strain

## 1. INTRODUCTION

The authors have been researching the lightweight aggregate concrete with low water absorption and high strength made from Huang River clay deposits in China to apply to the prestressed concrete structures, such as superstructures of bridges (Photo-1). Hereinafter "high performance lightweight aggregate" and "high performance lightweight concrete" are respectively called as "HLA" and "HLAC".

It is essential to clarify the basic properties such as elastic modulus, creep and shrinkage to apply HLAC to the prestressed concrete structures for appropriate evaluation of the prestressing force loss and estimation of the deflection. The standard specification of concrete – structural performance verification - of JSCE [1] (hereinafter called "JSCE Specification") allows to estimate the creep coefficient as 75% of that of normal concrete.

But, it is known that the property of the creep is largely influenced by the characteristic condition of the concrete, e.g. the properties of aggregate, cement, mix proportion etc. In addition, the results of creep experiments of high performance lightweight concrete are rarely reported.

That is why the authors have conducted the experimental test of creep and shrinkage of HLAC with rapid hardening cement that is widely employed to the prestressed concrete structures for the improvement of early age strength.

This paper summarizes the results of the experiments of creep and shrinkage of HLAC and gives discussion about such basic properties with comparison to that of normal concrete and conventional design codes.

## 2. BASIC PROPERTIES OF HLA AND HLAC

### 2.1 Materials

The basic properties of HLA are shown in Table-1. The experiment of HLA was performed in accordance with JIS A 5002. The cement

**Photo-1 High Performance Lightweight Aggregate**

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employed in the experiments is rapid hardening portland cement in JIS R 5210 and classified as rapid hardening high strength cement "RS" in CEB-FIB Model Code 1990 (hereinafter called "MC-90") as shown in Table-2 (i.e., the compressive strength is more than the requirement of 52.5MPa in MC-90).

The HLA with the 1.16 of absolutely dry density was only employed as coarse aggregate for the specimens, while fine aggregate comprises natural sand. The mix proportion is shown in Table-3 and other conditions are as follows.

(1) Nominal Strength: 40 N/mm$^2$
(2) Slump: 15cm
(3) Air Content: 4.5%
(4) Maximum Diameter of Coarse Aggregate: 20mm
(5) Unit Weight: 1845.5kg/m$^3$

**Table-1 Basic Properties of High Performance Lightweight Aggregate**

| | | | JIS | Results |
|---|---|---|---|---|
| Chemical Ingredient | ignition loss | % | Equal or less than 1.0 | 0.04 |
| | calcium oxide (CaO) | % | - | 8.4 |
| | sulfur trioxide ($SO_3$) | % | Equal or less than 0.5 | 0.00 |
| | chloride quantity (NaCl) | % | Equal or less than 0.01 | 0.005 |
| organic impurities | | % | lighter than standard color | lighter than standard color |
| clay clod quantity | | % | Equal or less than 1.0 | 0.02 |
| Gradation, fineness modulus | | FM | - | 6.58 |
| Water absorption | | % | - | 1.20 |
| absolutely dry density | | % | - | 1.16 |
| solid content of coarse aggregate | | % | Class A: Equal or more than 60 | 64.6 |

## 3. EXPERIMENTS OF CREEP AND SHRINKAGE OF HLAC

### 3.1 Experimental Condition

The experiments were conducted fundamentally based upon "JIS Draft" [2] for the experiment of creep and shrinkage among major specifications, ASTM C 512, RILEM CPC 12 and "JIS Draft". Each item of the experimental condition is shown in Table-4.

### 3.2 Static Elasticity Test

The static elasticity test was conducted for 2 cases for the material ages at the beginning of loading- 7days and 28days. The results are shown in Table-5 and Table-6. The unconfined compressive strength tests after 365days creep experiment were also conducted, then the both results were 61.9N/mm$^2$, i.e. 25% improvement from 7days strength. The results are summarized as follows with comparison to the elastic modulus of normal concrete specified in JSCE Specifications.

(1) The elastic modulus at the age of 7days is 69.6% of that of normal concrete that is estimated by JSCE Specifications.
(2) The elastic modulus at the age of 28days is 71.9% of that of normal concrete that is estimated by JSCE Specifications.

**Table-2 Unconfined Compressive Strength of Rapid Hardening Cement**

| Material Age | Compressive Strength (N/mm$^2$) | | | |
|---|---|---|---|---|
| | 1day | 3days | 7days | 28days |
| Strength | 28.0 | 47.0 | 58.0 | 68.0 |

**Table-3 Mix Proportion** (kg)

| Water/Cement Ratio | Cement | Water | Coarse Aggregate | Fine Aggregate | | Admixture |
|---|---|---|---|---|---|---|
| W/C | C | W | G | S1 | S2 | Sp |
| 37.5% | 440 | 165 | 416 | 567 | 254 | 3.52 |

Cement(c): Rapid Portland cement ("RS" in CEB-FIP Model Code 1990)
Coarse Aggregate(G): HLA(absolute density:1.16)
Fine Aggregate (S1) : Land Sand Produced in Hasaki, Ibaraki Pref. (Finer than S2)
Fine Aggregate (S2) : Crashed Sand Produced in Kuzuu, Tochigi Pref. (Coarser than S1)
Admixture(Sp) : High Range Super Plasticizer and Air Entrainer

**Table-4 Experimental Condition of Creep and Shrinkage**

| Items | JIS DRAFT | Experimental Condition |
|---|---|---|
| Shape of Specimens | Shape: Cylinder<br>$\phi$: More than 3 times of maximum diameter of coarse aggregate and more than 10cm<br>H: 2～4 times of Diameter ($\phi$),<br>3$\phi$ is desirable | Cylinder<br>($\phi$150×H300) |
| No. of Specimens | Creep: 2 (pcs.)<br>Shrinkage: 2 (pcs.)<br>Compressive Strength and Static Elastic Modulus: 3 (pcs.) | Creep: 2 (pcs.)×2(type)<br>Shrinkage: 2 (pcs.)<br>Compressive Strength and Static Elastic Modulus: 3 (pcs.) ×2(type) |
| Curing | Keep 24Hrs in formwork after casting,<br>Keep in the water until 7days material age,<br>Keep in the atmosphere of 20℃±1℃, R.H.65±5% | |
| | Sealed Curing | - |
| Loading intensity | 25～35% of compressive strength | Around 1/3 of compressive strength |
| Loading Precision | Keep the load within ±2% fluctuation | |
| Material Age at the Beginning of Loading | Standard: 28days | 7days, 28days |
| Measured Length of Strain | More than 3 times of maximum diameter of coarse aggregate and more than 10cm | 250mm |
| Position of Measurement | 2 points of the side of the specimen facing each other | |
| Precision of Strain Measurement | More than $10\times10^{-6}$ | More than $10\times10^{-6}$<br>(Measured by contact gauge) |
| Loading Term | Standard: 1 year | 1 year |
| Test Equipment | - | Pressure Loading Test Equipment<br>(Illustrated in Fig.-1) |

(3) These above results, around 70% of that of normal concrete, is higher than the specified value of 60% of that of normal concrete in JSCE Specifications.

(4) The unconfined compressive strength after 365days loading term is 61.9N/mm$^2$, 25% improvement from 7days material age strength.

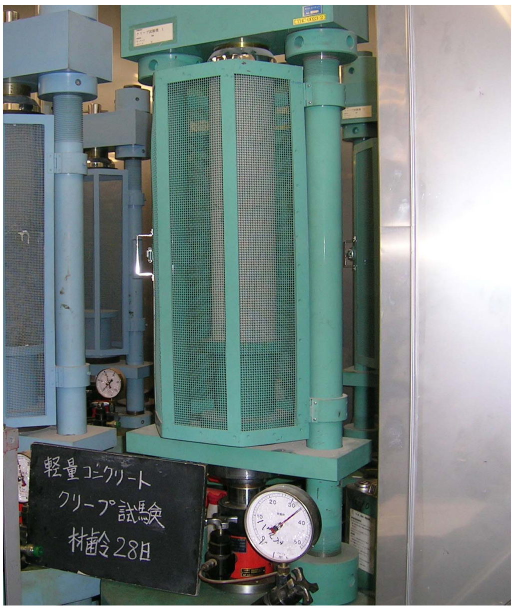


**Photo-2 Creep Experiment**

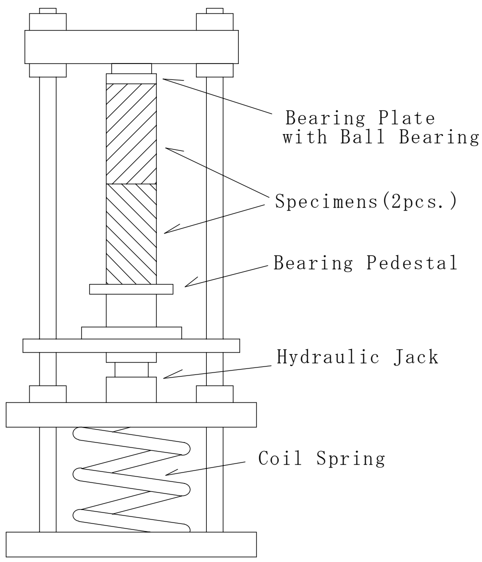


**Fig.-1 Creep Test Equipment**

3.3 Results of Creep and Shrinkage Experiments

The results of creep and shrinkage experiments at 365days loading term are shown in Table-7. The hysteresis curves of the experiments are illustrated in Fig.-2 and Fig.-3. The recovered strains immediately after unloading are also shown in Table-7. Here, the creep strain is calculated

**Table-5 Results of Static Elasticity Test（Loading Start at 7days）**

| No. of Specimens | Maximum Stress | Stress at 50×10$^{-6}$ Longitudinal Strain | Longitudinal Strain at 1/3 of Maximum Stress | Static Elastic Modulus |
|---|---|---|---|---|
| | N/mm$^2$ | N/mm$^2$ | ×10$^{-6}$ | N/mm$^2$ |
| No.1 | 50.2 | 1.2 | 716 | 2.34×10$^4$ |
| No.2 | 48.5 | 1.3 | 670 | 2.39×10$^4$ |
| No.3 | 49.5 | 1.6 | 752 | 2.13×10$^4$ |
| Average | 49.4 | 1.37 | 712.7 | 2.29×10$^4$ |

**Table-6 Results of Static Elasticity Test（Loading Start at 28days）**

| No. of Specimens | Maximum Stress | Stress at 50×10$^{-6}$ Longitudinal Strain | Longitudinal Strain at 1/3 of Maximum Stress | Static Elastic Modulus |
|---|---|---|---|---|
| | N/mm$^2$ | N/mm$^2$ | ×10$^{-6}$ | N/mm$^2$ |
| No.1 | 57.6 | 1.2 | 788 | 2.45×10$^4$ |
| No.2 | 58.3 | 1.3 | 752 | 2.54×10$^4$ |
| No.3 | 58.9 | 1.6 | 787 | 2.49×10$^4$ |
| Average | 58.3 | 1.37 | 775.7 | 2.49×10$^4$ |

from the total strain and elastic strain measured in the creep test, shrinkage strain obtained from the parallel performed shrinkage test in the same environment measured by contact gauge.

## 4. COMPARISON TO DESIGN CODE

### 4.1 Comparison to CEB-FIP Model Code 1990 for creep

Since the results should be compared with the code that can take into account the influence of the type of cement, hereinafter the results are discussed with MC-90 [3].

As the past reports, i.g. JSCE Specifications, says that the creep coefficient of lightweight aggregate ranges from 60% to 85% of that of the normal concrete, the results of the experiments also proves the conventional results. The description of JSCE Specification that allows to take 75% of the creep coefficient of normal concrete for lightweight concrete gives conservative value to calculate prestressing force loss of HLAC (Table-8).

### 4.2 Behavior after Unloading

The unloaded behavior after 365days loading was also monitored to study the behavior of the recover of the elastic strain, delayed elastic strain and flow strain. The monitoring was respectively conducted for 42days and 21days for the specimens which had been begun to load at the age of 7days and 28days. The results are illustrated in Fig.-4, 5 and shown in Table-9, 10.

The elastic strains immediately after unloading are not equal to the initial applied elastic strains, as shown in Table-7, which are

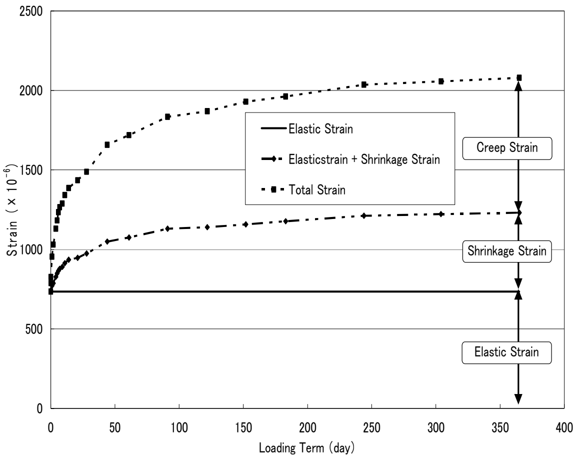


**Fig.-2 Time Dependent Strain of LHAC (Loading Start at the Age of 7days)**

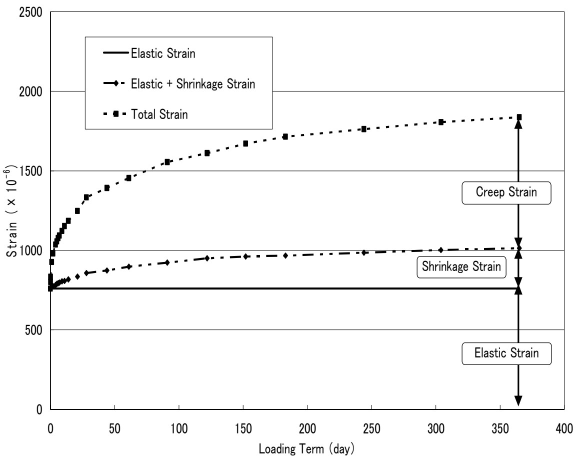


**Fig.-3 Time Dependent Strain of LHAC (Loading Start at the Age of 28days)**

86.3% and 80.7% of initial applied strains respectively for the specimens of loading age at 7days and 28days. Table-7, 9 and 10 say that it

**Table-7 Results of Creep Experiment（at 365days Loading）**

| Material age at the beginning of loading | Elastic Strain | Shrinkage Strain | Creep Strain | Total Strain | Recovered Strain Immediately After unloading |
|---|---|---|---|---|---|
| | $\times 10^{-6}$ | | | | |
| 7days | 735 | 489 | 848 | 2072 | 634 |
| 28days | 760 | 254 | 823 | 1837 | 613 |

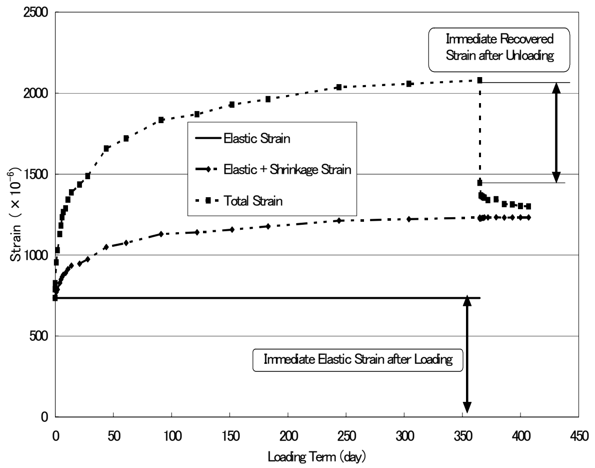


**Fig.-4 Time Dependent Strain of LHAC after Unloading (Loading Start at the Age of 7days)**

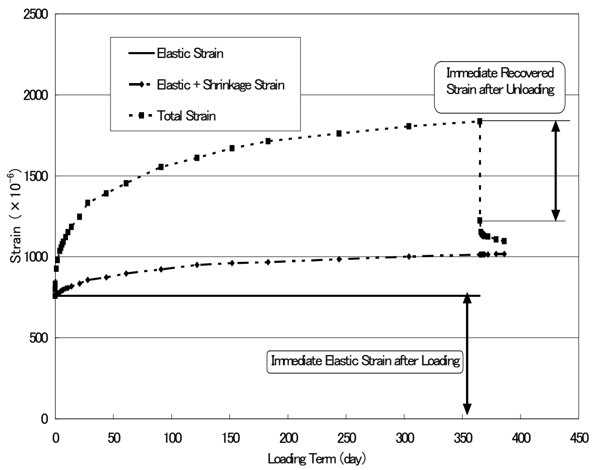


**Fig.-5 Time Dependent Strain of LHAC after Unloading (Loading Start at the Age of 28days)**

needs 2 or 3 weeks for complete recover of initial applied elastic strain.

### 4.3 Comparison to CEB-FIP Model Code 1990 for Shrinkage

The shrinkage of HLAC was also measured in the experiments in the same condition as creep test specimens except loading. The results of the shrinkage are shown in Table-11 with comparison to MC-90 that is able to take into account the

**Table-8 Comparison to MC-90**

| Material age at the start of loading | Creep coefficient obtained by Experiments | Estimation by MC-90 | Experiment ／MC-90 |
|---|---|---|---|
| 7days | 1.154 | 1.813 | 63.7% |
| 28days | 1.083 | 1.555 | 69.6% |

**Table-9 Behavior after Unloading ( Loading Start at the Age of 7days)**

| Day | Total | Shrinkage | Residual* |
|---|---|---|---|
| | $\times 10^{-6}$ | | |
| 0 | 1438 | 489 | 949 |
| 1 | 1368 | 491 | 877 |
| 2 | 1362 | 494 | 868 |
| 3 | 1357 | 495 | 862 |
| 4 | 1354 | 497 | 857 |
| 7 | 1339 | 497 | 842 |
| 14 | 1344 | 498 | 846 |
| 21 | 1314 | 496 | 818 |
| 28 | 1312 | 497 | 815 |
| 35 | 1302 | 497 | 805 |
| 42 | 1300 | 497 | 803 |

**Table-10 Behavior after Unloading ( Loading Start at the Age of 28days)**

| Day | Total | Shrinkage | Residual* |
|---|---|---|---|
| | $\times 10^{-6}$ | | |
| 0 | 1224 | 254 | 970 |
| 1 | 1153 | 254 | 899 |
| 2 | 1140 | 255 | 885 |
| 3 | 1133 | 255 | 878 |
| 4 | 1127 | 255 | 872 |
| 7 | 1125 | 255 | 870 |
| 14 | 1107 | 258 | 849 |
| 21 | 1097 | 258 | 839 |

* The residual strain contains recovering elastic strain, delayed elastic strain and flow strain.

**Table-11 Comparison to MC-90 at the Material Age of 365days**

| Material age at the beginning of shrinkage | Results of Experiments | MC-90 | Experiments / MC-90 |
|---|---|---|---|
| 7days | $496\times10^{-6}$ | $375\times10^{-6}$ | 132.3% |
| 28days | $493\times10^{-6}$ | $378\times10^{-6}$ | 130.4% |

influence of the kind of cement to calculate the shrinkage strain.

The shrinkage estimation by MC-90 gives about 30% smaller than the value obtained in the experiments. The reason of the difference is not clear at present. For one thing, the difference would be merely sprung of the variance of the property. On the other hand, autogenous shrinkage would be a reason for the difference. But, MC-90 does not refer to the autogenous shrinkage in clear sentence.

Here, if the autogenous shrinkage is estimated by Eurocode2 [4], the values are $118\times 10^{-6}$ (7days) and $119\times 10^{-6}$(28days) for each specimen. These values would be correspondent to the compensation for the difference between estimation by MC-90 and the experimental results, if autogenous shrinkage would be considered besides the "shrinkage" in MC-90, i.e. with the assumption that the "shrinkage" in MC-90 means drying shrinkage, though the contents of "shrinkage" in MC-90 is not clear.

## 5. CONCLUSIONS

Following knowledge was obtained through the experiments.

(1) The unconfined compressive strength of the specimens after 365days loading got 25% improvement compared with that of the age of 7days.

(2) The static elastic modulus of HLAC showed around 70% value of normal concrete.

(3) The creep coefficient of HLAC were respectively 63.7% (loading start at 7days material age) and 69.6%( loading start at 28days material age) of those of the normal concrete estimated by MC-90.

(4) The description to allow to assume the creep coefficient of HLCA as 75% of normal concrete by JSCE Specification gives conservative value for the estimation of prestressing force loss of prestressed concrete structures.

(5) The shrinkage strain obtained in the experiments proved larger than the estimation by MC-90 by around 30%.

(6) The recovered strains immediately after the unloading were respectively 86% (loading start at 7days material age) and 81% (loading start at 28days material age) of initial applied elastic strains.

(7) The complete recover of the initial applied elastic strain needed 2 or 3 weeks in the experiments.

(8) The HLA applied in these experiments is supposed to be suitable for prestressed concrete for the higher elastic modulus and the lower creep coefficient as lightweight aggregate that gives less deflection and prestressing force loss at least considered from the results obtained in the experiments.

## ACKNOWLEDGEMENT

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