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# Evaluation of compressive strength of concrete using small diameter core

Daisuke Yamamoto [1], Hidenori Hamada [1], Yasutaka Sagawa [1] and Toshiumi Hiromitsu [1]

[1] *Faculty of Engineering, Kyushu-university, Japan*
*744 Motooka,Nishi-ku,Fukuoka,819-0395 Japan*
*e-mail; yamamoto@doc.kyushu-u.ac.jp, h-hamada@doc.kyushu-u.ac.jp,*
*and sagawa@doc.kyushu-u.ac.jp*

## ABSTRACT

In Japan, large number of concrete structures were constructed in the high economic growth period (60’s~70’s), and they are entering a period over the designed service life, therefore the proper life cycle management for life extension of these structures is becoming necessary.

The use of small diameter core specimen for compressive strength test in conducting the maintenance procedures for existing structures is desirable technology because it gives minor damage to the structure and less risk to cut off reinforcements when the core sampling is done. However, it is known that the variance of compressive strength test result by a small diameter core becomes large and it is difficult to evaluate precisely the compressive strength. From this background, the research described in this paper focused on development of the compressive strength test method by using small diameter core.

**Keywords.** Small diameter core, Compressive strength test method, Ultimate strain value, Strain difference

## BACKGROUND

It is important to conduct a periodical inspection to maintain concrete structures for long term in good serviceability. Standard Specification for Concrete Structures by Japan Society of Civil Engineers (JSCE) describes the method of inspection and investigation, and states that concrete compressive strength by coring method is one of the important methods in the investigation. Compressive strength of the concrete is necessary to predict the penetration resistance against salt, resistance against neutralization, and planning the maintenance strategy.

Generally, compressive strength test is conducted with the core size of $\phi$100 x 200mm. However it is difficult to collect core sample of $\phi$100 x 200mm under condition where steel reinforcement is closely embedded in concrete or thickness of member less than 200mm. Moreover, the existing structures continue their service life even after the inspection, therefore investigation methods with minimum damage is required. From above reasons, several methods have been developed to estimate the compressive strength using non-destructive methods such as ultrasonic pulse velocity or Schmidt Hammer. Most of the non-destructive test results depend on the materials used and the measurement environment, thus it is difficult to estimate the exact compressive strength from non-destructive tests.

In this study, the main focus is on compressive strength test method using small-diameter core sample, which is one of the partial destructive test methods. In this research, small diameter core is defined as ϕ25 x 50mm, in order to be applied to the structure having closely embedded steel reinforcement, and to give minimum damage to the structure.

However, the maximum size of coarse aggregate in RC or PC structures is generally 20mm or 25mm. Therefore, the percentage of the area occupied by coarse aggregate against cross-sectional area of the core specimens increases. Hence, condition of coarse aggregate in the specimen will influence the compressive strength value (SHIMIZU 2008).

Several researchers have reported that compressive strength with sufficient accuracy can be obtained by average value of three small diameter cores at general strength level (KUNIMOTO 2000). By contrast, other researchers reported that to determine the compressive strength using small diameter core, much more number of specimen are required compared to ϕ100mm size core, and according to previous research result given by other researchers (*Public Works Research Center 2003, WAKABAYASHI 2002*), accuracy of the compressive strength obtained as an average of six small diameter cores is equivalent to the accuracy of the compressive strength obtained by average of three ϕ100mm size cores.

According to above background, this small core method has not been widely used, and this method needs further consideration for accuracy and variability of obtained data.

Due to this, compressive strength obtained by ϕ100mm core and small-diameter core were compared. It is well known that when variation of compressive strength value increase, average compressive strength decrease. There are many points which have not been clarified on the compressive strength test by the small diameter core. Therefore data accumulation is required. In this research, discussion on variation of experimental data, and evaluation of the compressive strength using small-diameter core are conducted.

## EXPERIMENTAL PROCEDURE

**Synopsis of specimen.** In order to discuss the variation of compressive strength test values of small-diameter core, the following Exp. I, Exp. II, and Exp. III were planed and conducted.

The “Exp.I” was performed to investigate the size effect of core specimen on the value of compressive strength. The original block was designed as mortar at w/c=0.45, with prism dimension of 100 x 300 x 300mm. Then, small diameter core were drilled in cylindrical size

**Table 1 Mix proportions (Exp. I, II, III)**

| | Mixture | Maximum size of coarse aggregate (mm) | W/B (%) | s/a (%) | Unit weight (kg/m$^3$) | | | | | AE water reducing (g/m$^3$) | AE agent (g/m$^3$) | High performance AE water reducing (g/m$^3$) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | W | C | BFS | Fine aggregate | Coarse aggregate | | | |
| Experiment I | AM | – | 45 | – | 290 | 645 | – | 1188 | – | 2016 | 2580 | – |
| Experiment II | A | 20 | 45 | 41 | 169 | 376 | – | 693 | 1127 | 1761 | 1502 | – |
| | B | 20 | 61 | 45 | 169 | 277 | – | 811 | 1107 | 866 | 1108 | – |
| Experiment III | C | 20 | 35 | 43 | 160 | 229 | 228 | 732 | 1143 | – | – | 2290 |

of ϕ25 x 50mm. The ϕ50 x 100mm and ϕ100 x 200mm, cylindrical specimens were made by casting into cylindrical mould.

In the "Exp.II", the effect of the position of coarse aggregate, and the difference of w/c on fracture behaviour of the small-diameter core under compression were studied. Concrete mixture for this experiment were w/c = 0.45 (A type), and w/c = 0.61 (B type). Original concrete block size was 300 x 500 x 300mm, and core specimens were drilled from the top surface of the concrete block.

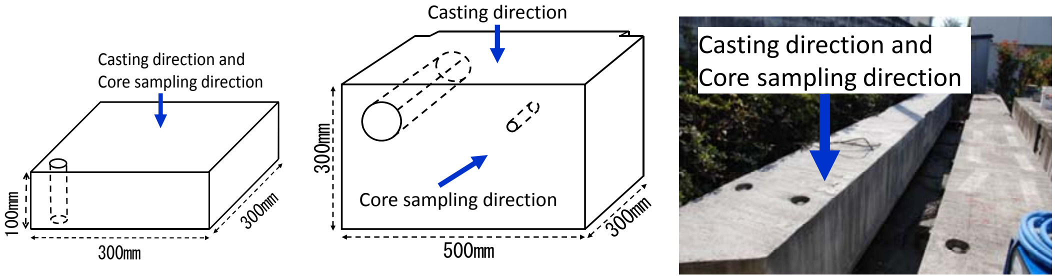
In the "Exp.III", core specimens were drilled from large scale beam specimen. In this experiment, the applicability of the small-diameter core to actual structure was investigated and evaluated.

**Table 1** shows the mix proportion of the concrete, and **Table 2** shows the materials used in this experiment. In addition, **Figure 1** shows the shape and size of the specimen. In the "Exp.I" and "Exp.II", ϕ100mm (L), ϕ50mm (M), and ϕ25mm (S) diameter core were investigated. Core specimen is notated as "(mixture) - (core size)", for example "AM-L". **Table 3** shows the factor and number of tested specimen.

**Method of experiment.** After coring the sample, a shape forming was trimmed using edge grinding machine. Compression test was conducted by applying Teflon sheet on loading surfaces. In addition, the strain and AE (Acoustic Emission) count were measured during

**Table 2 Materials**

| Material | Mixture A, AM, B | Mixture C |
|---|---|---|
| Cement | Ordinary portland cement, Density 3.16g/cm$^3$ | High early strength portland cement Density 3.14g/cm$^3$ |
| Mineral admixture | - | Ground granulated blast-furnace slag , Density: 2.91g/cm$^3$ |
| Fine aggregate | Sea sand, Density in SSD condition 2.58g/cm$^3$ | River sand, Density in SSD condition 2.55g/cm$^3$ |
| Coarse aggregate | Crusher-run coarse aggregate, Density in SSD condition 2.88g/cm$^3$ | Crusher-run coarse aggregate, Density in SSD condition 3.00g/cm$^3$ |
| AE water reducing | Lignin sulfonate acid | - |
| AE agent | Alkyl ether type | - |
| High performance AE water reducing | - | Polycarboxylate type |




Mixture AM (Exp.I)　Mixture A, B (Exp.II)　Mixture C (Exp.III) (700 x 700 x 7000mm)

**Figure 1 The shape and size of each specimen**

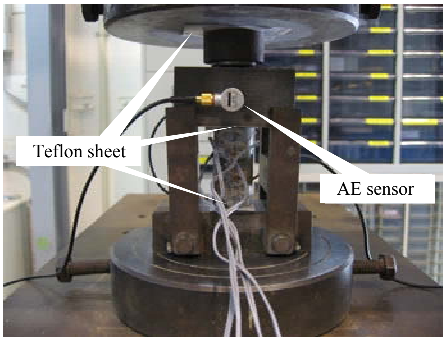
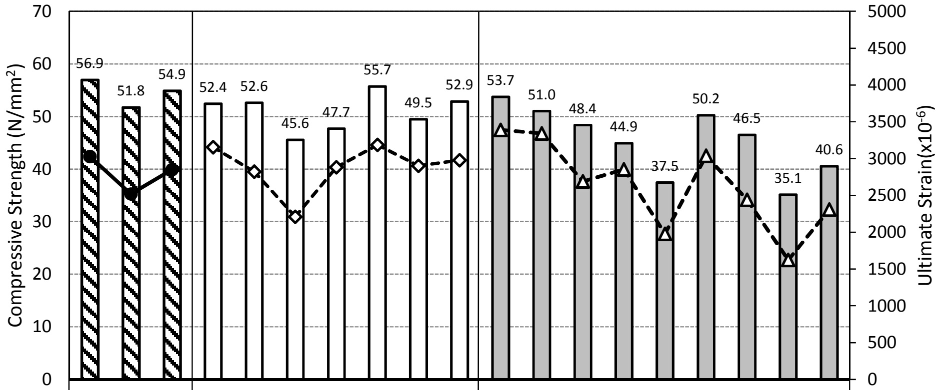



**Figure 2 Set-up of compressive strength test**

**Table 3 The factor and number of specimen**

| Exp. | Name of Specimen | Diameter of Core(mm) | Number of Specimen | Compressive Strength Average ($N/mm^2$) | Compressive Strength Variation Coefficient (%) |
|---|---|---|---|---|---|
| I | AM-L | $\phi$ 100 | 3 | 54.5 | 3.9 |
| | AM-M | $\phi$ 50 | 7 | 50.9 | 6.3 |
| | AM-S | $\phi$ 25 | 9 | 45.3 | 13.3 |
| II | A-L | $\phi$ 100 | 3 | 49.6 | 1.2 |
| | A-M | $\phi$ 50 | 3 | 49.8 | 4.1 |
| | A-S | $\phi$ 25 | 10 | 42.9 | 14.1 |
| | B-L | $\phi$ 100 | 3 | 34.8 | 5.3 |
| | B-M | $\phi$ 50 | 8 | 31.8 | 12.8 |
| | B-S | $\phi$ 25 | 10 | 32.4 | 7.5 |
| III | C-M | $\phi$ 62 | 2 | 59.0 | 14.9 |
| | C-S | $\phi$ 25 | 17 | 52.9 | 13.5 |

**Figure 3 Test results of AM series (Exp.I)**




| | AM-L | | | AM-M | | | | | | | AM-S | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No. | 1 | 2 | 3 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Strain Difference δ(%) | 6 | 57 | 3 | 3 | 22 | 63 | 18 | 8 | 27 | 16 | 30 | 17 | 24 | 44 | 4 | 32 | 81 | 82 | 39 |
| Average Conpressive Strength($N/mm^2$) | 54.5 | | | 50.9 | | | | | | | 45.3 | | | | | | | | |
| Variation Coefficient of Compressive Strength(%) | 3.9 | | | 6.3 | | | | | | | 13.3 | | | | | | | | |
| Name of Specimen | AM-L | | | AM-M | | | | | | | AM-S | | | | | | | | |

compressive strength test. A set of wire strain gauge were set on one specimen, and the average value of two strain data was taken as the strain value of the specimen. Acoustic emission (AE) count was measured using AE sensor of the resonant frequency of 140 kHz. After compressive loading, visual observation on fracture condition was conducted. **Figure 2** shows a set-up of compressive strength test. The strain difference δ at the ultimate load was defined as equation (1).

$$\delta = \frac{|\varepsilon_1 - \varepsilon_2|}{\bar{\varepsilon}} \ x\ 100\ (\%) \qquad (1)$$

Here ; $\delta$ :The strain difference (%), $\varepsilon_1$ :strain 1 (x $10^{-6}$) at ultimate load, $\varepsilon_2$ :strain 2 (x $10^{-6}$) at ultimate load, $\bar{\varepsilon}$ : average value of strain 1 and strain 2 (x $10^{-6}$) at ultimate load.

## RESULTS OF TESTING

**Effect of core size on the fracture behaviour (Exp.I)** Compressive strength test was conducted for ϕ100, ϕ50 mm cylindrical mortar specimens, and ϕ25mm core drilled mortar specimens (AM series). Test results for AM series are shown in **Figure 3**. From these results, it is clear that the smaller the core size becomes, the lower the average compressive strength becomes, and larger the variation of coefficient is. In addition, as strain difference δ becomes larger, compressive strength becomes smaller.

**Figure 4** shows the relationship between strain and cumulative AE count during compressive strength test of the specimens with small δ (strain difference). Compared with AM-M1 or AM-S2, AE cumulative count of AM-L3 increases rapidly at later stage of loading. The rapid increasing point is seen in the larger size specimen. On the other hand, this point is not clear in the smaller size core.

The same relation of AM-S5 and AM-S8, whose compressive strength is low, is shown in **Figure 5**. As seen in this figure, both strain and cumulative AE count at the ultimate stress were small, and there was no sudden strain change which is seen in AM-S2. From the observation of the fracture condition of the specimen, it was seen that the specimen is broken partially, and crack was concentrated in the part only, as shown in **Figure 6**.

As shown in **Figure 3**, the small diameter core tends to have large strain difference δ compared to the larger size core (AM-L and AM-M). **Figure 7** shows the relationship between the compressive strength and strain difference δ. From this figure, compressive strength tends to be lower when the strain difference δ is more than 40%.

**Effect of w/c and aggregate content on the fracture behaviour of small-diameter core (Exp.II)** In order to clarify the impact of the content of aggregate on fracture behaviour of small-diameter core, comparison of mortar specimen (AM) and concrete specimen (A) were performed. The test results of A series are shown in **Figure 8**. Similar to

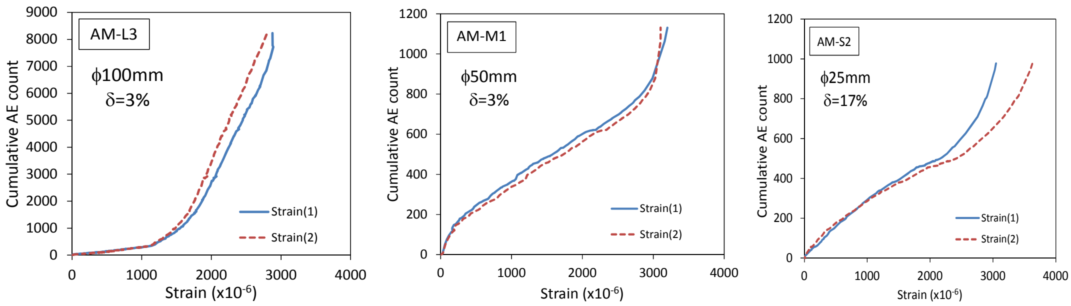



**Figure 4 Relationship between strain and cumulative AE count (AM series)**

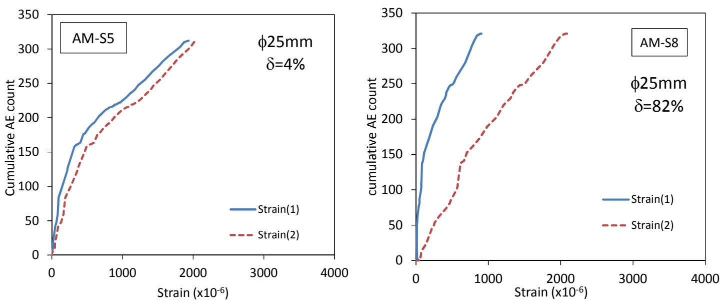



**Figure 5 Relationship between strain and cumulative AE count (AM-S8 & AM-S5)**

**Figure 6 Appearance after destruction**

AM series, results of the A series (AL, AM, AS) shows that the coefficient of variation of compressive strength is larger when the core size is smaller. In addition, the average value of the compressive strength of AL and AM is almost same but the compressive strength of AS is smaller than AL and AM. Density of AL and AM is almost same and stable however density variation of A-S is large. In the case of mortar specimen (AM-S), there was no significant density variation. Variation in the density of small-diameter core is caused by changes in the proportion of coarse aggregate volume in the core specimen. The content of coarse aggregate Rg in the concrete is calculated by Equation (2).

$$R_g = \frac{\rho_c - \rho_m}{\rho_a - \rho_m} \times 100(\%) \tag{2}$$

Here, $R_g$: Content of coarse aggregate (%), $\rho_c$: Air-dried density of concrete (g/cm$^3$), $\rho_a$: Absolute dry density of coarse aggregate (g/cm$^3$), $\rho_m$: Air-dried density of mortar (g/cm$^3$).

**Table 4** shows calculated coarse aggregate content Rg of A series (W/C=45%). From the

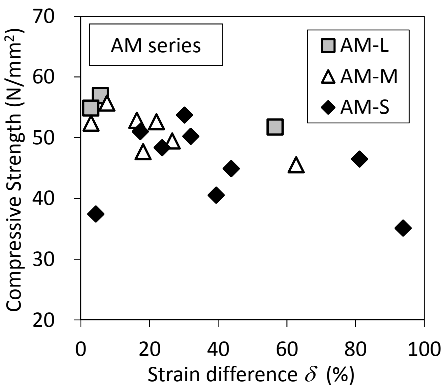
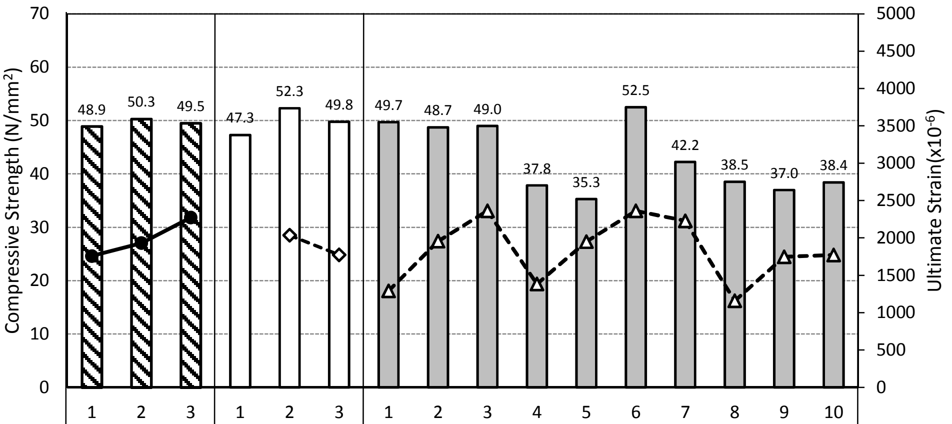



**Figure 7 Relationship between compressive strength and strain difference δ (Exp.I)**

**Figure 8 Test results of the A series (W/C=45%) (Exp.II)**




| | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Strain Difference δ(%) | 23 | 29 | 8 | - | 8 | 3 | 18 | 54 | 11 | 36 | 107 | 21 | 32 | 184 | 63 | 81 |
| Density of Specimen (g/cm³) | 2.46 | 2.42 | 2.38 | 2.37 | 2.41 | 2.41 | 2.60 | 2.43 | 2.37 | 2.43 | 2.50 | 2.39 | 2.51 | 2.36 | 2.41 | 2.36 |
| Average Conpressive Strength(N/mm²) | 49.6 | | | 49.8 | | | 42.9 | | | | | | | | | |
| Variation Coefficient of Compressive Strength(%) | 1.2 | | | 4.1 | | | 14.1 | | | | | | | | | |
| Name of Specimen | A-L | | | A-M | | | A-S | | | | | | | | | |

**Table 4 Calculated coarse aggregate content Rg (ExpII)**

| Name of Specimen | No. | Coarse Aggregate Content Rg (%) | Variation Coefficient of the Content of Coarse Aggregate (%) | Averege of Coarse Aggregate Content (%) |
|---|---|---|---|---|
| A-L | 1 | 48.8 | 4.5 | 44.5 |
| | 2 | 44.9 | | |
| | 3 | 39.9 | | |
| A-M | 1 | 37.5 | 3.1 | 41.0 |
| | 2 | 42.7 | | |
| | 3 | 42.9 | | |
| A-S | 1 | 67.5 | 10.2 | 44.4 |
| | 2 | 45.1 | | |
| | 3 | 37.5 | | |
| | 4 | 45.8 | | |
| | 5 | 36.8 | | |
| | 6 | 40.4 | | |
| | 7 | 56.3 | | |
| | 8 | 36.2 | | |
| | 9 | 42.7 | | |
| | 10 | 36.1 | | |

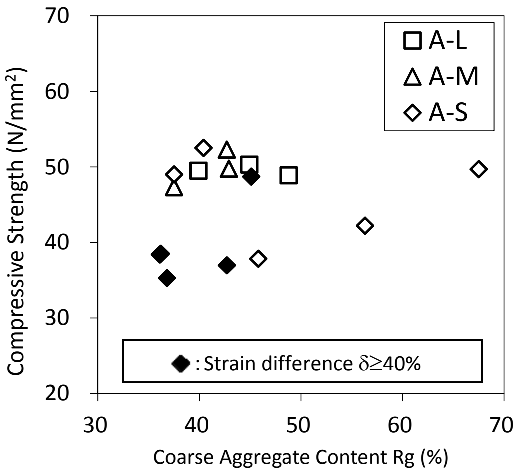
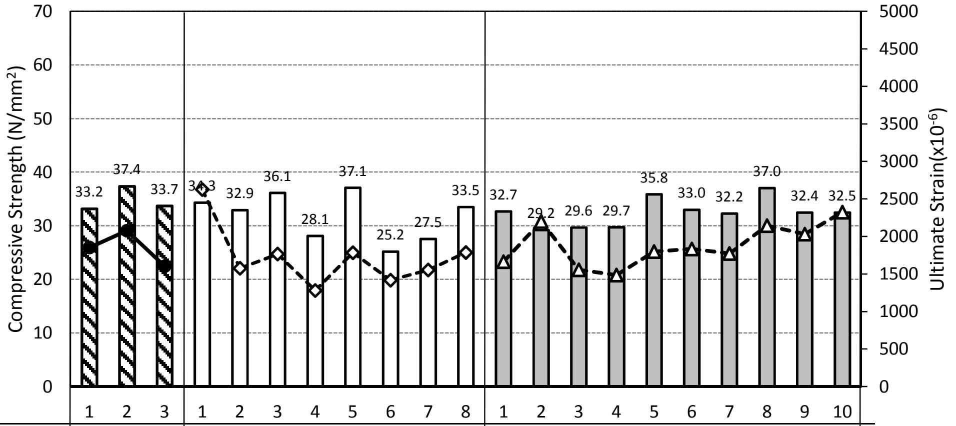



**Figure 9 Relationship between the compressive strength and coarse aggregate content $R_g$ (Exp.II)**

mix proportion of the A series, coarse aggregate content, Rg is calculated as 39.1%. The variation of the content of coarse aggregate in A-S series is larger than that of AL and AM. This is due to the ratio of coarse aggregate size to the size of the core. This indicates that content of coarse aggregate may be ranged from the extremely large to the slightly small in the small-diameter core.

**Figure 9** shows the relationship between the compressive strength and coarse aggregate content Rg. Here, the filled points in the figure show data of small-diameter core whose strain difference δ is larger than 40%. As explained above, strain difference δ tends to be large in the small-diameter core, and it causes the strength reduction. The strain differences δ of filled point are large. It means that the specimen has factors of reduction in strength. Even neglecting the filled point data, no clear relationship was observed between the content of coarse aggregate Rg and strength. Therefore, as influencing factors on compressive strength of the small-diameter core, positioning of coarse aggregate in the core may be an important.

**Figure 10 Test results of B series (W/C=61%) (Exp.II)**




| | 1 | 2 | 3 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Strain Difference δ(%) | 245 | 72 | 72 | 104 | 3 | 22 | 89 | 18 | 12 | 9 | 42 | 81 | 24 | 84 | 153 | 71 | 31 | 81 | 80 | 34 | 115 |
| Average Conpressive Strength(N/mm²) | 34.8 | | | 31.8 | | | | | | | | 32.4 | | | | | | | | | |
| Variation Coefficient of Compressive Strength(%) | 5.3 | | | 12.8 | | | | | | | | 7.5 | | | | | | | | | |
| Name of Specimen | B-L | | | B-M | | | | | | | | B-S | | | | | | | | | |

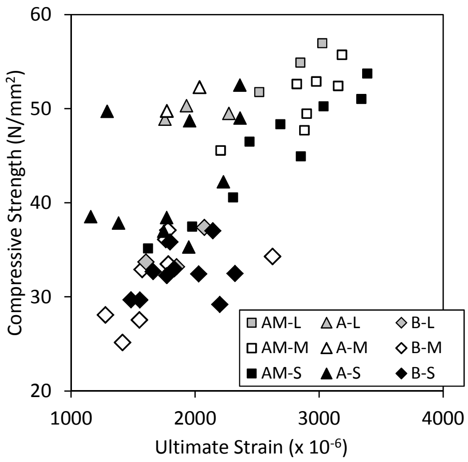
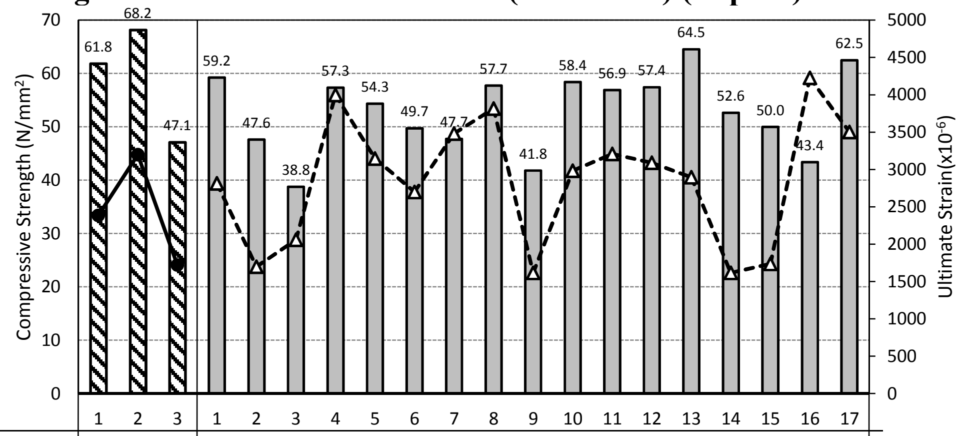



**Figure 11 Relationship between the compressive strength and ultimate strain (Exp.I, II)**

Next, the effect of differences in w/c to the compressive strength of small-diameter core was examined. **Figure 10** shows the test results of the B series, in which the w/c is different from the A series. It shows the same tendency as the A series, specimens show large strain difference δ in low compressive strength specimens. In addition, there is no significant differences in compressive strength test value between the A series and B series, however, the coefficient of variation of ϕ25mm (S) of B series is small.

**Strain at ultimate loading** **Figure 11** shows the relationship between the compressive strength and the ultimate strain of A, AM, and B series. From all data shown in this figure, it can be seen that compressive strength test values tend to be small if the ultimate strain is small. This indicates that if the local fracture progressed during the compressive strength test, compressive strength test value becomes small. In addition, the variation of ultimate strain of small-diameter core becomes larger. It is thought that if the ultimate strain of small-diameter

**Figure 12  Test results of C series (W/B=35%) (Exp.III)**




| | 1 | 2 | 3 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Strain Difference δ(%) | 15 | 3 | 105 | 14 | 1 | 6 | 54 | 9 | 5 | 48 | 33 | 26 | 8 | 0 | 34 | 47 | 22 | 37 | 158 | 1 |
| Average Compressive Strength(N/mm²) | 59.0 | | | 52.9 | | | | | | | | | | | | | | | | |
| Variation Coefficient of Compressive Strength(%) | 4.9 | | | 13.5 | | | | | | | | | | | | | | | | |
| Name of Specimen | C-M | | | C-S | | | | | | | | | | | | | | | | |

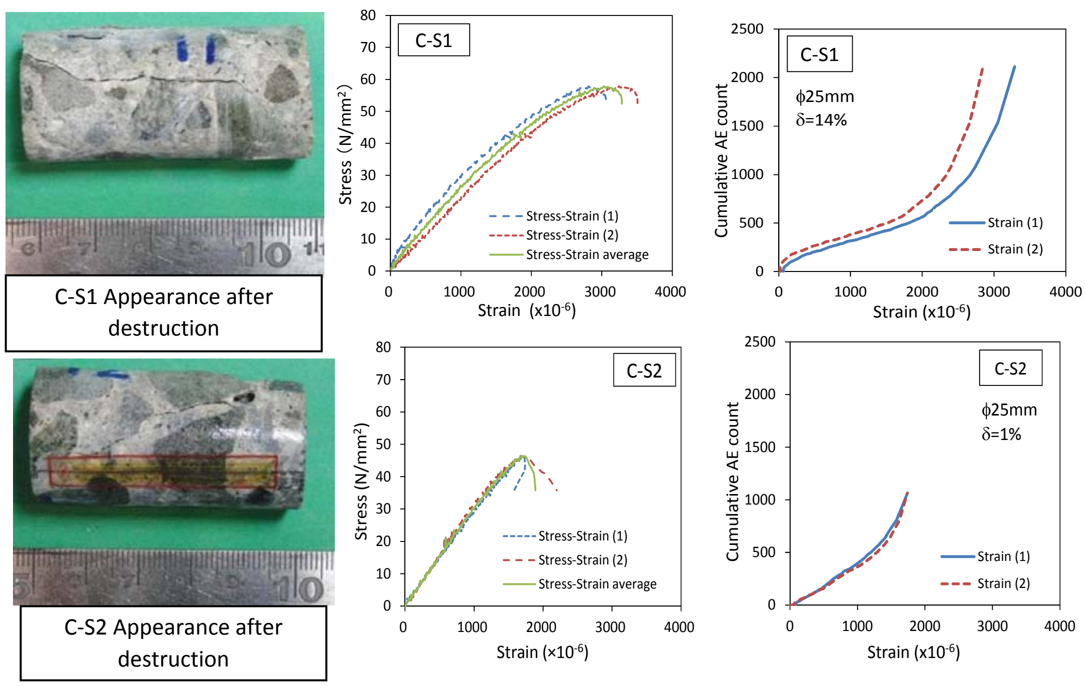



**Figure 13  Appearance and test results after destruction of small-core (C-S1, C-S2) (Exp.III)**

core is small, compressive strength test value is smaller than the original one. Therefore, the ultimate strain value can be used as a parameter of the judgment whether the test result is reliable or not.

**Application of compressive strength test method using small-diameter core to large scale beams (Exp.III)** The applicability of small-diameter core method for compressive strength test was evaluated using large size beam specimen as real structure size.

Test results of C-M (ϕ62mm) and C-S (ϕ25mm) are shown in **Figure 12**. The size of the reference specimen was ϕ62mm in this "Exp.III". Coefficient of variation of compressive strength of C-S is larger than C-M, as the test results of A and B series.

Comparing the specimen whose ultimate strain is large (C-S1) and small (C-S2) under the condition where the δ is small was carried out. **Figure 13** shows the fracture condition of the C-S1 and C-S2. As seen in this figure, C-S1 shows rapidly increasing point in cumulative AE count, and stress-strain curve increased moderately. However, In C-S2, the rapidly increasing point in cumulative AE count of is not clear, and stress-strain curve increased monotonically. Furthermore, the total cumulative AE count and the ultimate strain of C-S2 are smaller than those of C-S1. As seen in the photo, the crack of C-S1 progressed in the longitudinal direction, however crack of C-S2 progressed from the side which is a sign of local destruction.

## CONCLUSIONS

Influence of the size of specimen on the compressive strength test result with small-diameter core was investigated. Obtained results can be concluded as follows.

1) Mortar test results shows that when the core size is small, the coefficient of variation of compressive strength becomes larger. Large difference in strain at opposite sides of cylinder specimen can be seen in the compressive strength test caused by the core size difference.

2) The effect of coarse aggregate content in the specimen is small on the compressive strength result. The effect of particle size distribution of coarse aggregate in the specimen is rather large. In addition, the low compressive strength specimen tends to show the smaller ultimate strain and local destruction.

3) If the fracture pattern is partial breaking, the compressive strength value is low, and both strain and cumulative AE count at the ultimate stress are small and no sudden strain change.is seen in the relationship between strain and cumulative AE count.

4) Cause of the large variation of compressive strength of the small-diameter core is presumed to be uneven distribution of coarse aggregate in the core specimen, leading to local destruction.

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