# Inspection report for basic characteristics of high quality recycled aggregate concrete and crack property on a full scale wall specimen

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## Contents

# 1. Background and purpose of the research

## 1.1 Process of the research

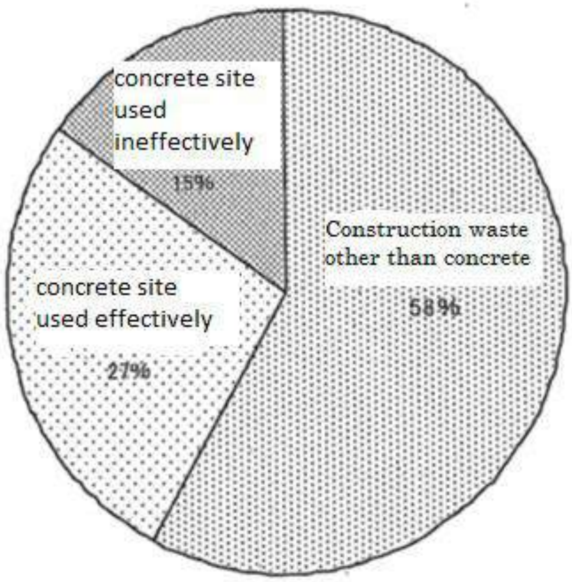
According to the Ministry of Land, Infrastructure, Transport and Tourism, the discharge amount of dismantling concrete mass was 35 million tons (2000 fiscal year) and it means 42% of the total amount of construction waste (85 million tons). However the demolished concrete mass used effectively was only 65%, moreover the construction waste, general waste and other industrial waste were mostly used for road works such as roadbed materials and even for recycling they were used for limited purpose.

Lots of concrete structures which made in the high economic growth period have come to be renewal or demolished. In the small country to reuse existing structural material without mine natural source is important direction for construction in the future.

For using demolished concrete as concrete again and secure the durability of structure, to use recycled aggregate with high quality and small water absorption is one of the way. Therefore the manufacturing technology has been proceeded to develop. However the accumulation of the data regarding characteristics of the concrete using recycled aggregate and the specification as a member is definitely less. This research tried to consider experimentally for practical use of these high quality recycled aggregate. Especially at the main part, the possibility of manufacturing high strength concrete using recycled coarse aggregate and using recycled fine aggregate which satisfied JIS standard of fine aggregate (absorption is under 4%) was examined

High quality：The definition of high quality in this research means the water absorption of recycled aggregate shall be satisfied the standard value of natural aggregate (recycled aggregate type1)

The construction waste is about 20% of total emission of the industrial waste, and the total amount from construction site is 85 million tons / year in Japan.
It means as same amount as to fill Tokyo Dome 50 times.




**Total construction waste is 85 million tons.**

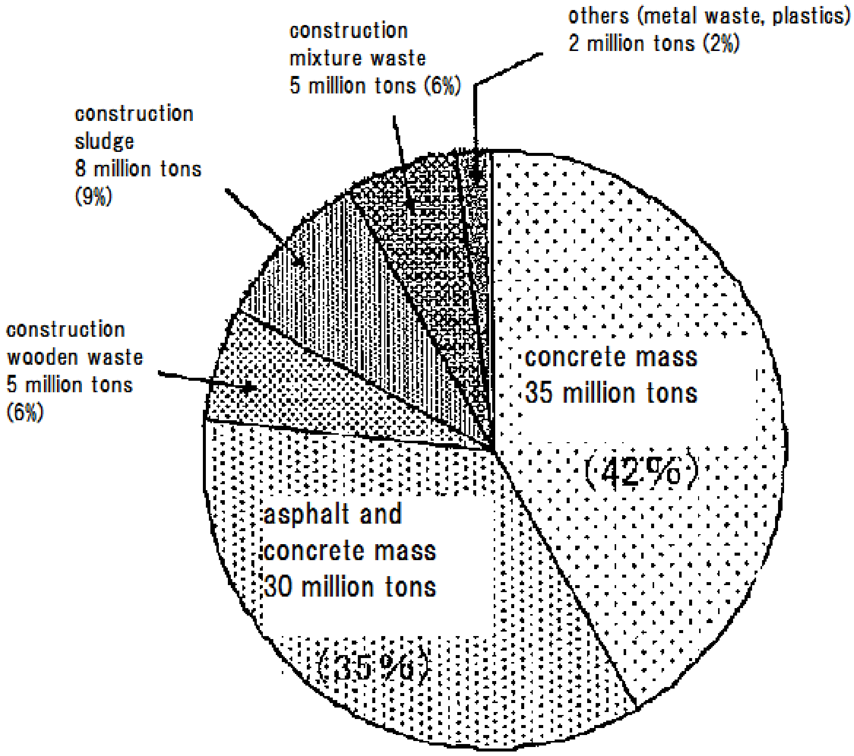



**Figure 1.1 state of construction waste** [1)]

## 2. Method of manufacturing high quality recycled aggregate

### 2.1 Manufacture high quality recycled fine aggregate

a) Apparatus for improving grain shape (Vertical rotary centrifugal lump crushing apparatus)

The recycled fine aggregate (sand) used for the experiment shall be manufactured by machine shown in figure 2.1. The material which fed from the upper side is thrown into the high speed rotor and ejected powerfully from side discharge opening by centrifugal force.

The material ejected at high speed is crushed into the outside wall of crushing room and fallen down during turning around inside of outside wall for several laps.

The ejected material receiver is consisted of gathered material called deadstock. The materials are crushed each other and rounded up in this receiver. It makes less abrasion for machine and cheaper the maintenance fee.

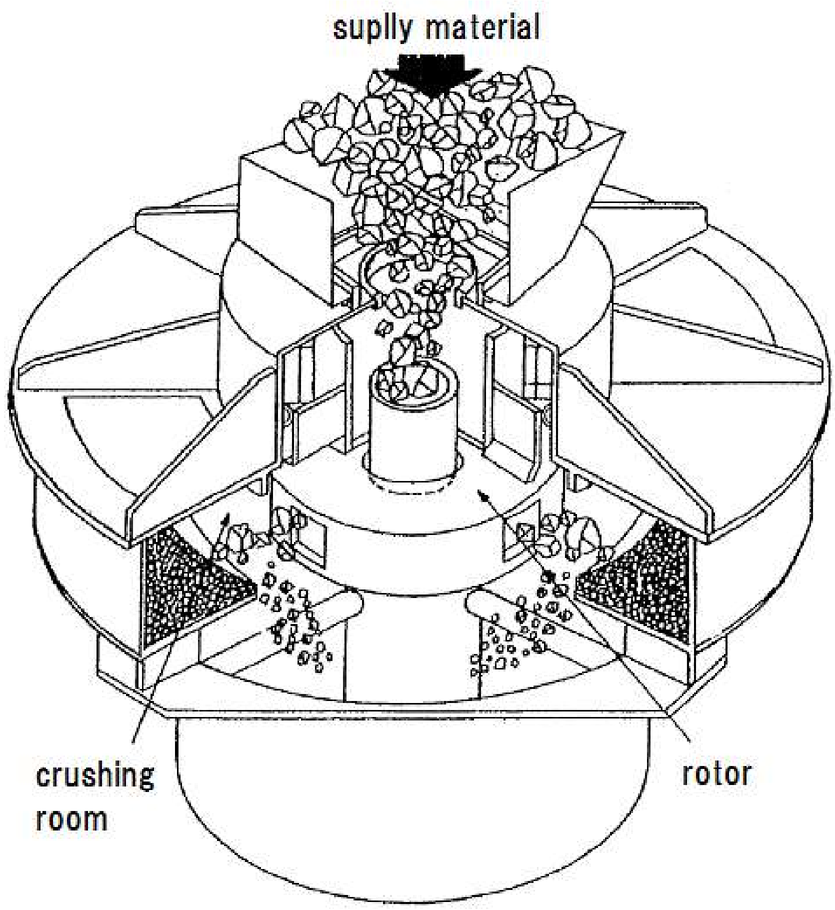



**Figure 2.1 Vertical rotary centrifugal lump crushing apparatus [2)]**

b) Manufacturing process

The air screen is used for to prevent manufacture rough grain sand of unbalanced grain size. The structure of air screen shall be shown in figure 2.2. The crushed grain is separated ① to ⑤ by wind force. In the air screen, all ⑤and most of ④ which grain sizes are 2.5 to 1.2mm are returned to BM7 for crushing again to adjust balance of grain size. Fine powder ① including finest powder is segregated by suction wind from hood. The fine powder which cannot be suctioned is fallen down and separated in high accuracy by rising wind from product chute. Moreover ①,②,③ and a part of ④ are fallen on the cut screen and sieved. The top size grains are uniformed and over size grains are returned for crushing again. As above, the air screen has three functions for grain size adjustment by wind power separation, segregation and top size cutting.

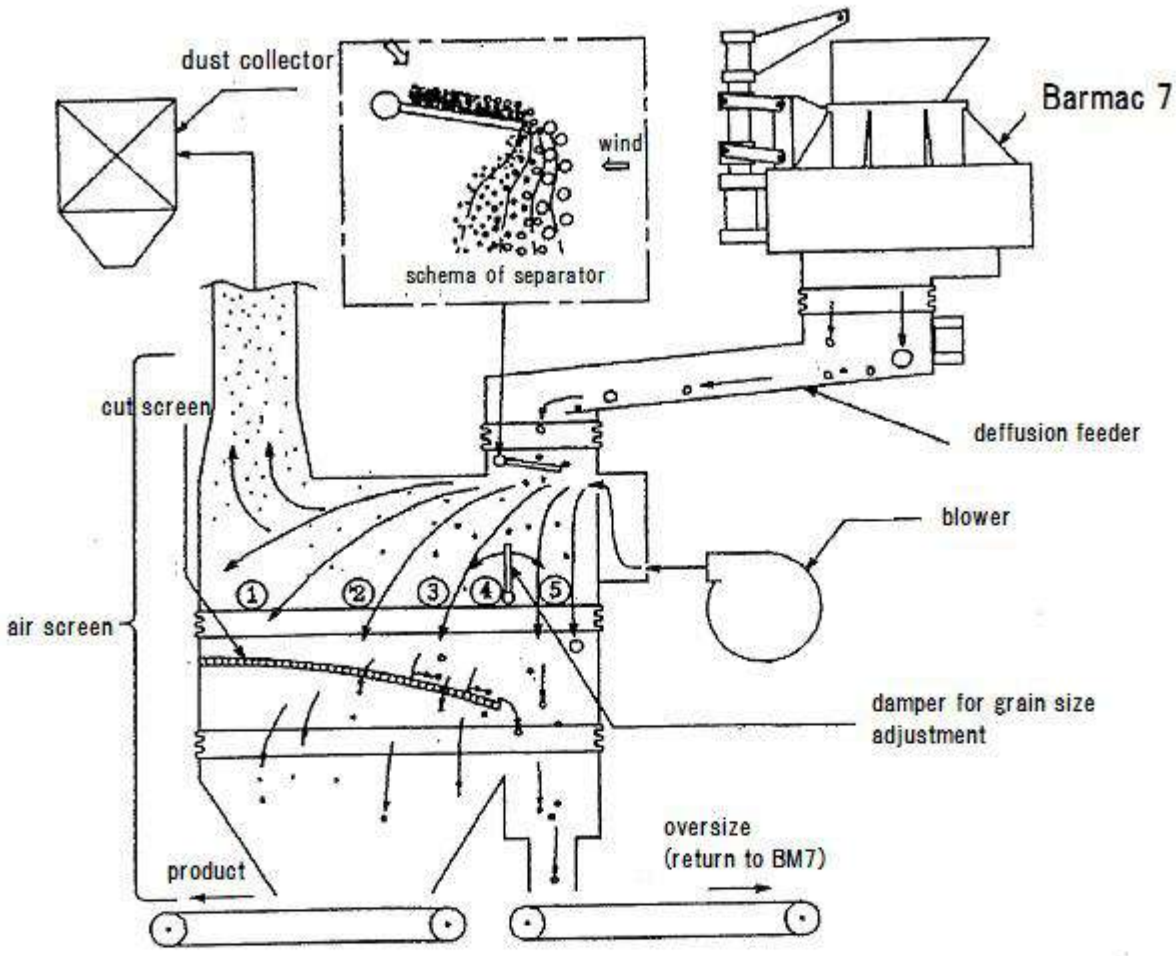



**Figure 2.2 structure of air screen**

2.2 Manufacturing high quality recycled coarse aggregate

At the recycled aggregate manufacturing plant, the process which grinded off the mortar adhered on the surface of aggregate by the wet type grinder in figure 2.3 and the process which eliminate the impurity of small specific gravity or mortar mass by means of gravity separation method in figure 2.4 are furnished. The recycled coarse aggregate manufactured in this plant is under 3% of water absorption approximately and the quality corresponds to the recycled coarse aggregate type 1.

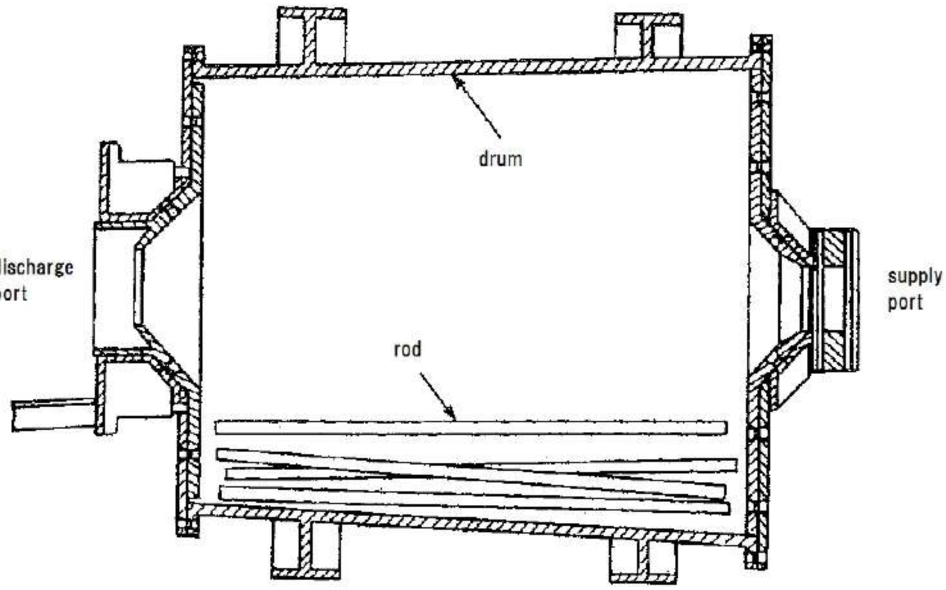



**Figure 2.3 Wet grinder** [3)]

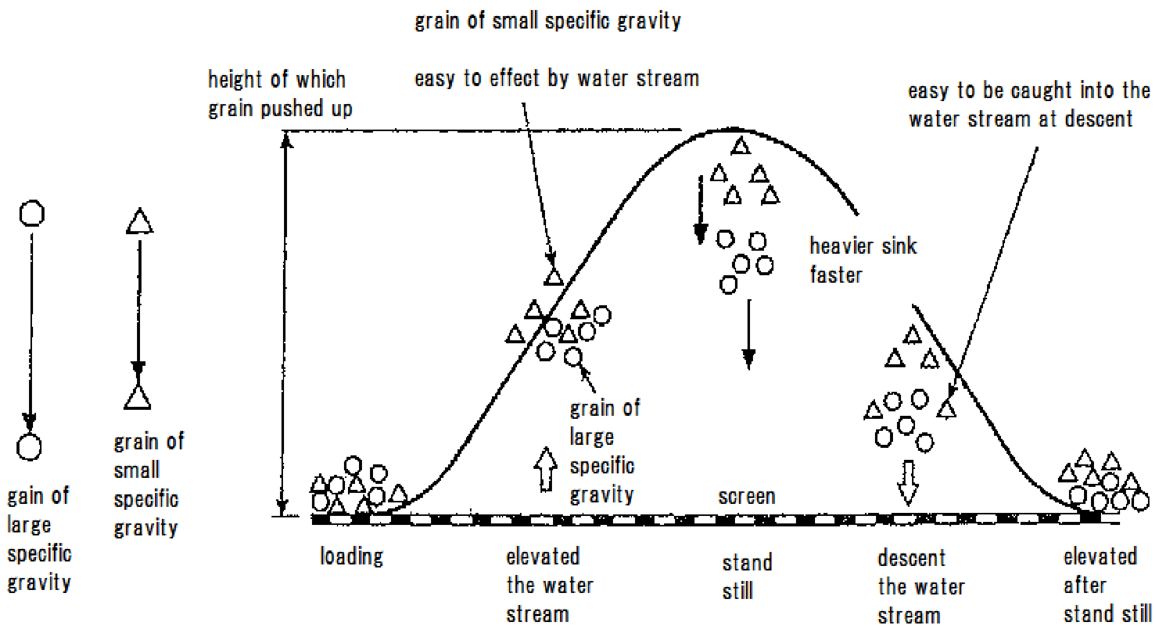



**Figure 2.4 Gravity separation method** [3)]

# 3. Basic characteristics of high quality recycled aggregate concrete

## 3.1 Purpose of experiment

The purpose of this chapter shall be to perceive the basic characteristics of the recycled aggregate which manufactured in accordance with the method shown in Chapter 2.

## 3.2 Outline of experiment

The experiment in this chapter shall be classified into two series. In Series 1, the mixture of recycled coarse aggregate and natural fine aggregate which water cement ratio shall be changed 50 to 30%, and in Series 2, when water cement ratio is 50%, the applicability of recycled fine aggregate shall be examined.

## 3.3 Series 1

In this series, confirm the basic characteristics of the concrete using recycled coarse aggregate type 1 when water cement ratio is 50 to 30% by indoor experiment, test by actual machine in the same mixture and examine the characteristics by means of to compare concrete using other types of aggregate.

### 3.3.1 Materials for use and specified mix proportion

Table 3.1 shows the materials for use for experiment and Table 3.2 and 3.3 show the specified mix proportion of experiment.

**Table 3.1 Series 1 material for use**

| | | | |
|---|---|---|---|
| cement | C | ordinary portland cement | density 3.16g/㎤<br>(made by Mitsubishi Materials Corporation) |
| fine aggregate | SN1 | mountain sand | density in surface-dry condition 2.55g/㎤<br>absorption 2.15% (mine from Hotani, Hirakata Osaka) |
| | SN2 | mountain sand and crushed sand (7 : 3) | density in surface-dry condition 2.59g/㎤<br>absorption 2.05% |
| | SR2 | recycled fine aggregate type 2 | density in surface-dry condition 2.32g/㎤<br>absorption 5.64% |
| coarse aggregate | GN1 | crushed sand | density in surface-dry condition 2.64g/㎤<br>absorption 0.64%, solid content 59% |
| | GR1 | recycled coarse aggregate type 1 | density in surface-dry condition 2.55g/㎤<br>absorption 2.95%, solid content 63% (made by Kyoboshi) |
| | GR3 | recycled coarse aggregate type 3 | density in surface-dry condition 2.46g/㎤<br>absorption 5.31% (made by Takeishi Sangyo) |
| admixture | NAE | AE and water-reducing admixture (made by NMB pozzolith No.70) | |
| | HAE | AE and high-range water-reducing admixture (Polycarboxylate-based) | |

Table 3.2 Series 1 specific mix proportion (indoor)

| symbol | bulk volume of coarse aggregate (m³/m³) | quantity of material per unit volume of concrete (kg/m³) | | | | admixture (%) | |
|---|---|---|---|---|---|---|---|
| | | water | C | SN1 | GR1 | NAE | HAE |
| SN1-GR1-50 | 0.60 | 185 | 370 | 722 | 964 | 1.0 | – |
| SN1-GR1-40 | 0.58 | 175 | 438 | 704 | 931 | – | 0.8 |
| SN1-GR1-30 | 0.56 | 170 | 567 | 645 | 900 | – | 1.4 |

Table 3.3 Series 1 specific mix proportion (actual machine)

| symbol | sand-total aggregate ratio (%) | quantity of material per unit volume of concrete (kg/m³) | | | | | | | | admixture (%) | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | water | C | SN1 | SN2 | SR2 | GN1 | GR1 | GR3 | NAE | HAE |
| Base (W/C 50) | 45.8 | 185 | 370 | 762 | — | — | — | 903 | — | — | — |
| SN1-GN1-50 | 47.4 | 180 | 360 | 799 | — | — | 918 | — | — | — | 2.84 |
| SN2-GN1-30 | 49.8 | 175 | 545 | — | 784 | — | 805 | — | — | — | 8.45 |
| SN1-GR3-50 | 41.5 | 177 | 354 | 705 | — | — | — | — | 958 | — | — |
| SR2-GR1-50 | 44.7 | 177 | 354 | — | — | 691 | — | 939 | — | 3.54 | — |
| SN1-GR1-50 | 45.8 | 185 | 370 | 762 | — | — | — | 903 | — | — | — |
| SN1-GR1-40 | 46.0 | 180 | 450 | 742 | — | — | — | 871 | — | — | — |
| SN1-GR1-30 | 44.6 | 175 | 583 | 677 | — | — | — | 841 | — | — | — |

### 3.3.2 Test items and measuring method

a) Compressive strength and Young's modulus

The test was carried out according to JIS A 1149.

b) Drying shrinkage

For measuring drying shrinkage of concrete, the embedded strain gauge was used for specimen (Ø10×20cm). Removed the formwork at 2 days of material age and cured 7 days in the 20℃ water. After that, measured drying shrinkage strain day by day in a constant temperature and humidity room (20℃ temperature, 60% humidity).

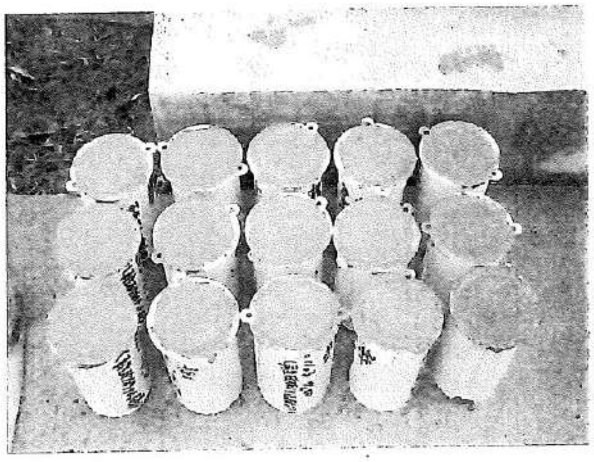
c) Neutralization

The specimen was removed the formwork at 2 days of material age and sunk 28 days in the 20℃ water and cured 28 days in a constant temperature and humidity room (20℃ temperature, 60% humidity). After that it was stocked in neutralization promotion tank

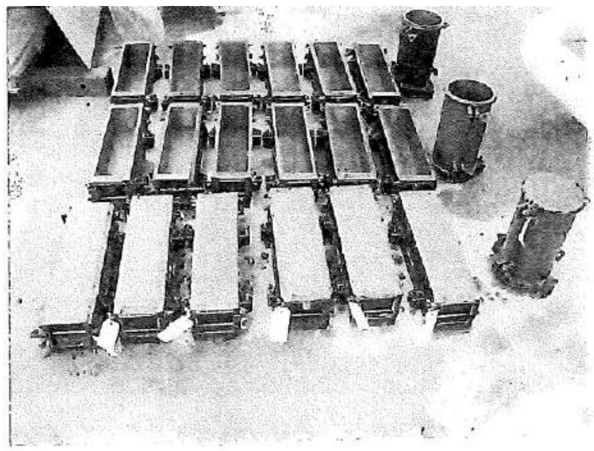
(20 ℃ temperature, 60% humidity, 10% carbon dioxide concentration) for indoor experiment, and (20℃ temperature, 60% humidity, 5% carbon dioxide concentration) for using actual machine experiment. After beginning of promotion of neutralization, in the specified material age, cut the specimen at 5cm height, sprayed 5% solution of phenolphthalein on the cutting surface and measured by caliper. And applied the epoxy resin on the cutting measuring part and stocked again.

**Photo 3.1 Specimen**

left: for strength test

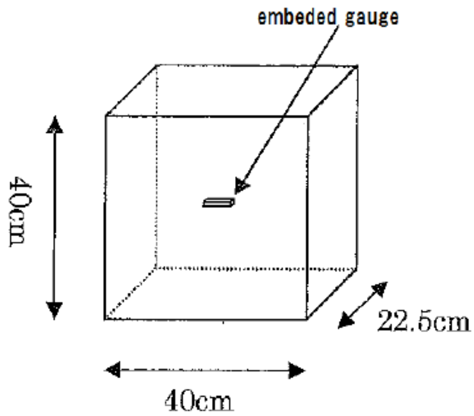


right: for promotion of neutralization

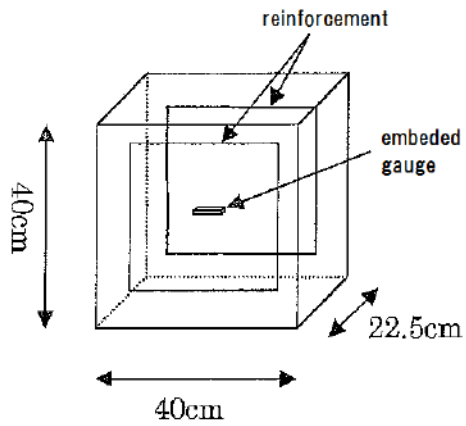


3.3.3 Shape of dummy specimen of full scale wall

Test for drying shrinkage strain using actual machine in Series 1 was carried out by dummy specimen shown in figure 3.1. In the center of each dummy specimen, embedded gauge was set.



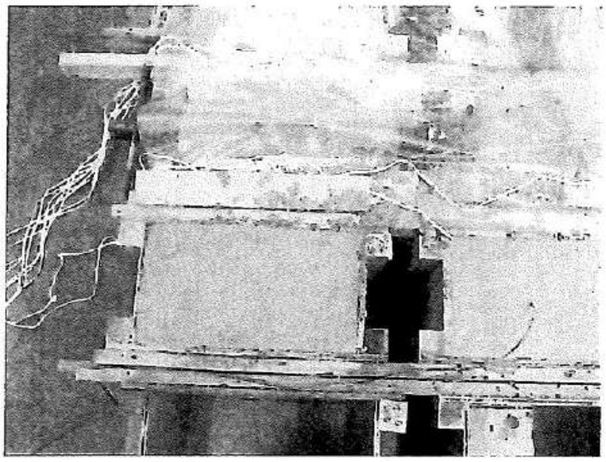

dummy wall (no reinforcement)



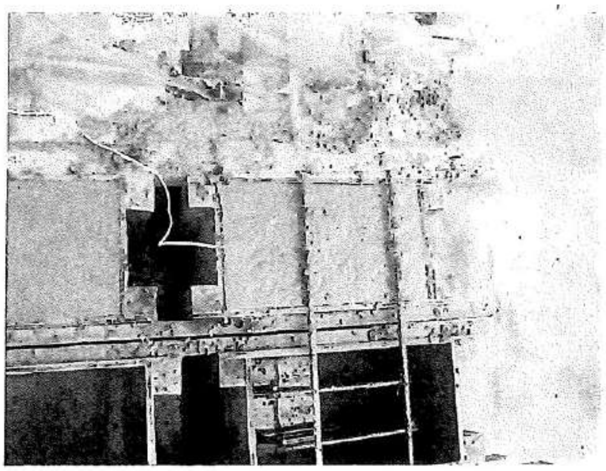

dummy wall (with reinforcement)

**Figure 3.1 Series 1 shape for dummy specimen of full scale wall**

**Photo 3.2 dummy specimen**



Series 1 (no reinforcement)



Series 1 (with reinforcement)

3.3.4 Test result

(1) Property of fresh concrete

The result of fresh concrete test shall be shown in Table 3.4 and 3.5. The changings of slump shall be shown in figure 3.2. The changings of air content shall be shown in figure 3.3. The changings for process of fresh concrete shall be shown in photo 3.3 and 3.4. According to the experiment using actual machine, the fresh property was almost as same value as the indoor experiment.

**Table 3.4 Series 1 fresh concrete test (indoor experiment)**

| symbol | time (min.) | slump (cm) | flow (cm × cm) | air content (%) |
|---|---|---|---|---|
| SN1-GR1-50 | 0 | 19.5 | — | 5.7 |
| | 30 | 12.0 | — | 5.9 |
| | 60 | 8.5 | — | 4.2 |
| SN1-GR1-40 | 0 | 24.0 | 37.0 × 36.0 | 4.8 |
| | 30 | 23.0 | 37.5 × 38.0 | 4.0 |
| | 60 | 22.0 | 31.0 × 31.0 | 3.9 |
| | 90 | 21.5 | 27.0 × 38.0 | 3.4 |
| SN1-GR1-30 | 0 | 25.0 | 39.5 × 41.0 | 4.0 |
| | 30 | 24.0 | 43.0 × 40.0 | 4.5 |
| | 60 | 23.5 | 35.0 × 36.0 | 3.6 |
| | 90 | 16.5 | 26.0 × 25.0 | 3.5 |

Table 3.5 Series 1 fresh concrete test (using actual machine)

| symbol | slump | flow | air content | concrete temperature |
|---|---|---|---|---|
| | (cm) | (cm × cm) | (%) | (%) |
| SN1-GN1-50 | 12.0 | — | 4.1 | 17.0 |
| SN2-GN1-30 | — | 61.0 × 65.0 | 5.4 | 18.0 |
| SN1-GR3-50 | 16.0 | 25.5 × 26.0 | 4.9 | 12.0 |
| SR2-GR1-50 | — | — | — | — |
| SN1-GR1-50 | 11.0 | — | 4.9 | 17.0 |
| SN1-GR1-40 | 19.5 | 31.5 × 32.5 | 5.1 | 16.5 |
| SN1-GR1-30 | 24.5 | 45.0 × 39.5 | 4.9 | 17.0 |

According to figure 3.2, the slump of concrete was in good condition just after mixing (photo 3.3 and 3.4), however at W/C 50%, due to using air-entraining and water-reducing admixture, the slump became lower relatively. While the slump using air-entraining and high-range water-reducing admixture at W/C 40 or 30% was in good condition until 60 minutes after mixing. It shall be judged as useful enough to supply fresh concrete. Moreover the result of air content (figure 3.3) shall be judged as well.

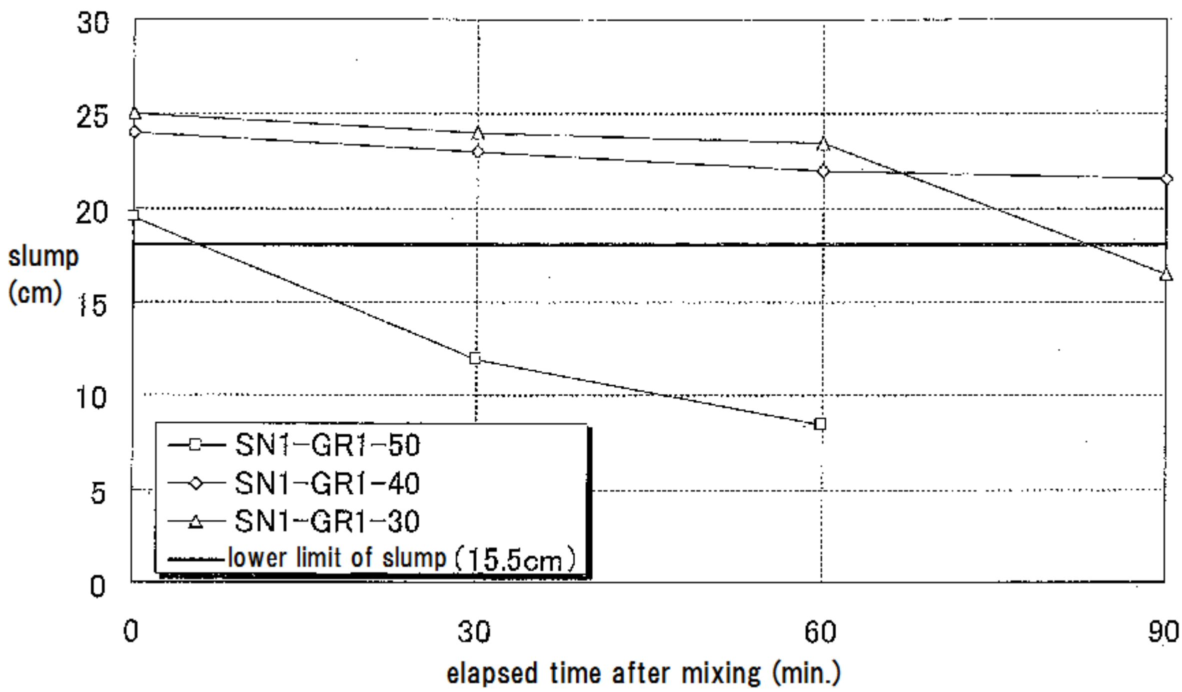



Figure 3.2 Series 1 Slump (indoor experiment)

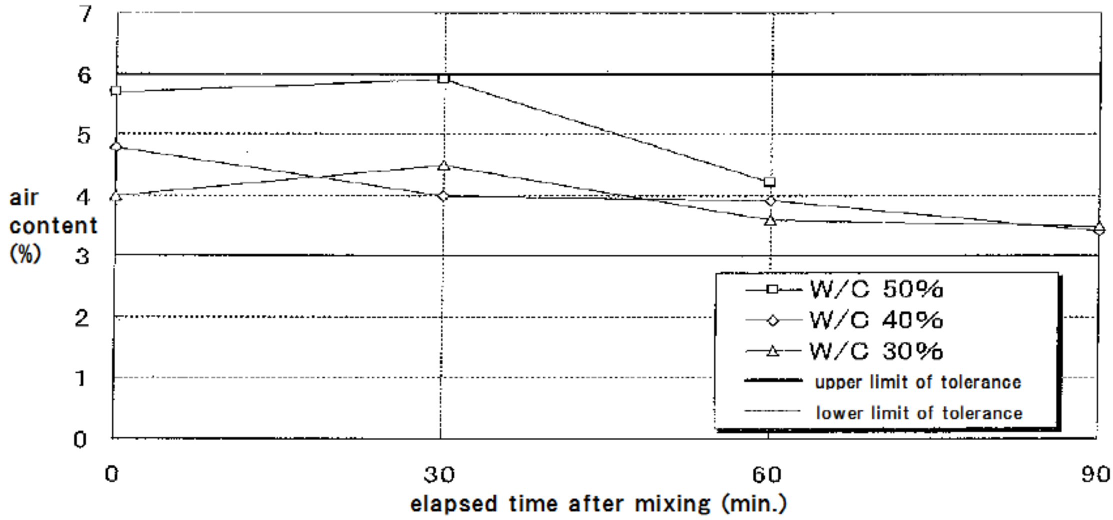
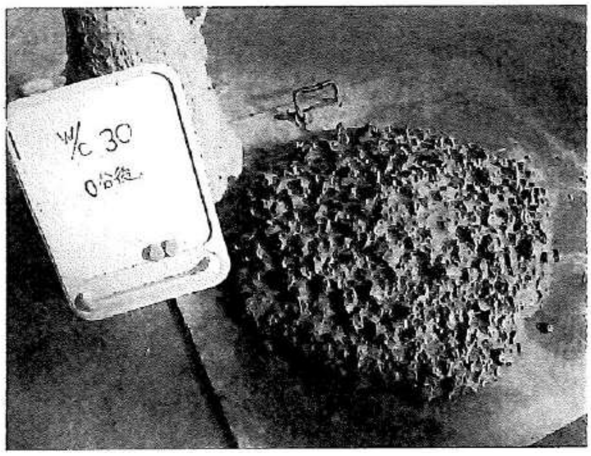
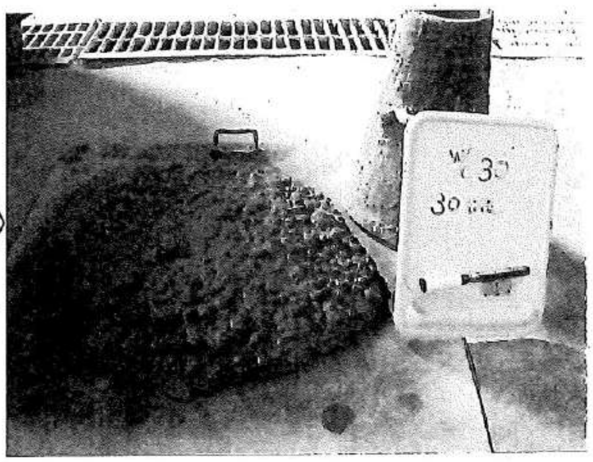



**Figure 3.3 Series 1 Air content (indoor experiment)**

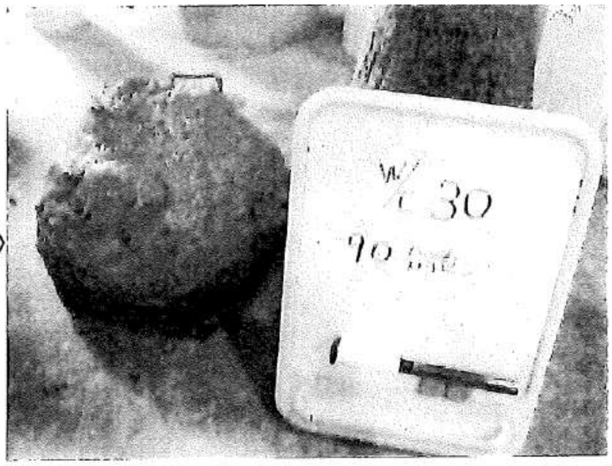



W/C 30% (0 min.)



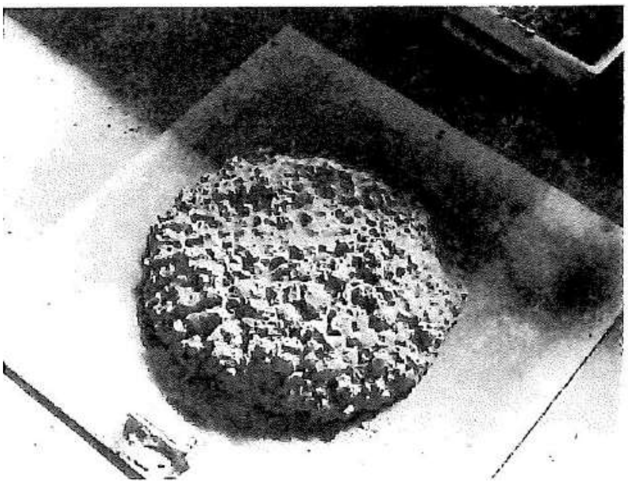
W/C 30% (30 min.)


W/C 30% (60 min.)

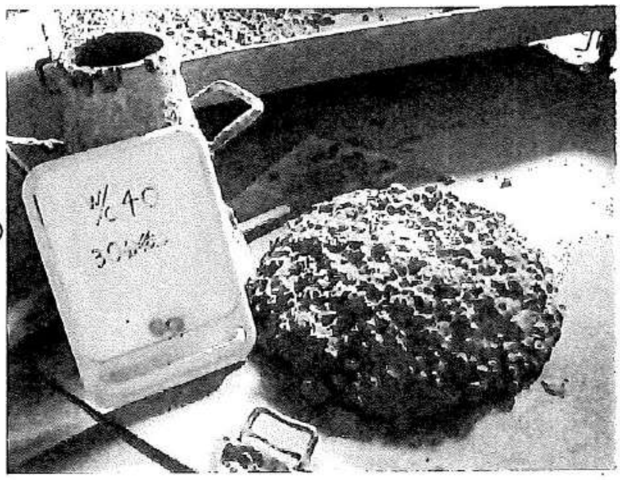



W/C 30% (90 min.)

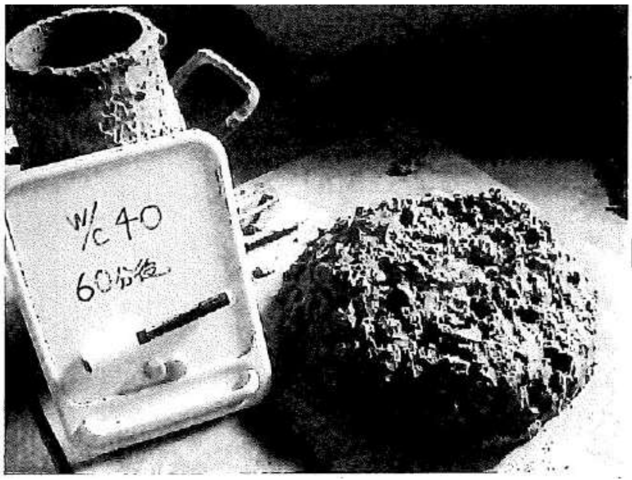
**Photo 3.3 Series 1 (indoor experiment)**



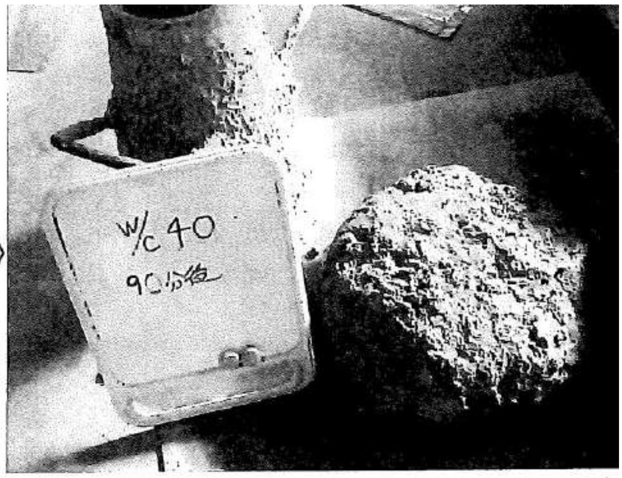
W/C 40% (0 min.)




W/C 40% (30 min.)

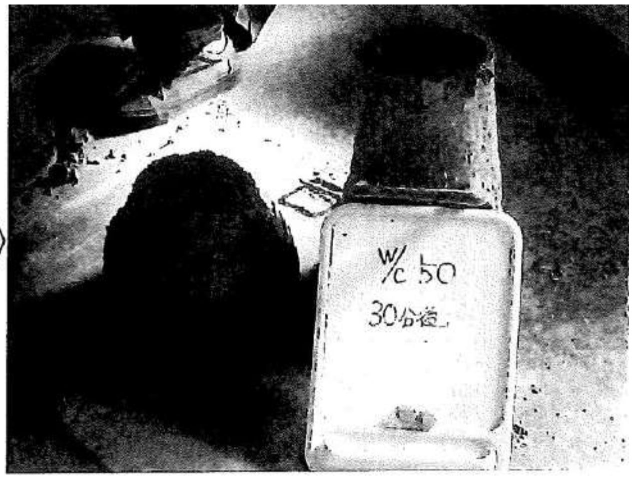



W/C 40% (60 min.)




W/C 40% (90 min.)

W/C 50% (0 min.)




W/C 50% (30 min.)

**Photo 3.4 Series 1 (indoor experiment)**

(2) Characteristics of compressive strength

The test result of the compressive strength for Series 1 shall be shown in Table 3.6.

**Table 3.6 Series 1 compressive strength**

| | experiment | symbol | cure condition | compressive strength (N/mm2 ) | | |
|---|---|---|---|---|---|---|
| | | | | 7days | 28days | 91days |
| Series 1 | indoor | SN1-GR1-50 | standard in the water | 29.5 | 34.8 | 41.6 |
| | | SN1-GR1-40 | standard in the water | 40.7 | 50.9 | 56.4 |
| | | SN1-GR1-30 | standard in the water | 59.1 | 60.5 | 71.0 |
| | using actual machine | SN1-GN1-50 | standard in the water | — | 37.0 | — |
| | | | onsite in the air | 24.0 | 33.9 | 35.0 |
| | | | onsite in the water | — | 34.9 | — |
| | | SN2-GN1-30 | standard in the water | — | 61.6 | — |
| | | | onsite in the air | 52.5 | 64.3 | 69.2 |
| | | | onsite in the water | — | 59.0 | — |
| | | SN1-GR3-50 | standard in the water | — | 28.7 | — |
| | | | onsite in the air | — | 29.7 | 33.3 |
| | | | onsite in the water | — | 28.1 | — |
| | | SR2-GR1-50 | standard in the water | — | 28.1 | — |
| | | | onsite in the air | — | 28.0 | 32.2 |
| | | | onsite in the water | — | 27.6 | — |
| | | SN1-GR1-50 | standard in the water | — | 30.3 | 30.9 |
| | | | onsite in the air | 19.0 | 28.9 | — |
| | | | onsite in the water | — | 29.1 | — |
| | | SN1-GR1-40 | standard in the water | — | 38.9 | — |
| | | | onsite in the air | 29.0 | 38.9 | 43.5 |
| | | | onsite in the water | — | 37.6 | — |
| | | SN1-GR1-30 | standard in the water | — | 48.1 | — |
| | | | onsite in the air | 38.8 | 44.6 | 50.5 |
| | | | onsite in the water | — | 44.7 | — |

a) Influence of water cement ratio at indoor mixing

The compressive strength at indoor mixing shall be shown in figure 3.4.

For recycled coarse aggregate concrete, if lower the water-cement ratio, the compressive strength is higher as normal weight concrete. The compressive strength of recycled coarse aggregate concrete at W/C 30% in indoor experiment where materials are well managed shall be over 60N/㎟ for 28 days of material age, over 70N/㎟ for 91 days of material age.

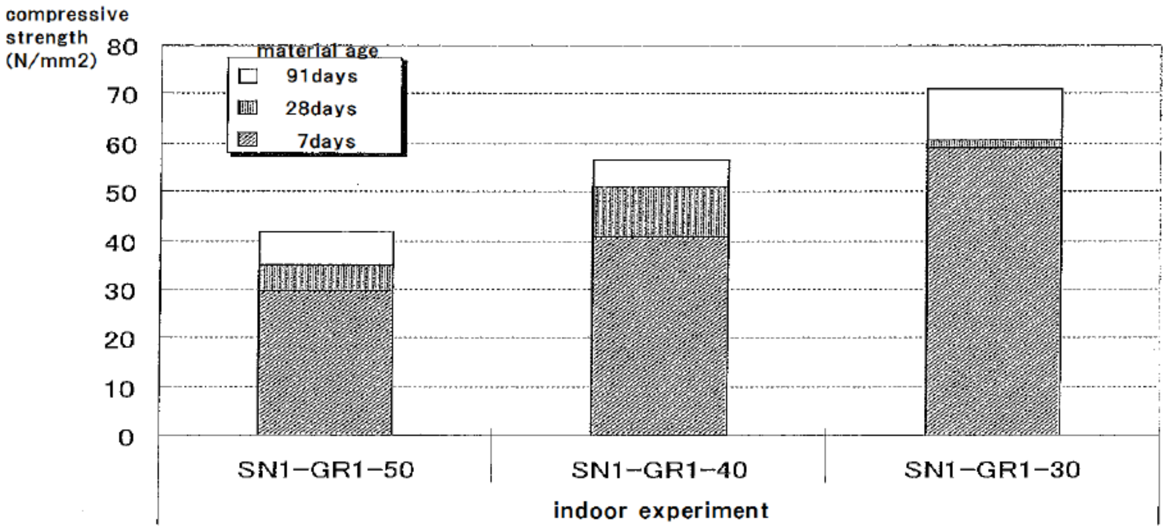



**Figure 3.4 compressive strength at indoor experiment**

b) Influence of aggregate type by mixing of actual machine

The compressive strength using each aggregate at W/C 50% shall be shown in figure 3.5. The compressive strength for concrete using natural aggregate which material age is 28days is the strongest and none of big differences are found in the others. It shall be almost the same result even in the different curing method.

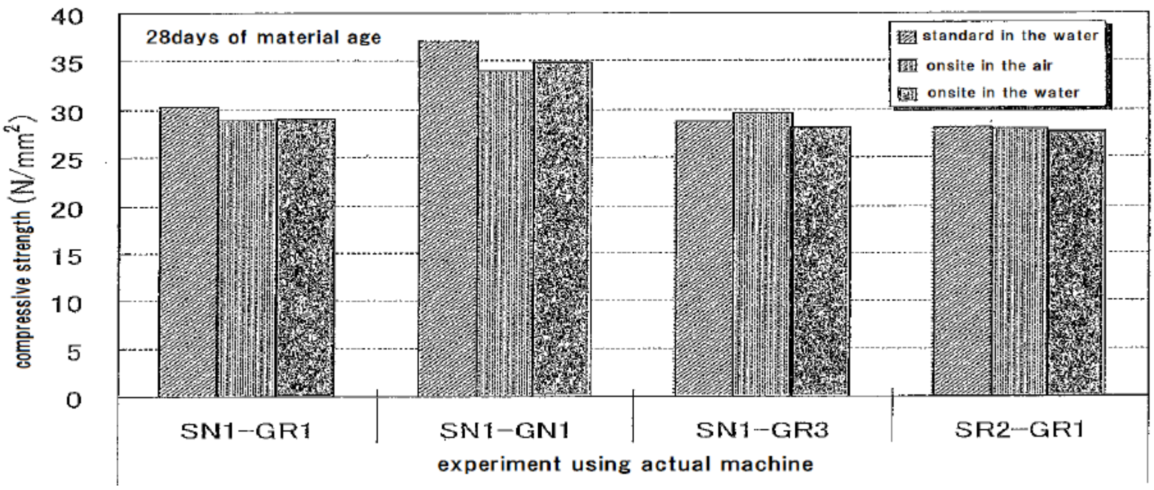



**Figure 3.5 Influence of each aggregate when W/C 50%**

c) Influence of water cement ratio

The figure 3.6 shows the comparison for the result of indoor experiment and using actual machine experiment according to the mixture of 28 days material age ordinary fine aggregate and recycled coarse aggregate type 1. According to the result of both experiment, if the water cement ratio is smaller, the compressive strength becomes stronger however most of the result by using actual machine is in lower value such as approximately 10N/㎟ lower at W/C 30%. Moreover the compressive strength of recycled coarse aggregate concrete for using actual machine, it is approximately 13 N/㎟ lower at W/C 30% and approximately 7N/㎟ lower at W/C 50% compared to natural aggregate concrete. It is believed that the reason for the lower value by using actual machine is the failure of management for materials. According to the result of indoor experiment, it seems that the manufacturing high strength concrete as same level as normal-weight concrete by using recycled coarse aggregate type 1 is sufficiently possible however if using actual machine and obtaining same ability, it must be important to manage the surface water of aggregate and unit water amount as concrete.

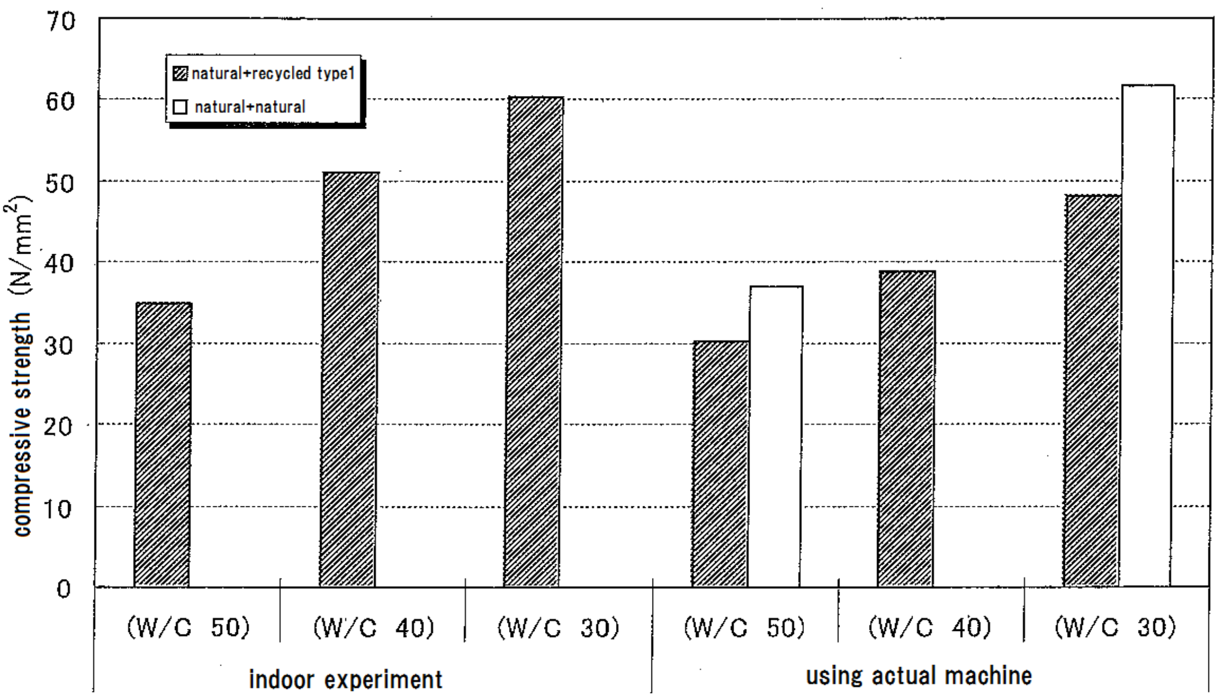



**Figure 3.6 influence of water-cement ratio**

(3) Drying shrinkage

The changing for drying shrinkage of concrete shall be shown in figure 3.7. When the value of water-cement ratio is low, the strain of drying shrinkage becomes smaller even for the recycled coarse aggregate concrete (Series 1). The strain of drying shrinkage at W/C 50% of 140 days material age is $600\times10^{-6}$ and $100\times10^{-6}$ smaller at W/C 40%, another $100\times10^{-6}$ smaller at W/C 30% approximately. However it must be considered that the strain of self-shrinkage of these high strength concrete shall be big.

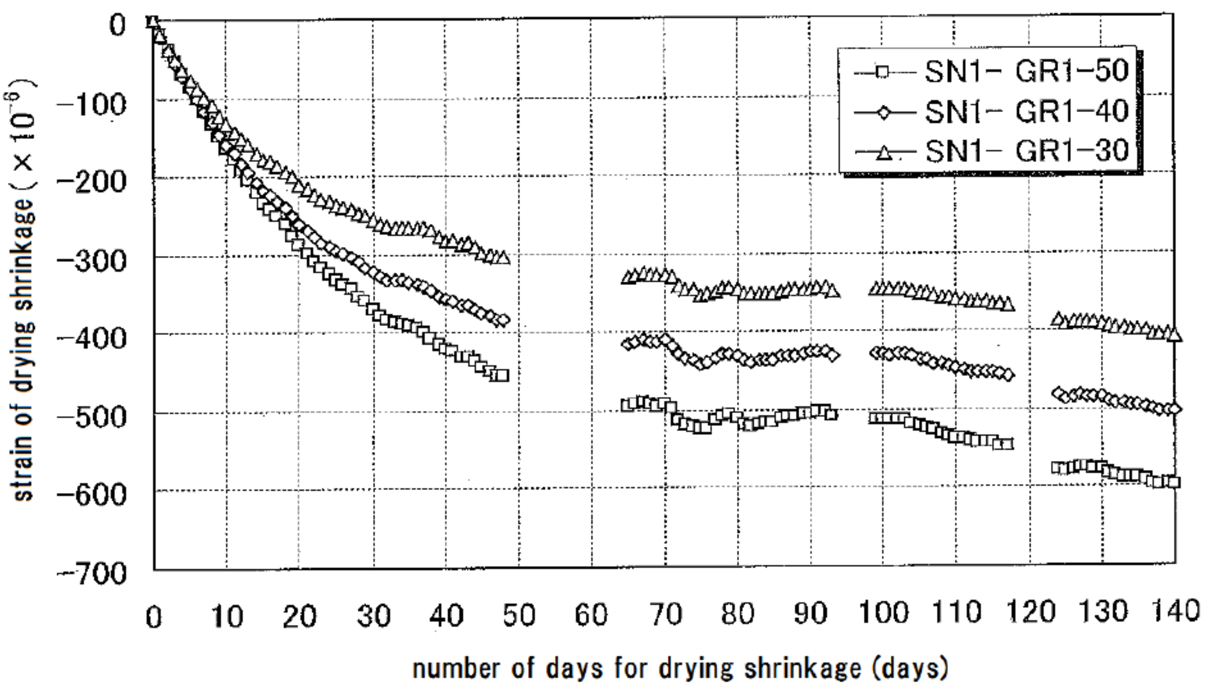



**Figure 3.7 Series 1 (indoor experiment) strain of drying shrinkage**

(4) Neutralization

The result of indoor experiment shall be shown in Table 3.7 and figure 3.8, and using actual machine shall be shown in Table 3.8 and figure 3.9. For recycled coarse aggregate concrete, the neutralization is not proceeded under the low water-cement ratio (30%) as well as in the experiment using actual machine. The neutralization test for concrete by using this actual machine shall be in accordance with JIS standard. The neutralization depth of concrete using recycled aggregate at W/C 50 % is a little deeper than the concrete using natural aggregate, however all the result is satisfied the standard value 25mm in the guideline for manufacture high durability reinforced concrete.

**Table 3.7 Series 1 (indoor experiment) neutralization depth**

| Series1 | symbol | material age (month) | | | |
|---|---|---|---|---|---|
| | | 0 | 1 | 3 | 6 |
| indoor | SN1−GR1−50 | 0 | 7.82 | 10.93 | 13.73 |
| | SN1−GR1−40 | 0 | 1.00 | 3.06 | 4.68 |
| | SN1−GR1−30 | 0 | 0 | 0 | 0 |

**Table 3.8 Series 1 (using actual machine) neutralization depth**

| Series1 | symbol | material age (day) | | | | |
|---|---|---|---|---|---|---|
| | | 0 | 28 | 56 | 91 | 182 |
| actual machine | SN1−GR1−50 | 0 | 8.6 | 12.5 | 14.6 | 20.6 |
| | SN1−GR1−40 | 0 | 3.7 | 5.4 | 6.7 | 9.5 |
| | SN1−GR1−30 | 0 | 0 | 0 | 0 | 1.0 |
| | SN1−GR3−50 | 0 | 9.5 | 13.5 | 16.2 | 20.6 |
| | SR2−GR1−50 | 0 | 8.6 | 12.5 | 14.6 | 20.2 |
| | SN1−GN1−50 | 0 | 8.2 | 10.8 | 12.8 | 16.7 |
| | SN2−GN1−30 | 0 | 0 | 0 | 0 | 0 |

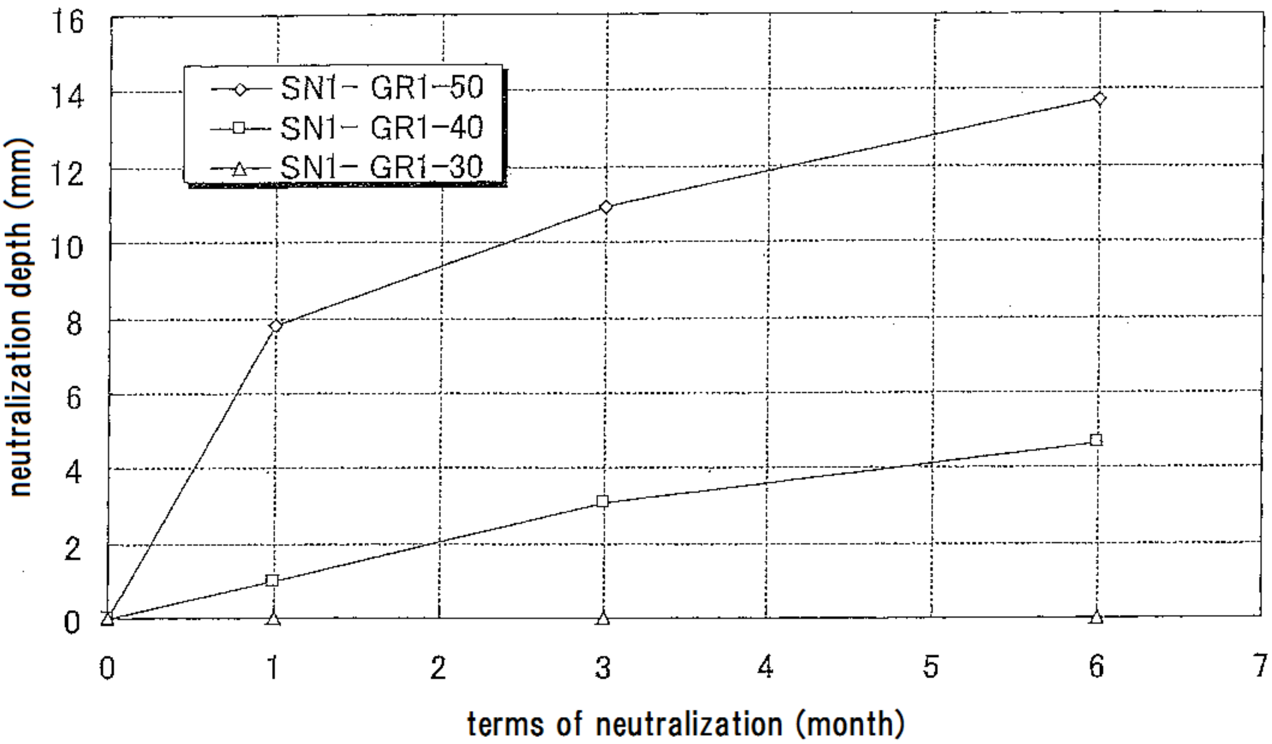



Figure 3.8 Series 1 (indoor experiment) neutralization depth

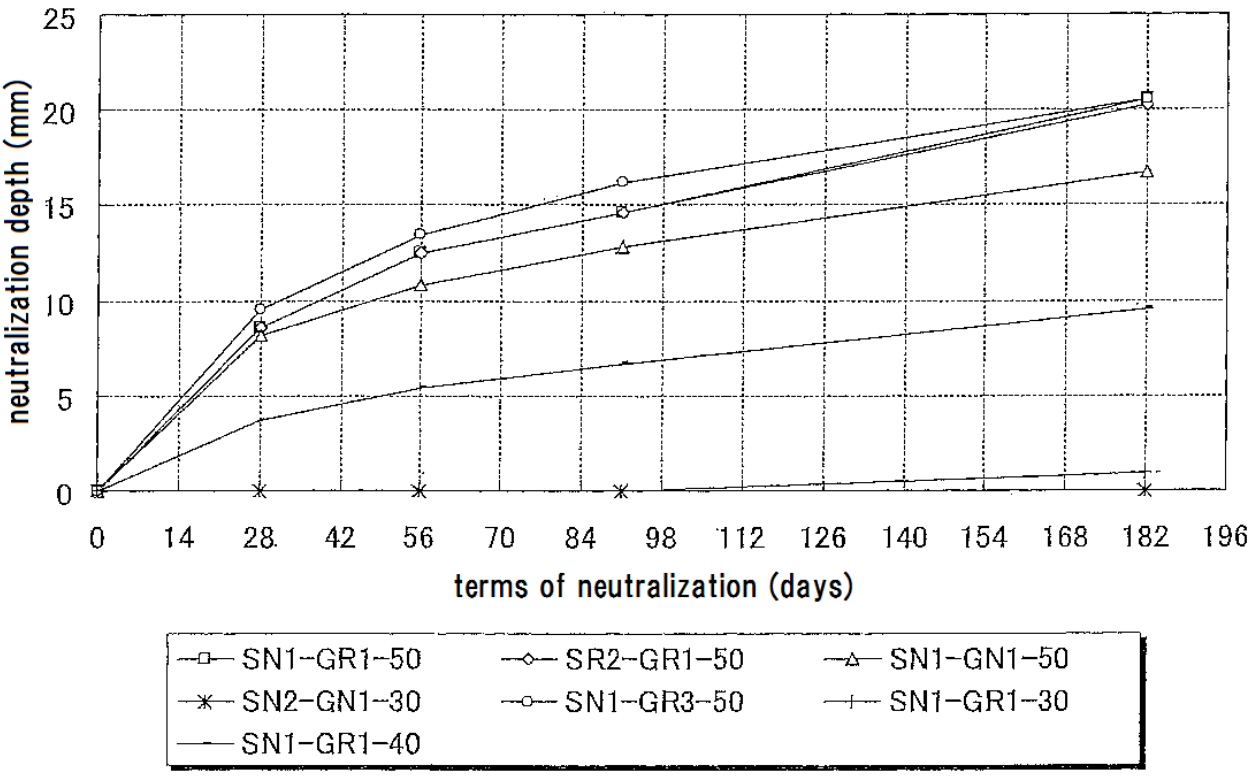



Figure 3.9 Series 1 (using actual machine) neutralization depth

(5) Compressive strength and neutralization

The relation between compressive strength and neutralization shall be shown in figure 3.10. The specimen shall be 182 days of material age in neutralization term.
According to figure 3.10, when the compressive strength is stronger, the neutralization depth is lower. The approximation line of recycled aggregate concrete is steeper than the line of normal-weight line. Accordingly, when the recycled aggregate concrete is used practically and has the same strength as normal-weight concrete, the neutralization resistance is judged definitely in safe side.

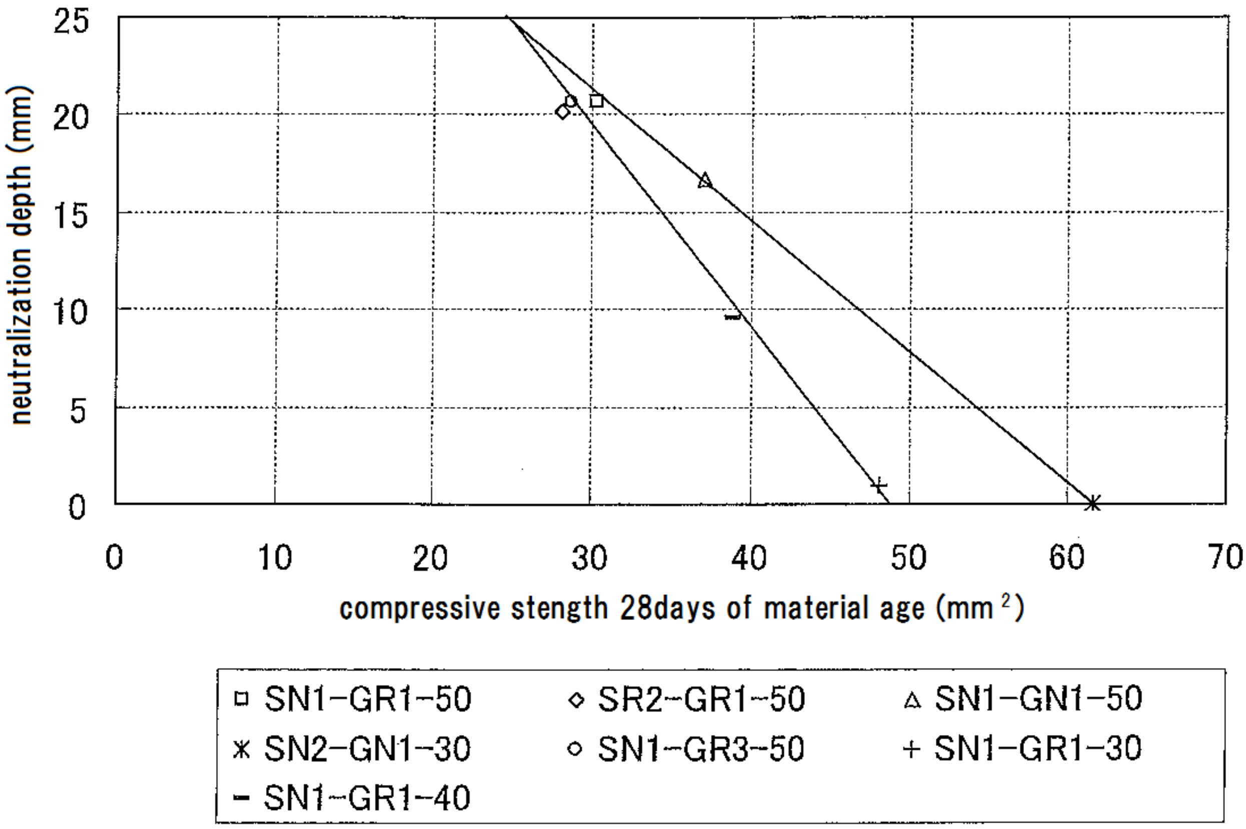



**Figure 3.10 Series 1 (using actual machine)**
**Compressive strength and neutralization**

3.3.5 Summery of Series 1

1. According to the test result of compressive strength and Young's modulus, manufacture high strength concrete by using recycled coarse aggregate type 1 shall be possible.

2. For concrete using recycled coarse aggregate type 1, when water cement ratio is lower, the strain of drying shrinkage shall be smaller.

3. For concrete using recycled coarse aggregate type 1, when water cement ratio is lower, the neutralization depth shall be smaller.

## 3.4 Series 2

In this series, confirm the basic characteristics of the concrete using recycled fine aggregate type 1 when water cement ratio is 50 by indoor experiment and examine the characteristics by means of to compare concrete using other types of aggregate.

### 3.4.1 Materials for use and mix proportion

For the experiment, using materials of concrete shall be shown in table 3.9 and mix proportion shall be shown in table 3.10.

**Table 3.9 Series 2 materials for use**

| | | | |
|---|---|---|---|
| cement | C | ordinary portland cement | density 3.16g/$cm^3$ |
| fine aggregate | SN1 | mountain sand and crushed sand (7 : 3) | density in surface-dry condition 2.59g/$cm^3$ |
| | | | absorption 2.05% |
| | SR1 | recycled fine aggregate type 1 | density in surface-dry condition 2.54g/$cm^3$ |
| | | | absorption 3.31% |
| coarse aggregate | GN1 | crushed sand | density in surface-dry condition 2.64g/$cm^3$ |
| | | | absorption 0.64%, solid content 59% |
| | GR1 | recycled coarse aggregate type 1 | density in surface-dry condition 2.55g/$cm^3$ |
| | | | absorption 2.95%, solid content 59% |
| admixture | HAE | AE and high-range water-reducing admixture (Polycarboxylate-based) | |
| | MAE | AE and water-reducing admixture of slump loss reduction type (Polycarboxylate-based) | |
| | AE | air-entraining agent | |

**Table 3.10 Series 2 specific mix proportion (indoor and using actual machine experiment)**

| symbol | bulk volume of coarse aggregate ($m^3$/$m^3$) | quantity of material per unit volume of concrete (kg/$m^3$) | | | | | | admixture (%) | |
|---|---|---|---|---|---|---|---|---|---|
| | | water | C | SN1 | SR1 | GN1 | GR1 | HAE | MAE |
| SN1-GN1-50 | 0.60 | 180 | 360 | 811 | − | 919 | − | 0.7 | − |
| SR1-GN1-50 | 0.60 | 180 | 360 | − | 795 | 919 | − | 0.5 | − |
| SR1-GR1-50 (M) | 0.60 | 180 | 360 | − | 780 | − | 903 | − | 1.5 |
| SR1-GR1-50 (H) | 0.60 | 180 | 360 | − | 780 | − | 903 | 0.5 | − |

### 3.4.2 Test items and measuring method

a) Compressive strength and Young's modulus

The test shall be carried out in accordance with JIS A 1149.

b) Drying shrinkage

For measuring drying shrinkage of concrete, the embedded strain gauge was used for specimen (Ø10×20cm). Removed the formwork at 2 days of material age and cured 7 days in the 20℃ water. After that, measured drying shrinkage strain day by day in a constant temperature and humidity room (20℃ temperature, 60% humidity).

c) Neutralization

The specimen was removed the formwork at 2 days of material age and cured 28 days in the 20℃ water and 28 days in a constant temperature and humidity room (20℃ temperature, 60% humidity). After that it was stocked in neutralization promotion tank (20℃ temperature, 60% humidity, 10% carbon dioxide concentration) for indoor experiment, and (20℃ temperature, 60% humidity, 5% carbon dioxide concentration) for using actual machine experiment. After beginning of promotion of neutralization, in the specified material age, cut the specimen at 5cm height, sprayed 5% solution of phenolphthalein on the cutting surface and measured by caliper. And applied the epoxy resin on the cutting measuring part and stocked again.

d) Freeze thaw

The test shall be carried out in accordance with JIS A 1148.

### 3.4.3 Test result

#### (1) Property of fresh concrete

The result of fresh concrete test shall be shown in Table 3.11 and 3.12. The changings of slump shall be shown in figure 3.11. The changings for process of fresh concrete shall be shown in photo 3.5. According to the experiment using actual machine, the fresh property is almost as same value as the indoor experiment.

**Table 3.11 Series 2 fresh concrete test (indoor experiment)**

| symbol | time (min.) | slump (cm) | flow (cm × cm) | air content (%) | concrete temperature (%) |
|---|---|---|---|---|---|
| SN1-GN1-50 | 0 | 15.5 | — | 4.7 | 25.6 |
| SR1-GN1-50 | 0 | 18.0 | 29.5 × 26.5 | 3.6 | 26.0 |
| SR1-GR1-50(M) | 0 | 19.5 | 35.0 × 37.0 | 3.0 | 25.8 |
| | 30 | 20.0 | 31.2 × 33.6 | 3.1 | 25.9 |
| | 60 | 17.0 | 28.5 × 27.7 | 2.9 | 26.0 |
| | 90 | 11.5 | 20.5 × 20.0 | 2.7 | 26.0 |
| SR1-GR1-50(H) | 0 | 20.5 | 25.8 × 29.5 | 5.0 | 25.6 |

**Table 3.12 Series 2 fresh concrete test (using actual machine)**

| symbol | slump (cm) | flow (cm × cm) | air content (%) | concrete temperature (%) |
|---|---|---|---|---|
| SN1-GN1-50 | 12.5 | 23.0 × 23.5 | 4.0 | 32.5 |
| SR1-GN1-50 | 15.0 | 25.5 × 25.0 | 4.7 | 31.0 |
| SR1-GR1-50 | 14.5 | 24.5 × 23.5 | 6.4 | 30.5 |
| SR1-GR1-50 (lower beam) | 8.5 | — | 4.6 | — |

In this series, the fresh property of concrete using recycled fine aggregate at finish mixing is almost as same value as concrete using natural aggregate despite the less admixture is added (table 3.11). Moreover, applicability for the admixture (M) which has slump holding performance of almost as same as AE and high-range water-reducing admixture shall be considered. The changing process for slump of concrete using this admixture shall be shown in figure 3.11. The test result is obtained in settling indoor condition however the slump is hold for about 60 minutes and the property is good as shown in photo 3.5. Accordingly, it is possible to use the admixture of slump loss reduction type for recycled fine and coarse aggregate concrete. For experiment using actual machine, the slump is a little smaller due to consider the placing on the wall as follows.

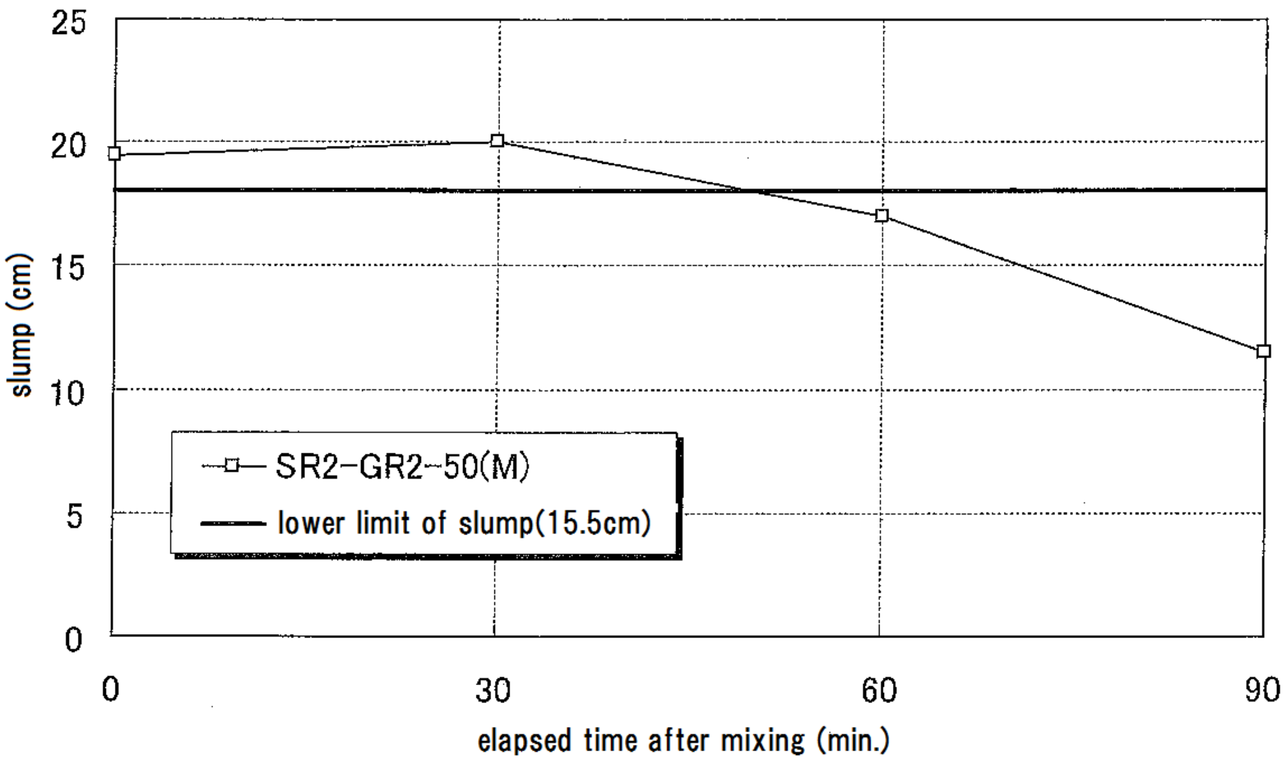
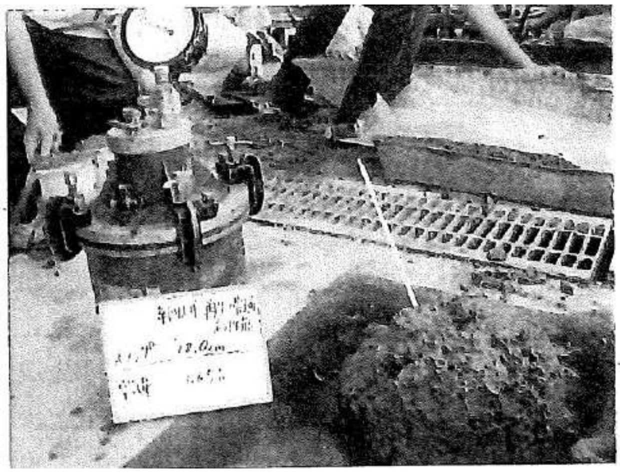
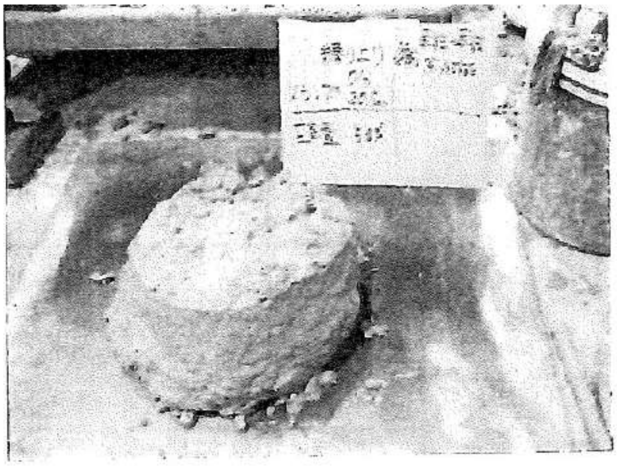


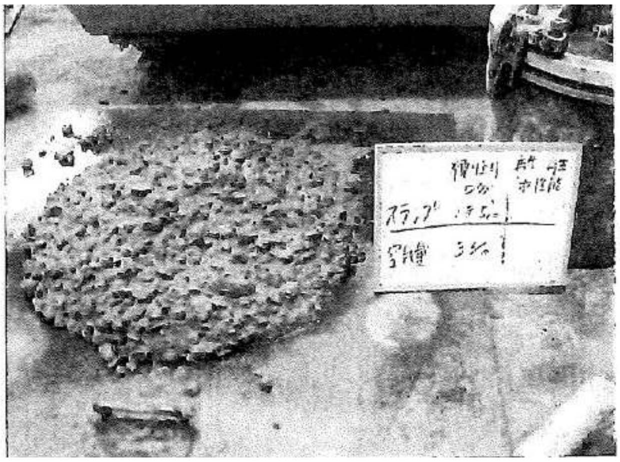

**Figure 3.11 Series 2 Slump (indoor experiment)**



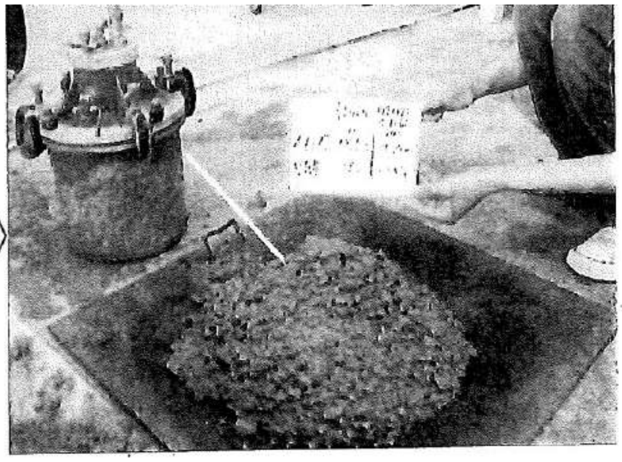
recycled + natural



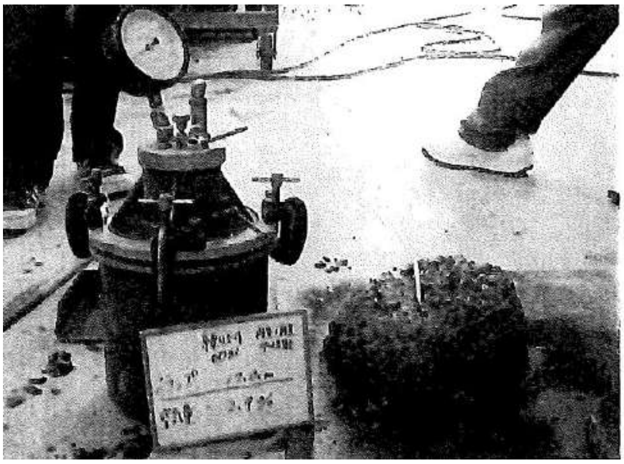
recycled + recycled (H)



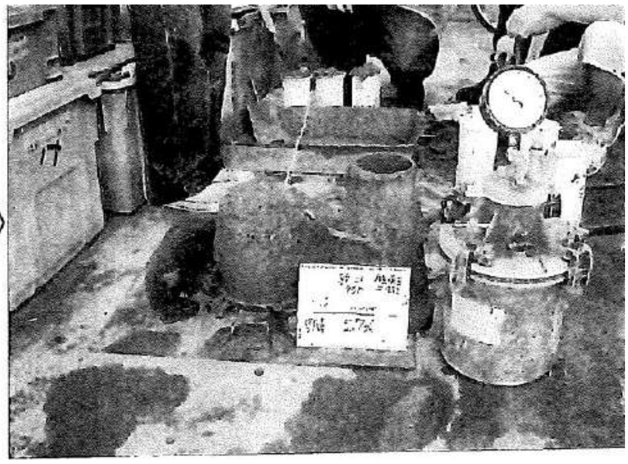
recycled + recycled (M)　0 min.



recycled + recycled (M)　30 min.



recycled + recycled (M)　60 min.



recycled + recycled (M)　90 min.

**Photo 3.5　Series 2　(indoor experiment)**

(2) Characteristics of high quality recycled fine aggregate

The test result of compressive strength in Series 2 shall be shown in table 3.13.

**Table 3.13 Series 2 compressive strength**

| | experiment | symbol | cure condition | compressive strength (N/mm2 ) | | |
|---|---|---|---|---|---|---|
| | | | | 7days | 28days | 91days |
| Series 2 | indoor | SN1-GN1-50 | standard in the water | 25.8 | 35.1 | 40.1 |
| | | SR1-GN1-50 | | 28.2 | 38.0 | 43.9 |
| | | SR1-GR1-50 (M) | | 27.9 | 39.1 | 43.7 |
| | | SR1-GR1-50 (H) | | 28.1 | 38.2 | 44.8 |
| | using actual machine | SN1-GN1-50 | in the air | 21.6 | 30.6 | 31.5 |
| | | SR1-GN1-50 | | 22.3 | 31.8 | 33.2 |
| | | SR1-GR1-50 (H) | | 23.0 | 30.4 | 31.8 |

Figure 3.12 shows the compressive strength of each concrete in Series 2 at W/C 50% for each aggregate. Compare to the normal-weight concrete, the compressive strength for concrete using high quality recycled fine aggregate and recycled fine and coarse aggregate in this experiment is as same value or approximately 5N/㎟ higher than the normal weight concrete. Moreover the test result for mixing by actual machine is confirmed to obtain almost the same strength as indoor test. (SR-GR-50 (H) in using actual machine) According to the result, it seems that the concrete using high quality recycled fine aggregate and recycled fine and coarse aggregate is possible to have the same strength as normal weight concrete.

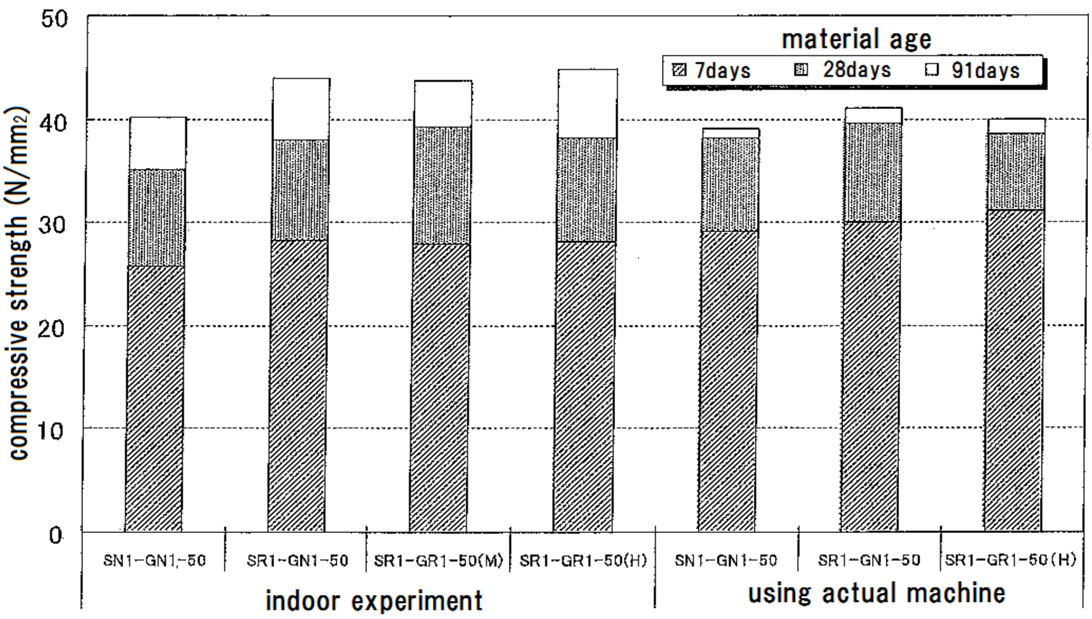



**Figure 3.12 in comparison with natural aggregate (Series 2)**

(3) Young's modulus

The test result of Young's modulus for Series 1 and 2 shall be shown in Table 3.14.

The Young's modulus in this experiment shall be evaluated according to the formula of "The calculation standard of reinforced concrete structure and commentation" [5] (3.3)

$$E = 21.0 \times \left[\frac{\gamma}{2.3}\right] 1.5 \times \left[\frac{Fc}{20}\right] 0.5 \qquad (3.3)$$

where, $E$ : Young's modulus of concrete (kN/㎟)

$\gamma$ : density of concrete (t/㎥ )

$Fc$ : design strength of concrete (N/㎟)

The figure 3.13 shows the relations between the test value which obtained by experiment in Series 1 and 2 and the calculation value of Young's modulus by RC formula according to the reinforced concrete structure calculation standard and commentation. It seems both of them have good conformity. It is found that the Young's modulus of recycled aggregate concrete in this experiment can be eliminated by RC standard formula.

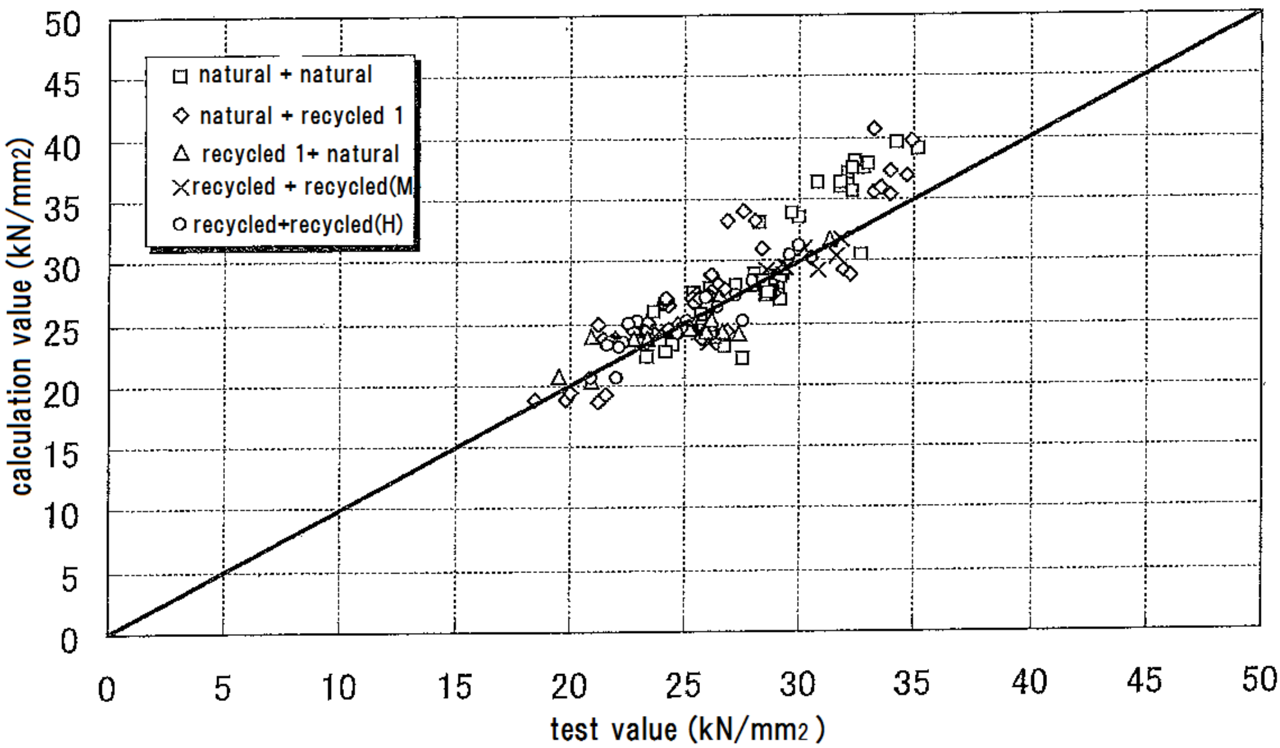



**Figure 3.13 Young's modulus**
**(Series 1 & 2 including indoor and using actual machine)**

Table 3.14　Series 1 & 2　　Young's modulus

| | experiment | symbol | cure condition | Young's modulus (kN/㎟) | | |
|---|---|---|---|---|---|---|
| | | | | 7days | 28days | 91days |
| Series 1 | indoor | SN1-GR1-50 | standard in the water | 25.0 | 25.3 | 31.5 |
| | | SN1-GR1-40 | standard in the water | — | 27.4 | 33.5 |
| | | SN1-GR1-30 | standard in the water | — | 34.0 | 34.8 |
| | using actual machine | SN1-GN1-50 | standard in the water | — | 28.8 | — |
| | | | onsite in the air | 25.1 | 25.2 | 29.1 |
| | | | onsite in the water | — | 28.0 | — |
| | | SN2-GN1-30 | standard in the water | — | 32.3 | — |
| | | | onsite in the air | 29.3 | 31.8 | 34.1 |
| | | | onsite in the water | — | 32.0 | — |
| | | SN1-GR3-50 | standard in the water | — | 22.3 | — |
| | | | onsite in the air | — | 20.5 | 21.7 |
| | | | onsite in the water | — | 21.7 | — |
| | | SR2-GR1-50 | standard in the water | — | 22.5 | — |
| | | | onsite in the air | — | 21.0 | 22.6 |
| | | | onsite in the water | — | 22.5 | — |
| | | SN1-GR1-50 | standard in the water | — | 23.1 | 26.2 |
| | | | onsite in the air | 20.8 | 22.8 | — |
| | | | onsite in the water | — | 23.0 | — |
| | | SN1-GR1-40 | standard in the water | — | 26.2 | — |
| | | | onsite in the air | 22.8 | 24.6 | 26.4 |
| | | | onsite in the water | — | 25.2 | — |
| | | SN1-GR1-30 | standard in the water | — | 25.2 | — |
| | | | onsite in the air | 18.3 | 19.0 | 20.8 |
| | | | onsite in the water | — | 20.8 | — |
| Series 2 | indoor | SN1-GN1-50 | standard in the water | 26.1 | 28.7 | 32.7 |
| | | SR1-GN1-50 | | 26.0 | 28.8 | 31.3 |
| | | SR1-GR1-50 (M) | | 25.2 | 29.6 | 31.2 |
| | | SR1-GR1-50 (H) | | 27.1 | 28.4 | 29.8 |
| | using actual machine | SN1-GN1-50 | in the air | 20.2 | 22.4 | 26.2 |
| | | SR1-GN1-50 | | 25.5 | 25.1 | 28.7 |
| | | SR1-GR1-50 (H) | | 21.5 | 22.1 | 23.9 |

(4) Drying shrinkage

Figure 3.14 shows drying shrinkage of concrete. When drying material age 140days, the strain of shrinkage for concrete using recycled fine aggregate is $50 \times 10^{-6}$ smaller than natural aggregate concrete and $160 \times 10^{-6}$ smaller for concrete using together with recycled fine and coarse aggregate approximately. In this case, variability of the strain according to the types of admixture is not seen (comparison H and M in the following figure). The drying shrinkage of concrete tends to finish at 140days of material age, especially the strain of drying shrinkage for concrete using high quality recycled fine and coarse aggregate is approximately $550 \times 10^{-6}$ and it is low enough to satisfy the standard value $800 \times 10^{-6}$ of JASS5.

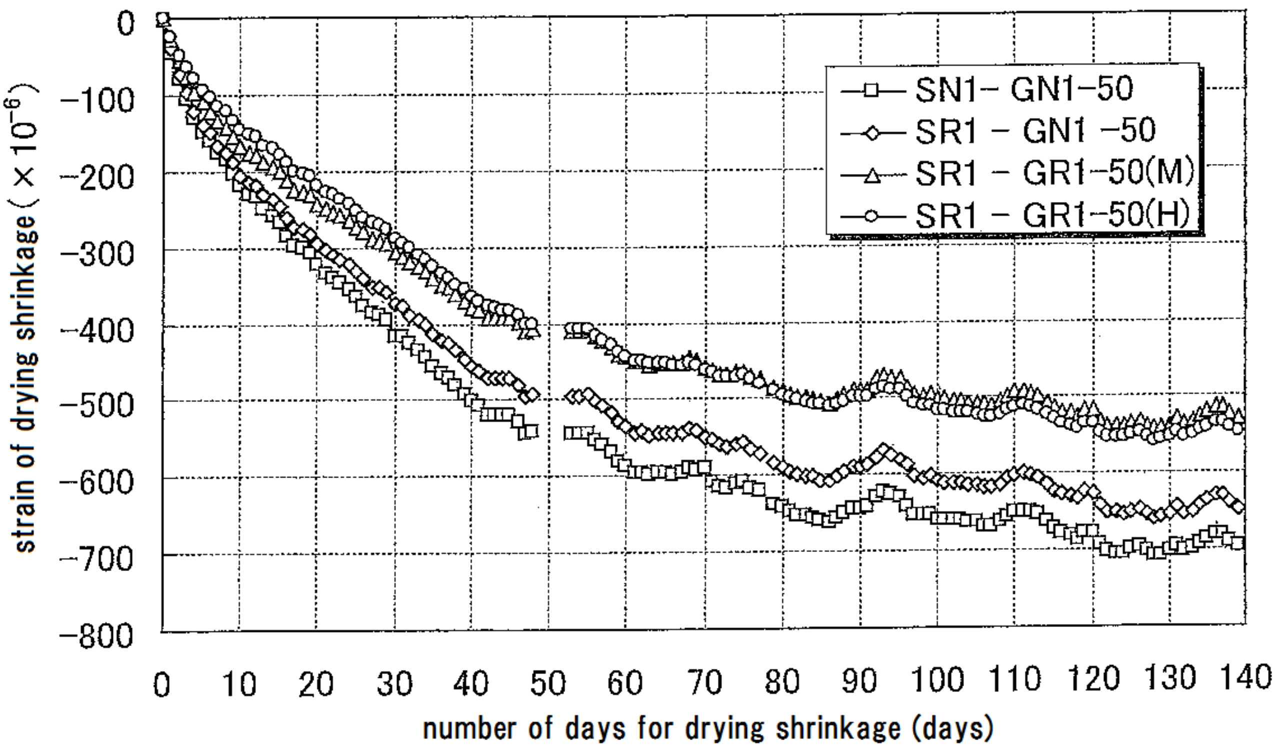



**Figure 3.14 Series 2 strain of drying shrinkage (indoor)**

(5) Neutralization

The neutralization depth shall be shown in Table 3.15 and Figure 3.15. According to Figure 3.15, regardless of the types of using aggregate (natural aggregate, high quality recycled fine and coarse aggregate), the neutralization depth is in almost same range. Thus it can be judged that the neutralization resistance for high quality recycled fine and coarse aggregate is as same level as the concrete using natural aggregate. The $CO^2$ concentration shall be 10% in this experiment. The test conform to JIS ($CO^2$ concentration 5%) shall be continuing, however due to the test result satisfied JIS standard value of 25mm high durability reinforced concrete structure guideline under the circumstances of twice of $CO^2$ concentration, the concrete using these high quality recycled fine and coarse aggregate shall be conjectured to certify the quality of high durability concrete.

**Table 3.15 Series 2 neutralization depth (indoor)**

| Series 2 | symbol | material age (month) | | | |
|---|---|---|---|---|---|
| | | 0 | 1 | 3 | 6 |
| indoor | SN1−GN1−50 | 0 | 6.59 | 11.36 | 16.22 |
| | SR1−GN1−50 | 0 | 5.76 | 11.53 | 15.42 |
| | SR1−GR1−50 (M) | 0 | 6.18 | 11.98 | 18.44 |
| | SR1−GR1−50 (H) | 0 | 6.41 | 10.91 | 15.95 |

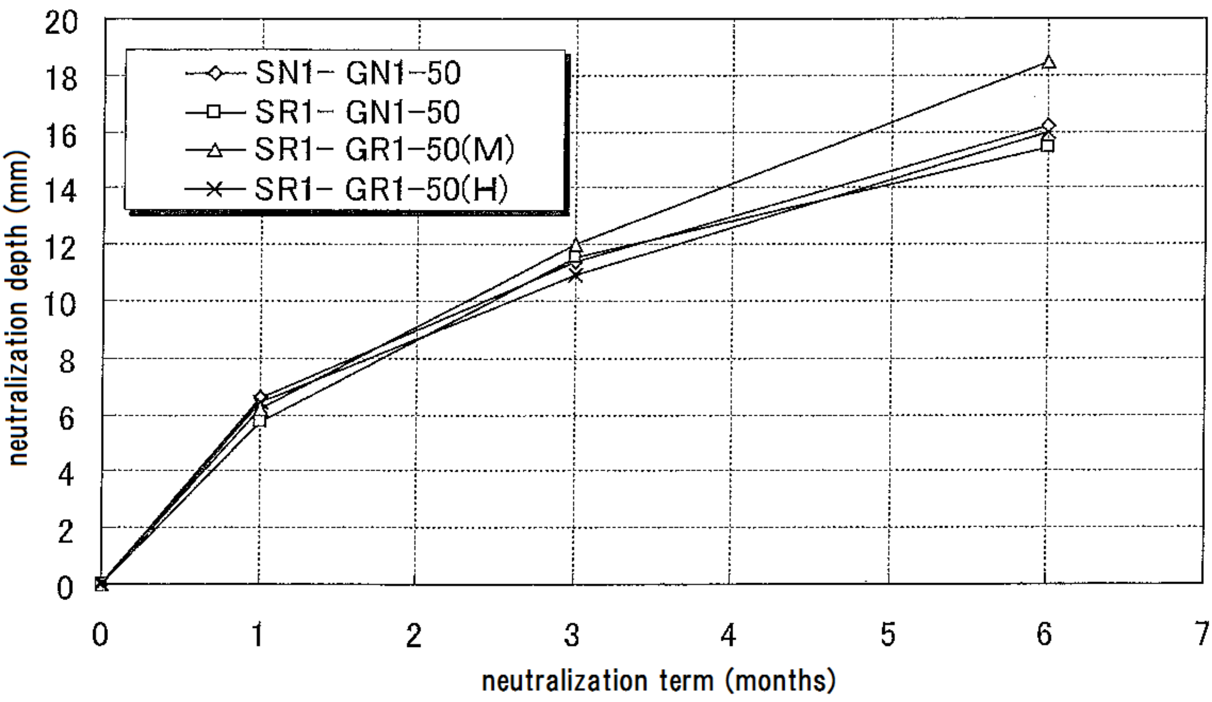



**Figure 3.15 Series 2 neutralization depth (indoor)**

(6) Freeze thaw

Table 3.16 and Table 3.17 show the test result of freeze thaw. Figure 3.16 and Figure 3.17 show the test result of freeze thaw for concrete (Series 2). Compare to the concrete using natural aggregate, the durability index for concrete using high quality recycled fine aggregate is as same value and the result is satisfied the property of division A for JASS5 "Concrete Subjected to Freezing and Thawing" (the relative dynamic modulus of elasticity is over 60%, durability index is over 60 in 300 cycle) and specified value in JIS A 6204 (durability index is over 80 in 200 cycle).

**Table 3.16 durability index**

| cycles (times) | SN1-GN1-50 | SR1-GN1-50 | SR1-GR1-50 (M) | SR1-GR1-50 (H) |
|---|---|---|---|---|
| 0 | 100.00 | 100.00 | 100.00 | 100.00 |
| 30 | 96.31 | 101.35 | 95.24 | 97.01 |
| 60 | 96.36 | 98.64 | 94.80 | 92.69 |
| 90 | 95.76 | 99.39 | 92.09 | 95.01 |
| 120 | 95.25 | 99.28 | 93.31 | 97.10 |
| 150 | 95.28 | 97.69 | 91.04 | 94.49 |
| 180 | 93.66 | 95.50 | 88.96 | 95.88 |
| 210 | 93.76 | 97.55 | 88.23 | 94.15 |
| 240 | 92.77 | 96.02 | 87.09 | 92.95 |
| 270 | 92.18 | 94.28 | 86.12 | 93.46 |
| 300 | 91.27 | 94.72 | 84.23 | 92.44 |

**Table 3.17 decrement of density**

| cycles (times) | SN1-GN1-50 | SR1-GN1-50 | SR1-GR1-50 (M) | SR1-GR1-50 (H) |
|---|---|---|---|---|
| 0 | 0.000 | 0.000 | 0.000 | 0.000 |
| 30 | 0.059 | 0.037 | 0.037 | 0.016 |
| 60 | 0.222 | 0.140 | 0.077 | 0.058 |
| 90 | 0.349 | 0.222 | 0.138 | 0.117 |
| 120 | 0.454 | 0.306 | 0.208 | 0.183 |
| 150 | 0.557 | 0.392 | 0.271 | 0.244 |
| 180 | 0.647 | 0.475 | 0.323 | 0.244 |
| 210 | 0.759 | 0.581 | 0.415 | 0.379 |
| 240 | 0.869 | 0.684 | 0.496 | 0.468 |
| 270 | 1.006 | 0.808 | 0.594 | 0.566 |
| 300 | 1.127 | 0.922 | 0.677 | 0.650 |

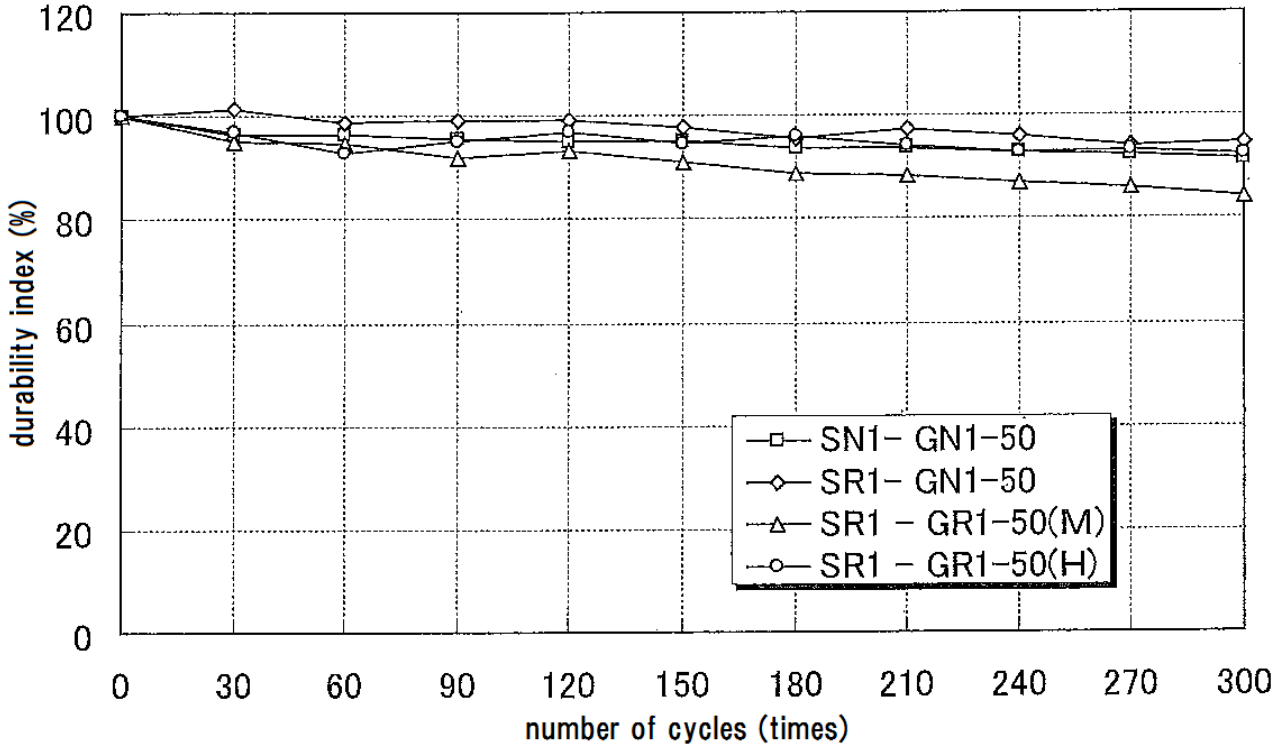



Figure 3.16 Series 2 durability index (indoor)

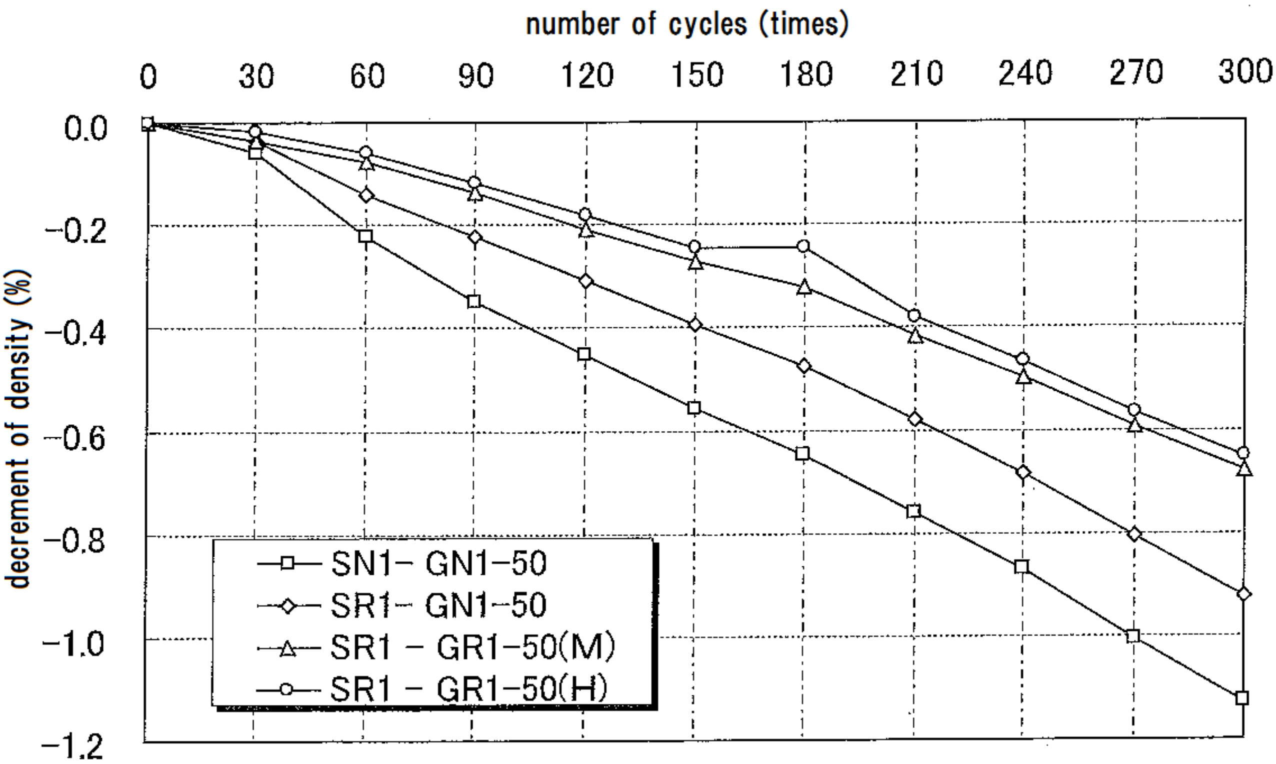



Figure 3.17 Series 2 decrement of density

3.4.4 Summery of Series 2

1. The characteristics of the fresh concrete using high quality recycled fine aggregate or recycled fine and coarse aggregate shall be as same as the concrete using natural aggregate under the same condition.

2. The concrete using high quality recycled fine aggregate and recycled fine and coarse aggregate shall be sufficiently possible to have as same strength as natural aggregate concrete.

3. The Young's modulus of recycled aggregate concrete which inspected in this experiment (including recycled coarse aggregate Type 1 and fine aggregate) shall be evaluated by RC standard formula.

4. The strain of drying shrinkage for high quality recycled fine and coarse aggregate tends to be smaller compare to the concrete using natural aggregate. The strain of drying shrinkage for this concrete tends to settle at 140 days of material age, and the size shall be $550 \times 10^{-6}$ and smaller than the standard value $800 \times 10^{-6}$ given in JASS5.

5. The neutralization and freeze thaw of the concrete using high quality recycled fine and coarse aggregate shall be as same as the concrete using natural aggregate. The result of neutralization shall be satisfied the standard value (25mm) shown in high durability concrete in Architectural Institute of Japan. While the durability index for freeze thaw resistance shall be satisfied the standard value 80 given in JIS A 6204.

# 4. Effect on the full scale wall

For the member of concrete using recycled aggregate, the crack occurred by drying shrinkage is the concern. In Chapter 3, it was confirmed that the strain of drying shrinkage for concrete using high quality recycled fine and coarse aggregate shall be same or smaller than that of concrete using natural aggregate. However the crack of drying shrinkage shall be effected by several factor other than the strain of shrinkage and the mechanism is quite complicated. In this chapter the mixture in Series 2 using experiment above, in order to inspect the strain of shrinkage for SN1-GN1, SN1-GR1, SR1-GR1 as a member and built an actual wall and inspect the cracks. In addition, conducted a follow-up survey on the progress of crack range from the happening of crack to collect data for the establishment of crack range analysis method for concrete member of these kinds.

## 4.1 Appearance of specimen

The appearance of specimen for actual wall shall be shown in Figure 4.1 and 4.2, the appearance of dummy specimen for beam and wall shall be shown in Figure 4.3. In the middle of lower and upper beam of actual size specimen, the several embedded gauge were set at (━━ ) marked on the figure. The arrangement of reinforcement (refer to Figure 4.1,4.2 and 4.3) shall be D13@250 double for horizontal reinforcement on the wall, D13@500 double for vertical reinforcement on the wall, 6-D22 for main reinforcement of beam and pillar, D13@200 for shear reinforcement, the vertical reinforcement on the wall run through lower to upper beam and the cover of reinforcement shall be 40mm. The length of vertical reinforcement in the wall shall be 5m and welded in 50cm each in the pillar. The steel ratio of wall member shall be 0.56%. To measure strain of reinforcement with crack, the strain gauge shall be set on the position shown in figure 4.4. Therefore cutting the reinforcing bar and the strain gauge shall be set at 75mm intervals on the groove on a bar. Prepare two these reinforcing bars and shift from each other, the gauge shall be set 37.5mm intervals inside the wall on appearance (see figure 4.4). During the measurement, the specimen is retained in the condition which does not get wet with rain.

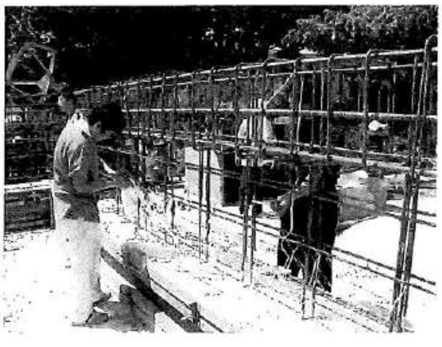


**Photo 4.1 Reinforcement**

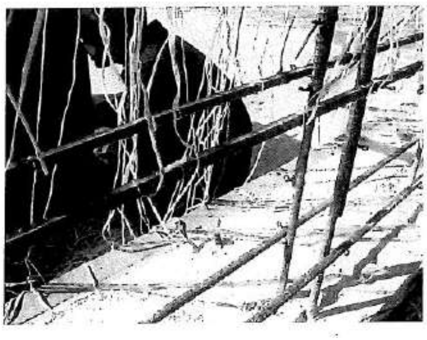


**Photo 4.2 gauge set on the bar**

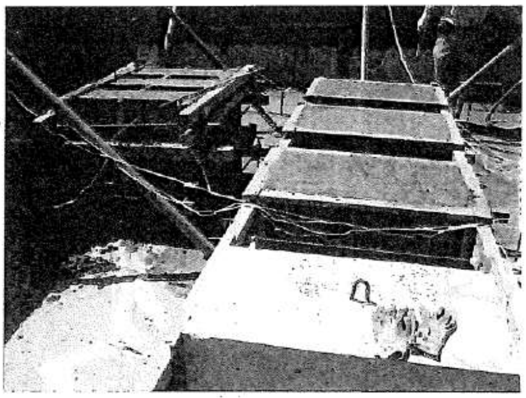


Photo 4.3　dummy member

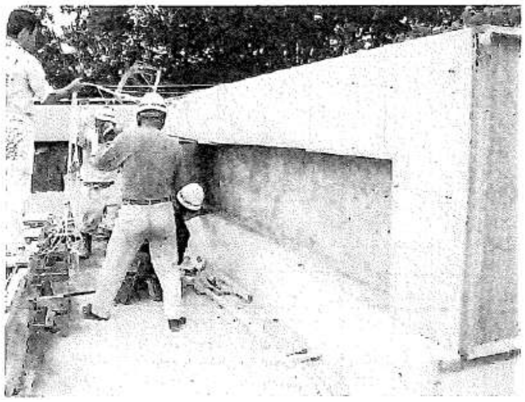


Photo 4.4　accomplished specimen

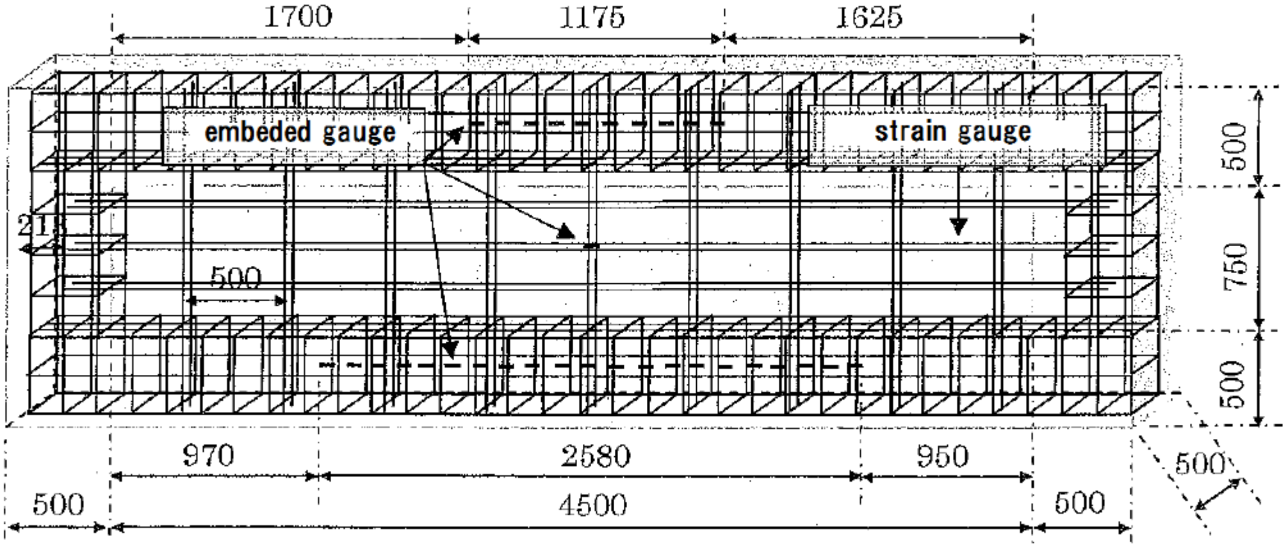



Figure 4.1　actual size specimen（$S_{N1}-G_{N1}$）

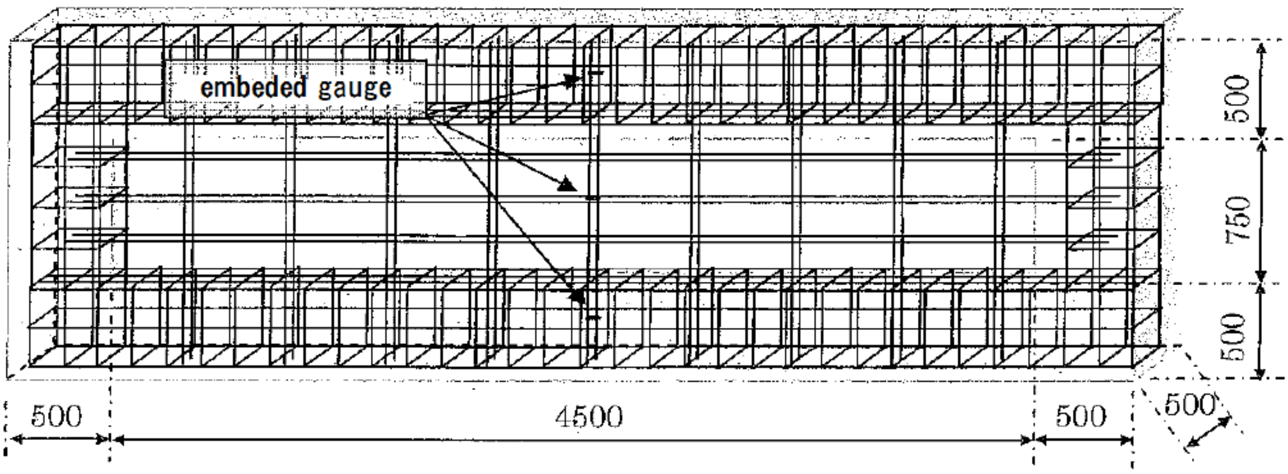
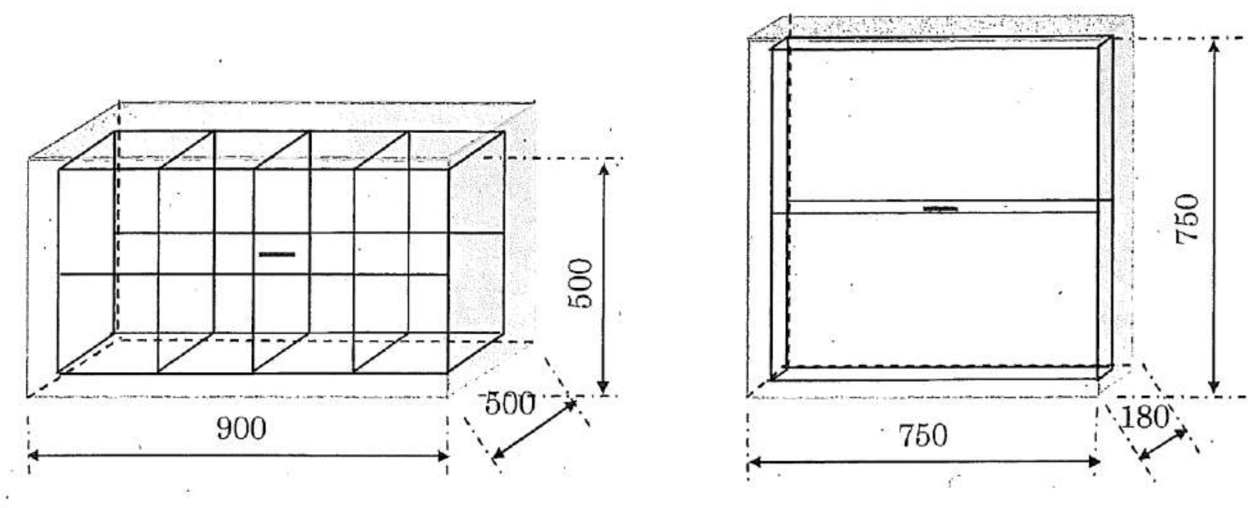



Figure 4.2　actual size specimen（$S_{N1}-G_{R1}$,　$S_{R1}-G_{R1}$）




Lower beam：1　upper beam：3　　　　　　　　　wall：3

**Figure 4.3　dummy specimen (same reinforcement as actual size specimen)**

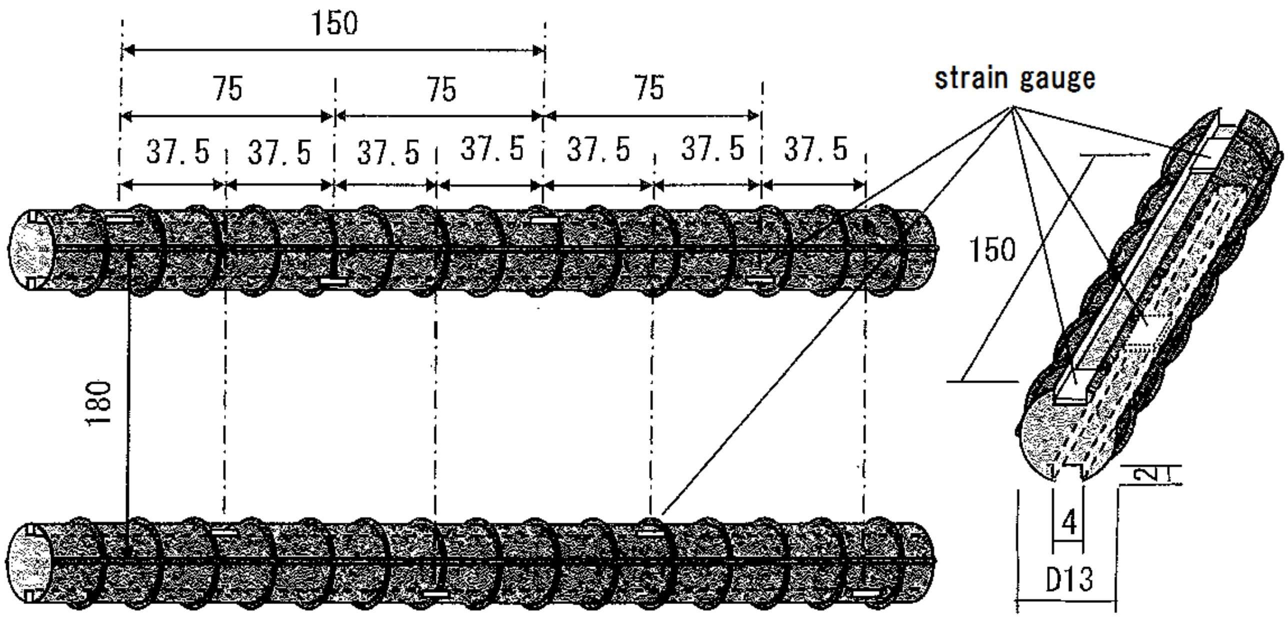



**Figure 4.4　strain gauge**

4.2 Measuring result

a) Test result of fresh concrete

The test result of each fresh concrete shall be shown in Table 4.1.

**Table 4.1 Test result of fresh concrete**

| types | slump | flow | air content | concrete temperature |
|---|---|---|---|---|
| | (cm) | (cm × cm) | (%) | (%) |
| SN1-GN1 | 12.5 | 23.0 × 23.5 | 4.0 | 32.5 |
| SN1-GR1 | 15.0 | 25.5 × 25.0 | 4.7 | 31.0 |
| SR1-GR1 | 14.5 | 24.5 × 23.5 | 6.4 | 30.5 |
| SN1-GR1(lower beam) | 8.5 | — | 4.6 | — |

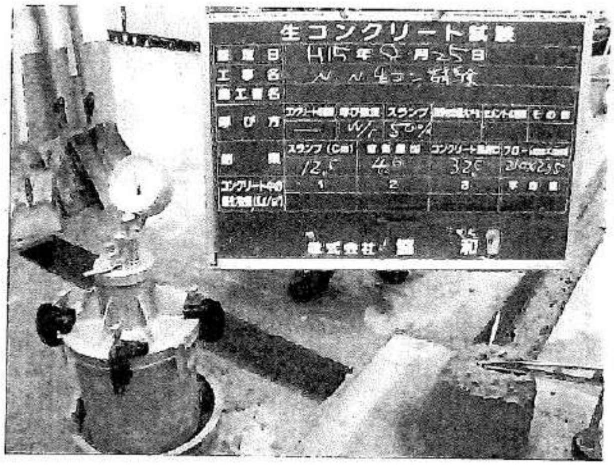



Photo 4.5 SN1-GN1
(natural fine and coarse aggregate)

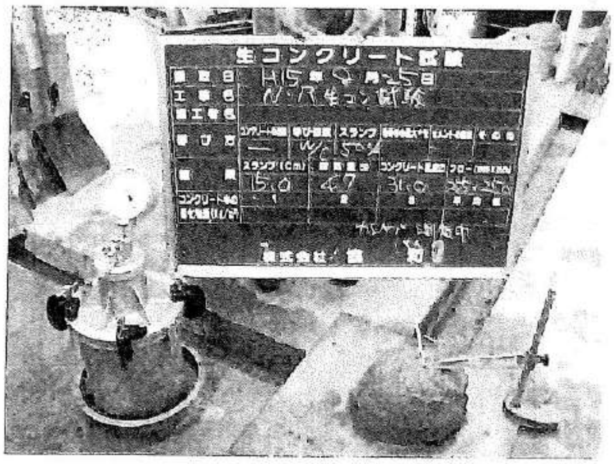



Photo 4.6 SN1-GR1 (recycled fine aggregate, natural coarse aggregate)

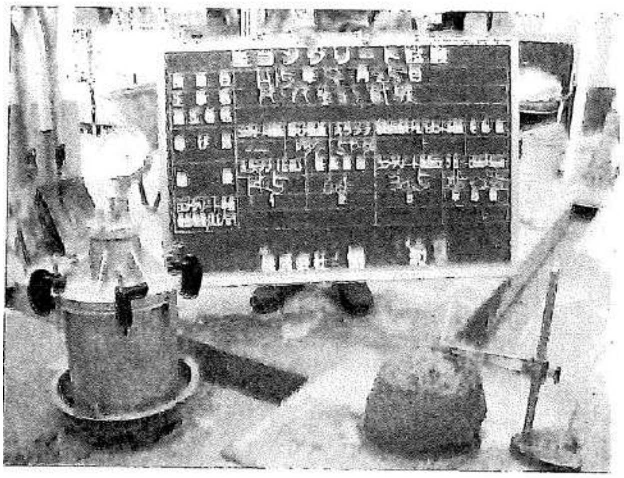


Photo 4.7 SR1-GR1
(recycled fine and coarse aggregate)

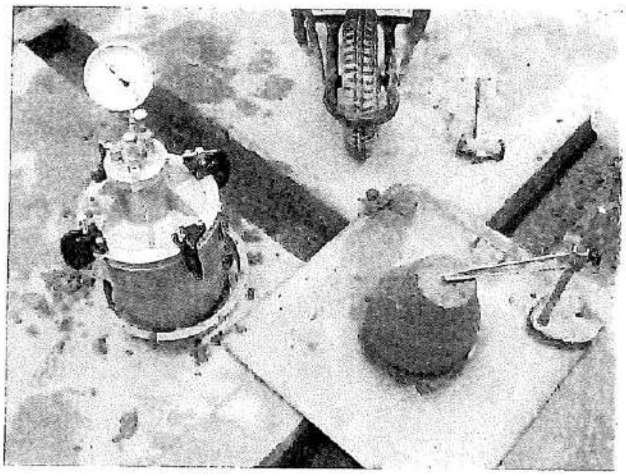


Photo 4.8 SR1-GN1(lower beam) (recycled fine aggregate, natural coarse aggregate)

b) Compressive strength

The compressive strength of concrete in each material age shall be shown in figure 4.5. The characteristics of high quality recycled aggregate shall be as same as normal weight concrete by using actual machine test.

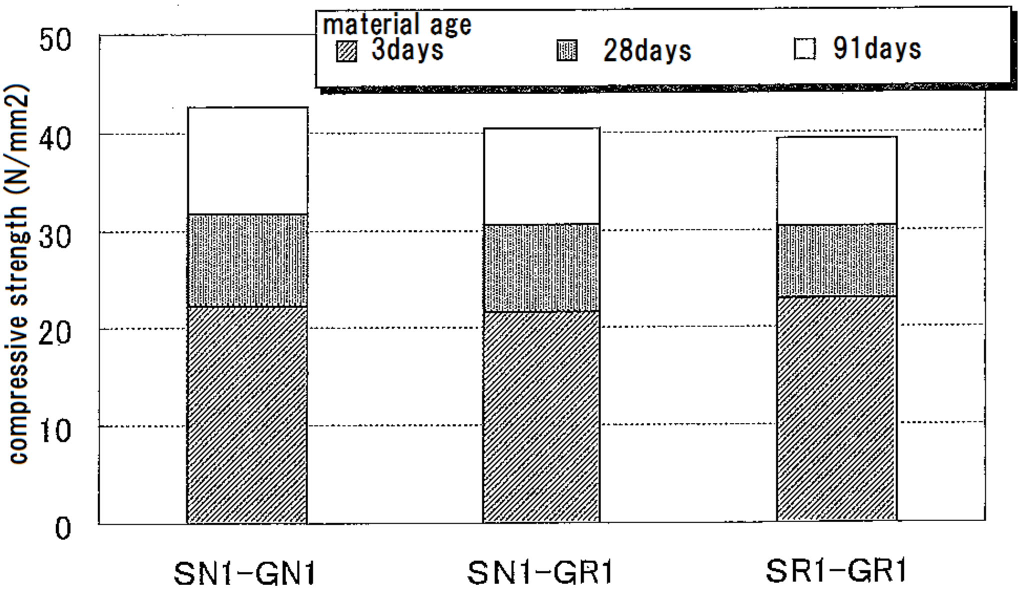



Figure 4.5 Compressive strength

Table 4.2 Test result of compressive strength

| material age (N/mm²) | SN1-GN1 | SN1-GR1 | SR1-GR1 |
|---|---|---|---|
| 3 days | 22.3 | 21.6 | 23.0 |
| 28 days | 31.8 | 30.6 | 30.4 |
| 91 days | 33.2 | 31.5 | 31.8 |

Photo 4.9

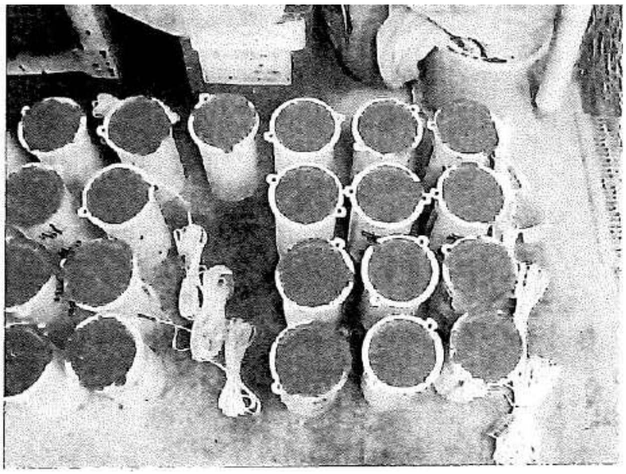


Photo 4.10

c) Shrinkage strain and creep strain of specimen (Ø 10 × 20)

Figure 4.6 shows the drying shrinkage strain for specimen(Ø 10 × 20) of each concrete and figure 4.7 shows the creep strain per unit stress intensity of each concrete. The drying shrinkage strain of SN1-GN1, SN1-GR1 and SR1-GR1 are almost same however for SN1-GR1 (lower beam), it is approximately $120 \times 10^{-6}$ difference. For the creep strain per unit stress intensity, the difference between SN1-GR1 and SR1-GR1 is approximately $10 \times 10^{-6}$ while SN1-GN1 and SN1-GR1 (lower beam) is the same. The maximum difference is $40 \times 10^{-6}$ approximately.

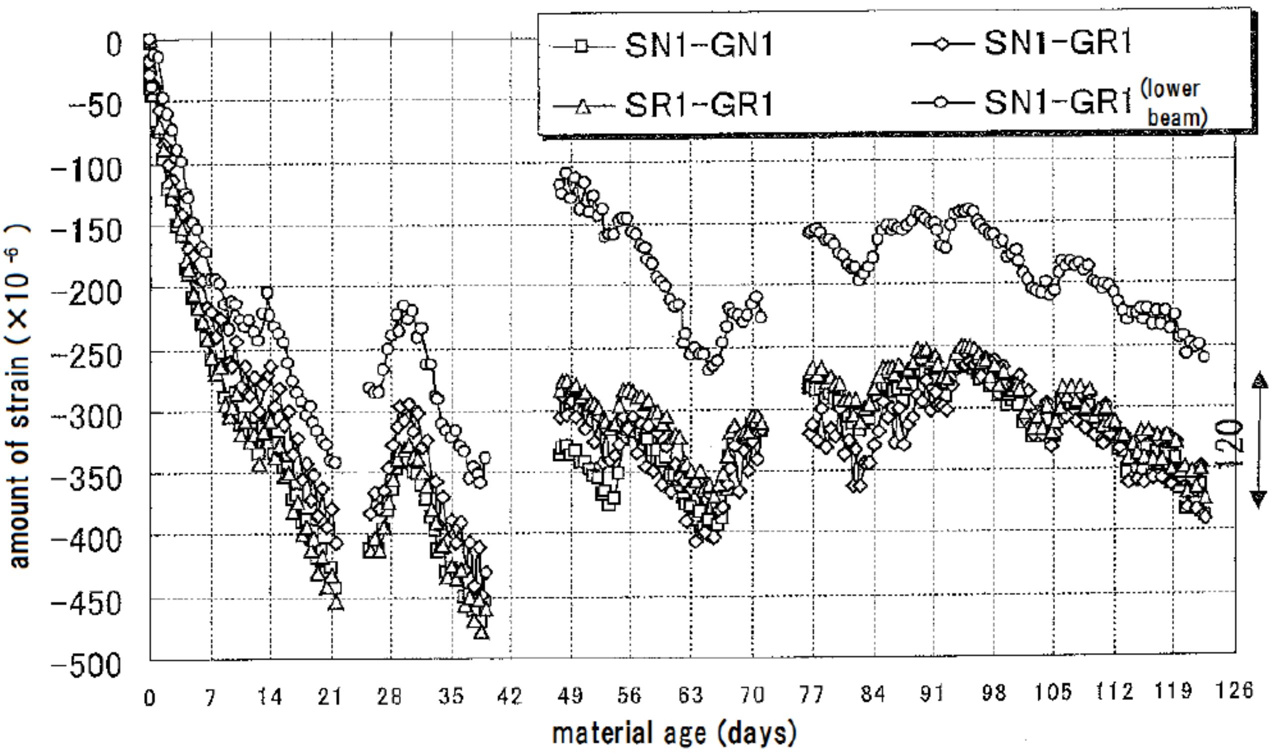



**Figure 4.6 Drying shrinkage strain for specimen(Ø 10 × 20)**

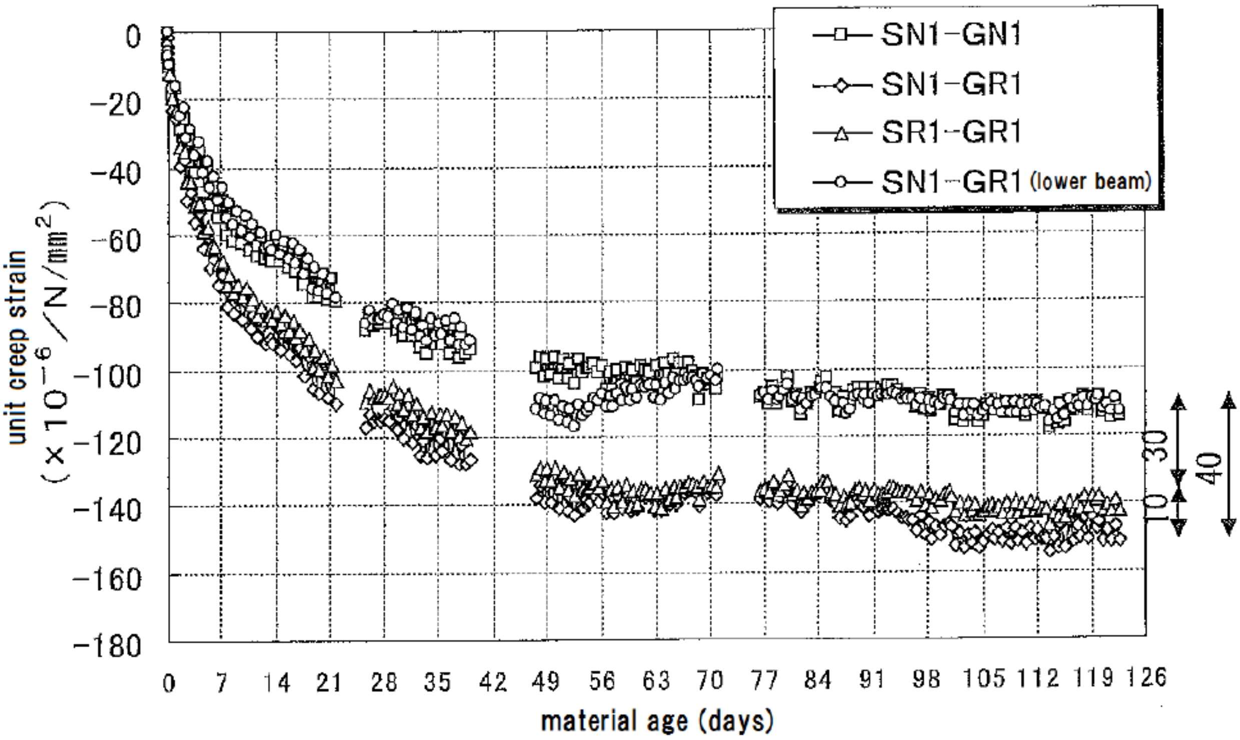



Figure 4.7 Creep strain per unit stress intensity

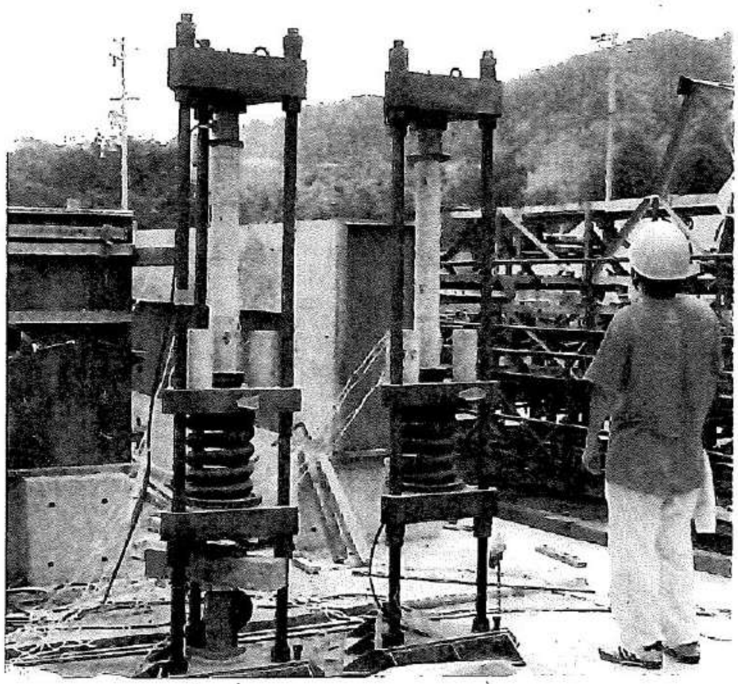


Photo 4.11 Creep test

d) Transition of outside temperature, concrete temperature of each member

Figure 4.8 shows the change of outside temperature and the concrete temperature of each member. The outside temperature is a little higher than the concrete temperature and the difference is approximately 4℃. The concrete temperature of each member is not seen big differences.

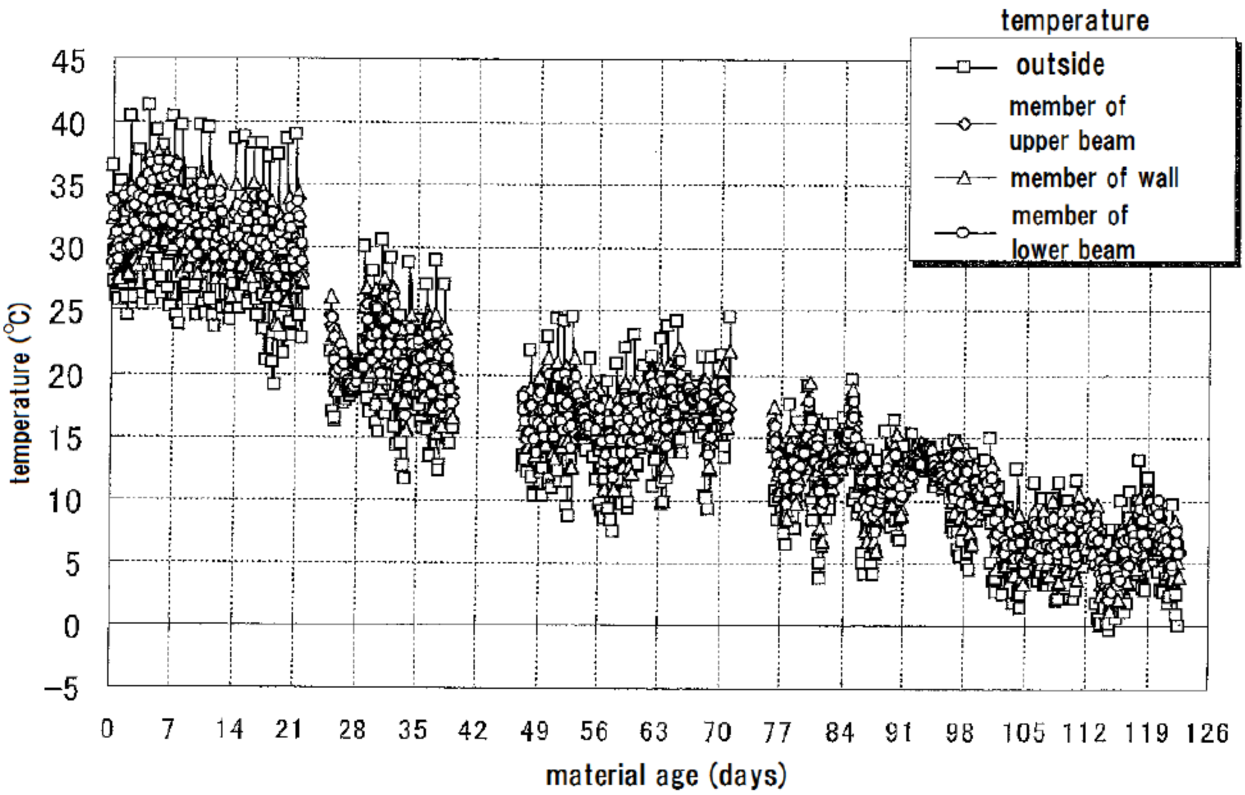



**Figure 4.8 Change of outside temperature, concrete temperature of each member (SN1-GN1)**

e) Shrinkage strain of dummy member

Figure 4.9 shows the shrinkage strain of dummy member for each concrete. The strain of wall is larger than the strain of beam and maximum difference is 130 $\times 10^{-6}$ approximately. The difference of beam is $50\times 10^{-6}$, wall is $20\times 10^{-6}$ approximately and the big difference is not seen for each aggregate.

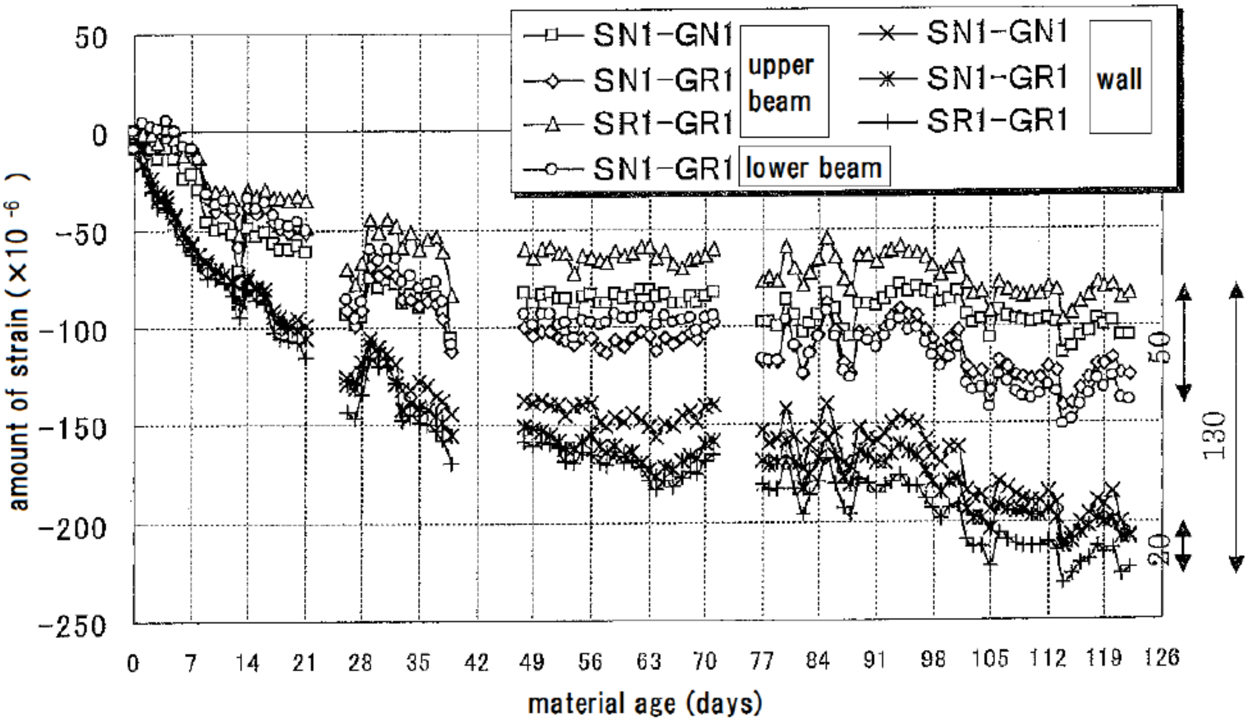



**Figure 4.9 Shrinkage strain of dummy member**

f) Transition of strain in center part of each member

Figure 4.10, 4.11, 4.12 show the transition of strain in the center part of upper beam, wall and lower beam.

The strain of upper beam, SN1-GN1 and SR1-GR1 are same however SN1-GR1 is large. The difference is $60\times10^{-6}$ approximately. For the strain of upper beam dummy, SR1-GR1 is the largest and SN1-GR1 is the smallest and the difference is $15\times10^{-6}$ each, the maximum difference is $30\times10^{-6}$.

On the wall of SN1-GN1, the cracks appeared at 33days of material age and it seems that the concrete is suddenly turned into the tensile strain side.
While the cracks of SN1-GR1 appeared at 102 days of material age, gradually expanded in twelve days and after that suddenly the cracks were growing in the tensile side. The differences is $550\times10^{-6}$ .
For SR1-GR1, the cracks appeared at 56 days of material age and were growing 7days as above.

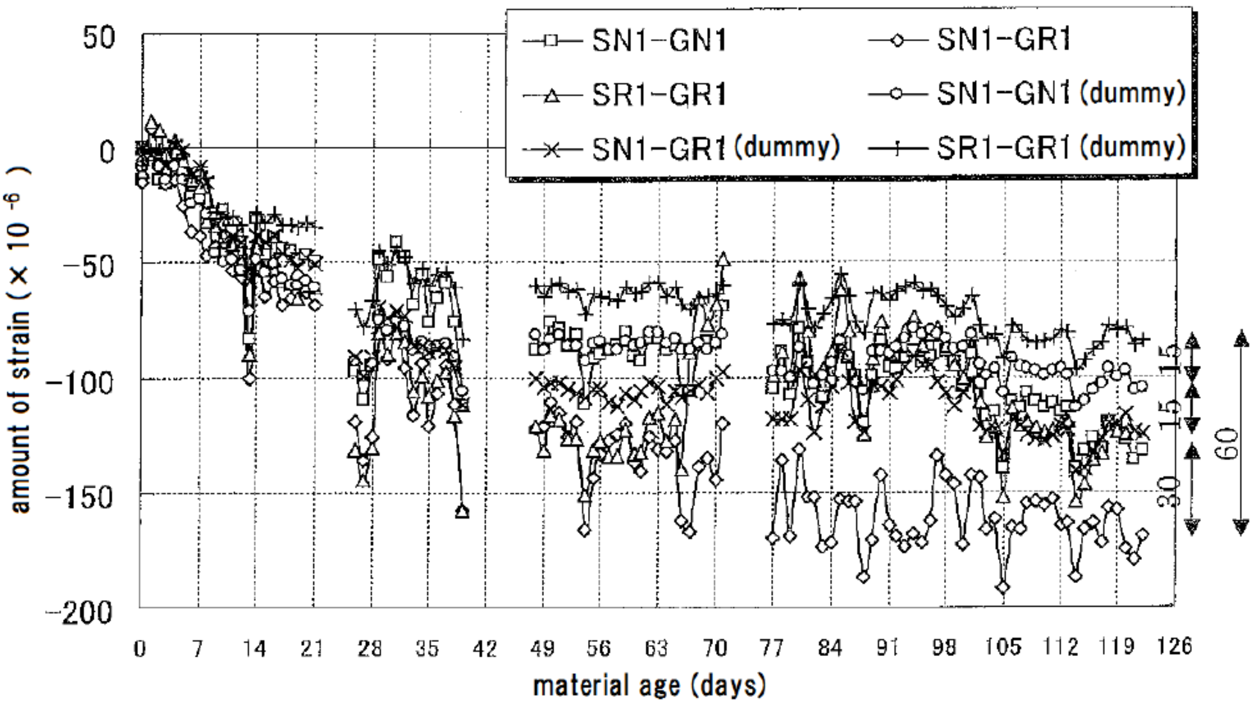



**Figure 4.10 variety of strain according to the difference of in the center part of upper beam member of concrete**

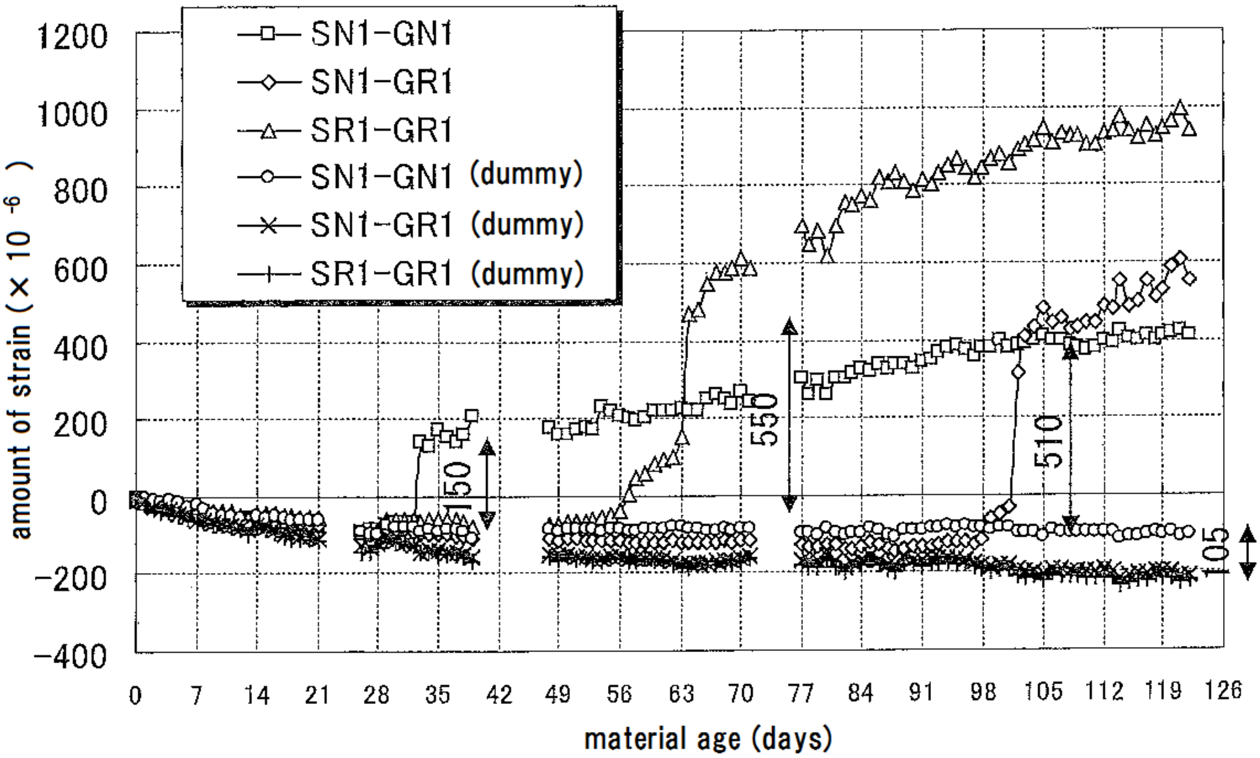



Figure 4.11 variety of strain according to the difference of in the center part of wall member of concrete

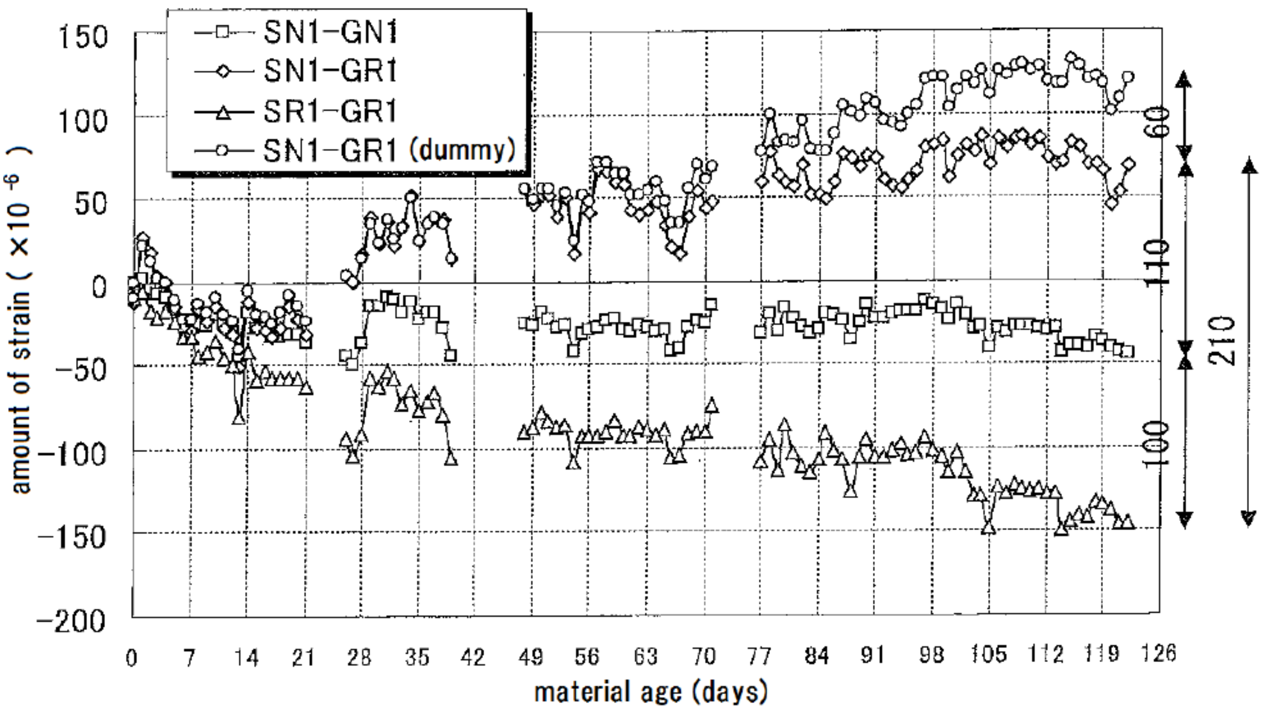



Figure 4.12 variety of strain according to the difference of in the center part of lower beam member of concrete

g) Cracks

Figure 4.13 shows the cracks of actual size specimen using normal-weight concrete at 66 days of material age (one month after cracks appeared). Figure 4.14 and 4.15 show the cracks of actual size specimen using high quality recycled aggregate at 120 days of material age (20days for SN1-GR1, 60days for SR1-GR1 after cracks appeared). As aforementioned, the cracks appeared at 33days of material age in normal-weight concrete. While it appear at 98 days of material age for concrete using high quality recycled fine aggregate, at 56 days of material age for concrete using high quality recycled fine and coarse aggregate.

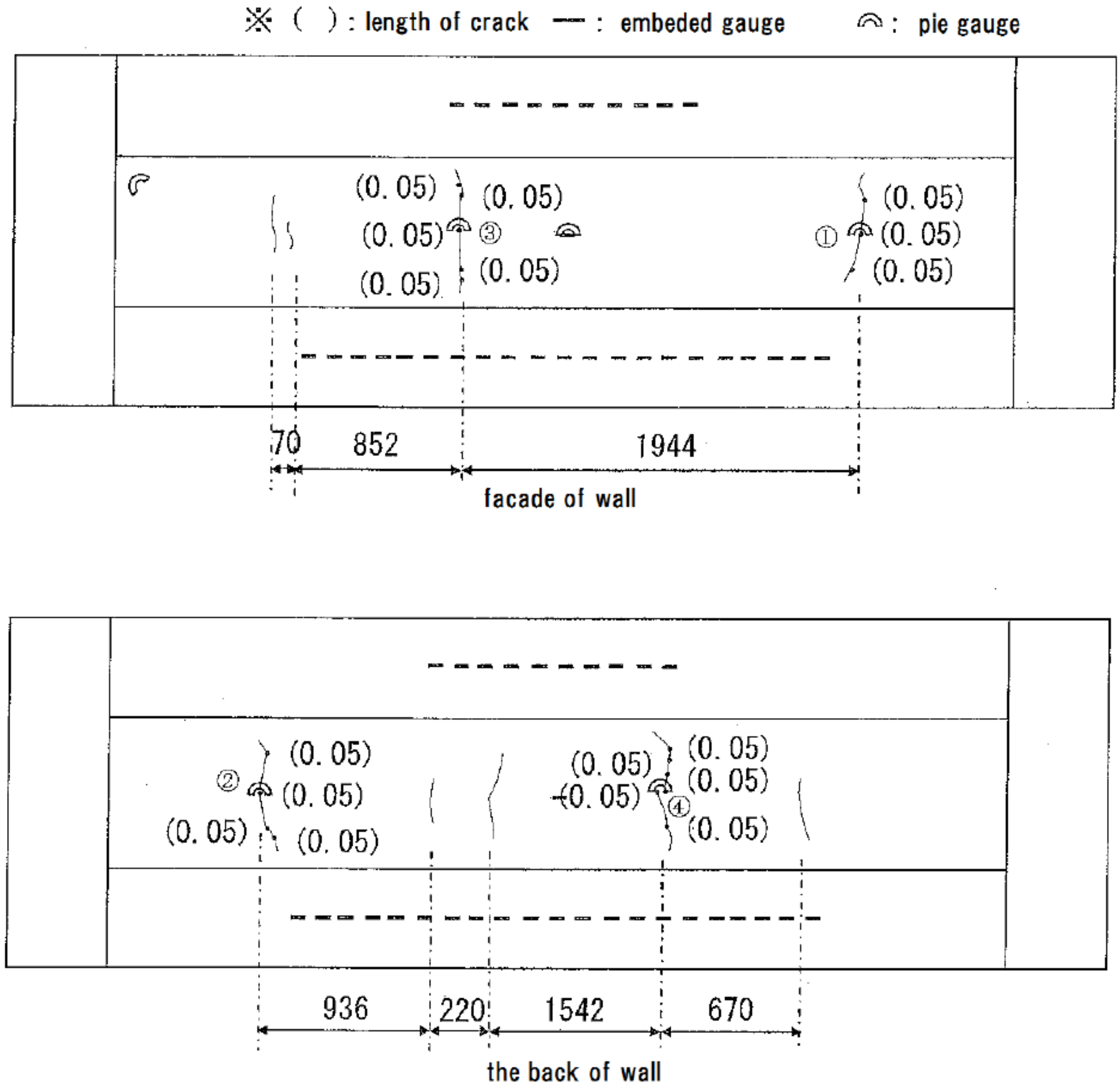
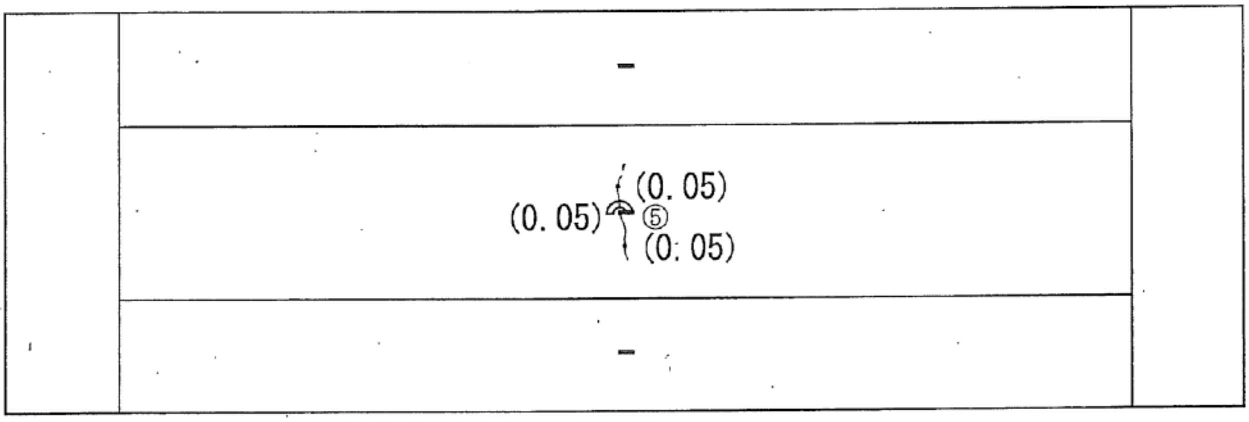
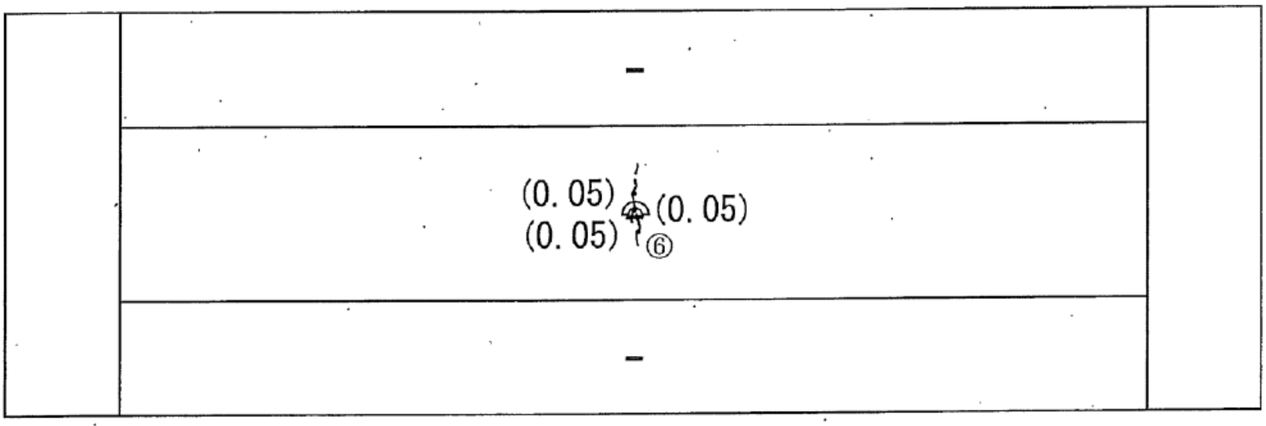



Figure 4.13 crack distribution map (SN1-GN1)

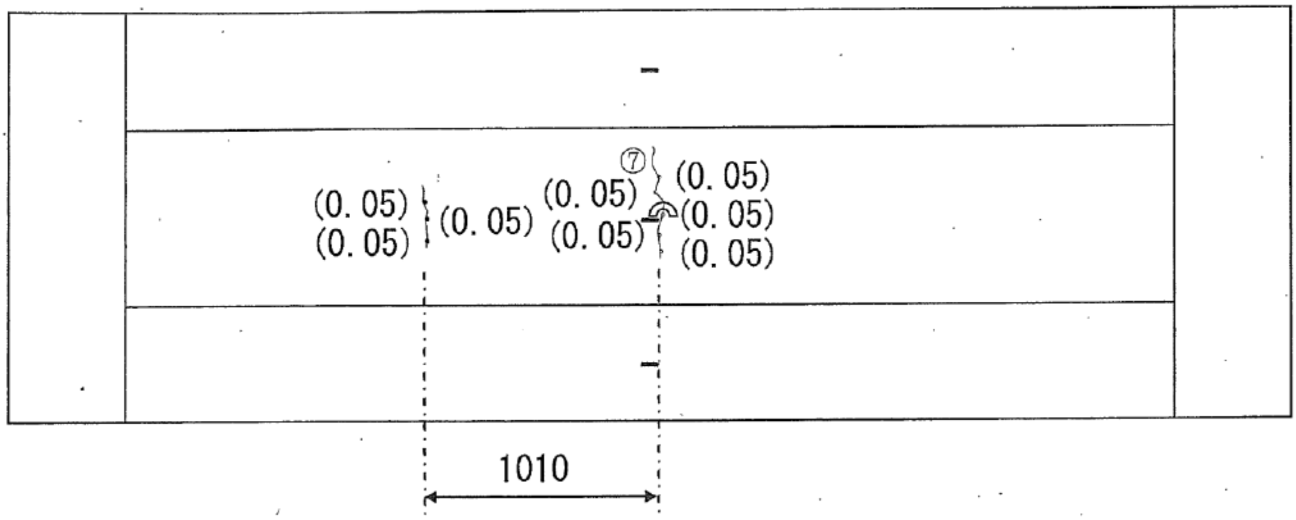



façade of wall

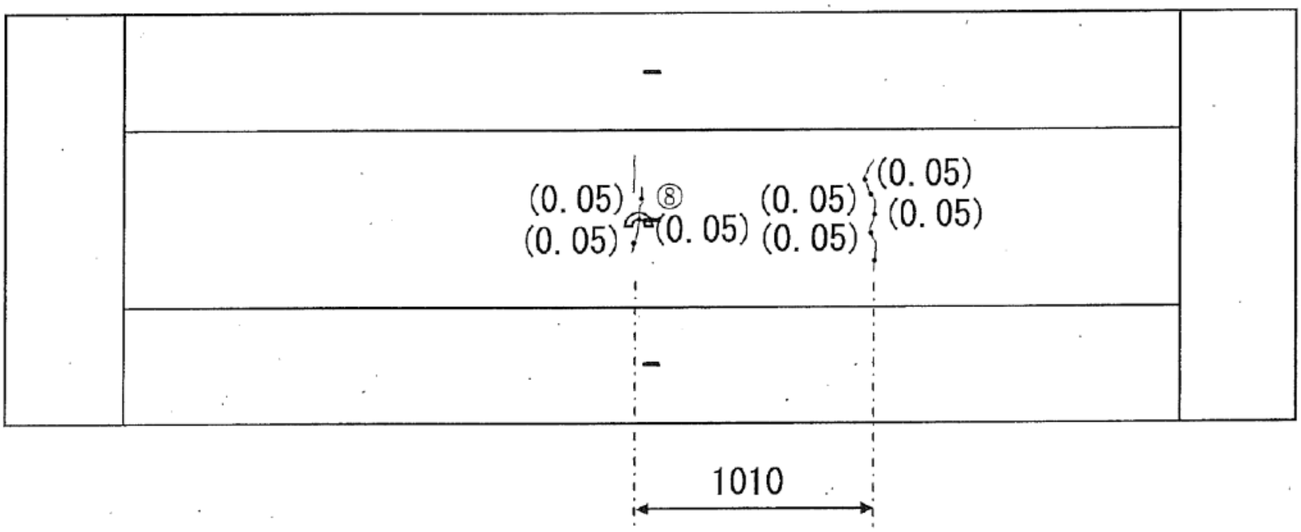



The back of wall

Figure 4.14 crack distribution map (SN1-GR1)




façade of wall

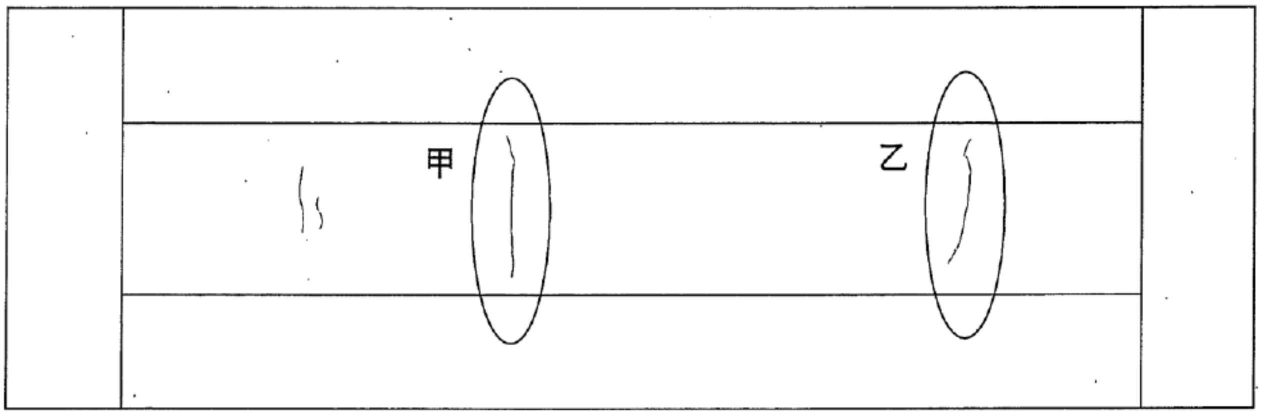



The back of wall

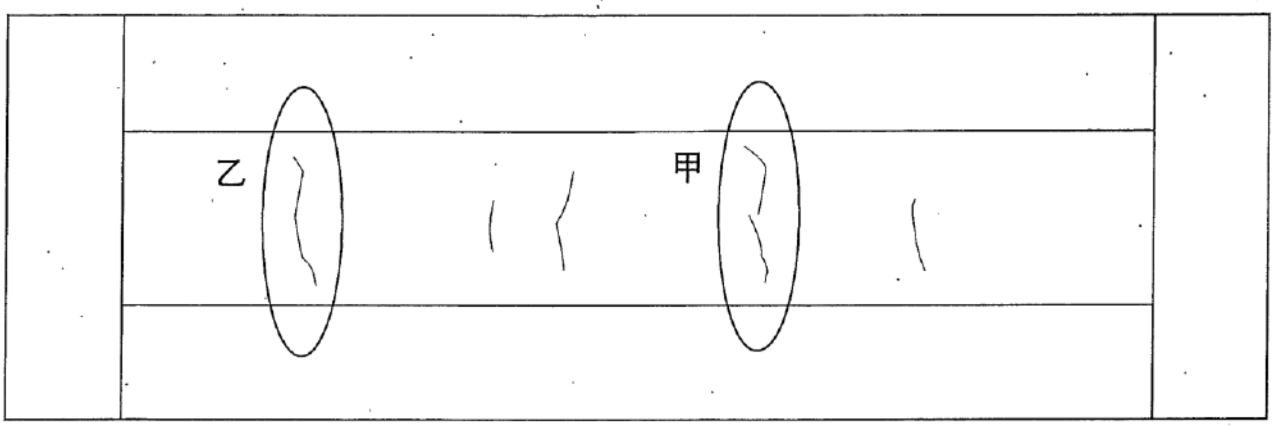
Figure 4.15　crack distribution map (SR1-GR1)

h) Distribution of strain

Figure 4.17 and 4.18 show distribution of reinforcing strain on the cracks of “甲” and “乙” shown in figure 4.16 on the concrete wall using natural aggregate. According to this figure, the reinforcing strain is going to increase to tensile side by material age and around the cracks the size is $640 \times 10^{-6}$ in 70 days of material age. Moreover the influence from cracks is 300mm and going to spread by material age. Figure 4.17 and 4.18 show range of influence for crack (甲) in strain gauge of upper beam and lower beam. The influence of the cracks is not occurred immediately and the influence of the strain spreads out gradually however the range is approximately 1000mm and smaller than the reinforcing strain gauge.




**façade of wall**




**the back of wall**

**Figure 4.16 crack distribution map (SN1-GN1)**

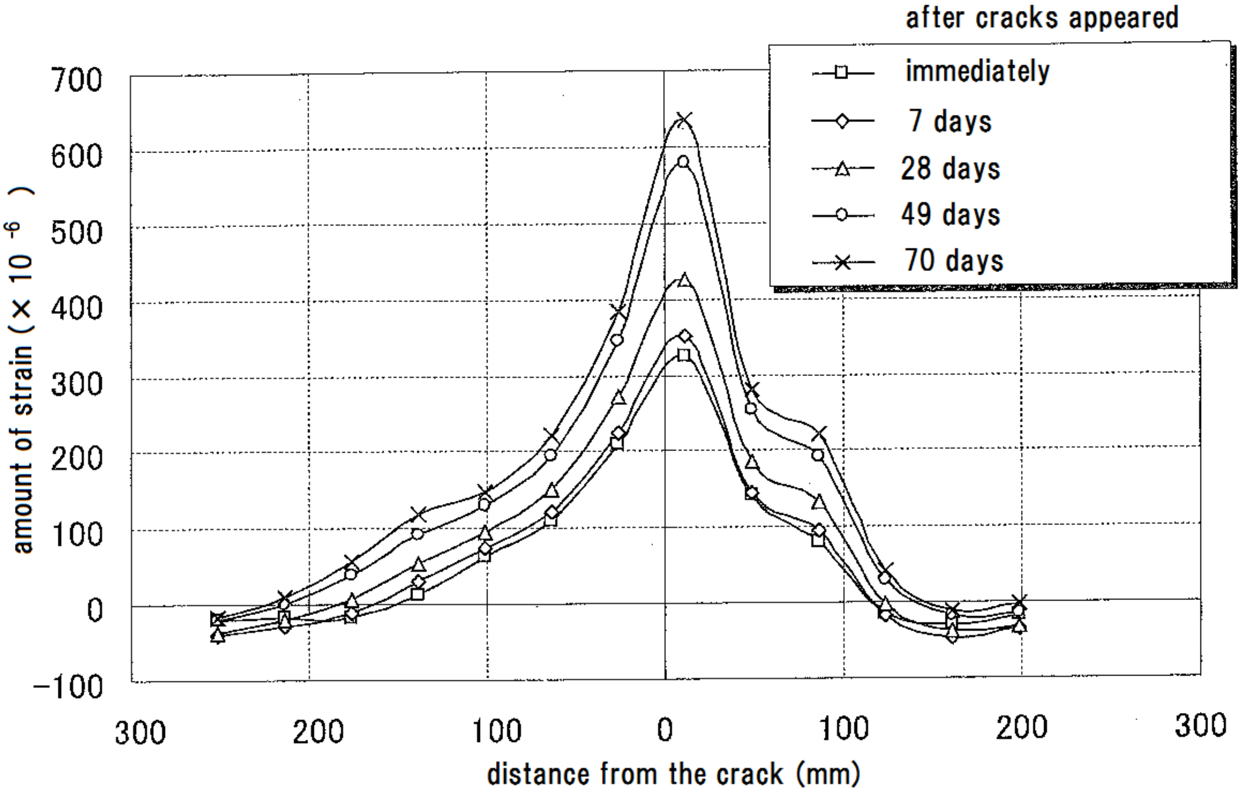



Figure 4.17 distribution of strain at the cracks (reinforcing ・甲)

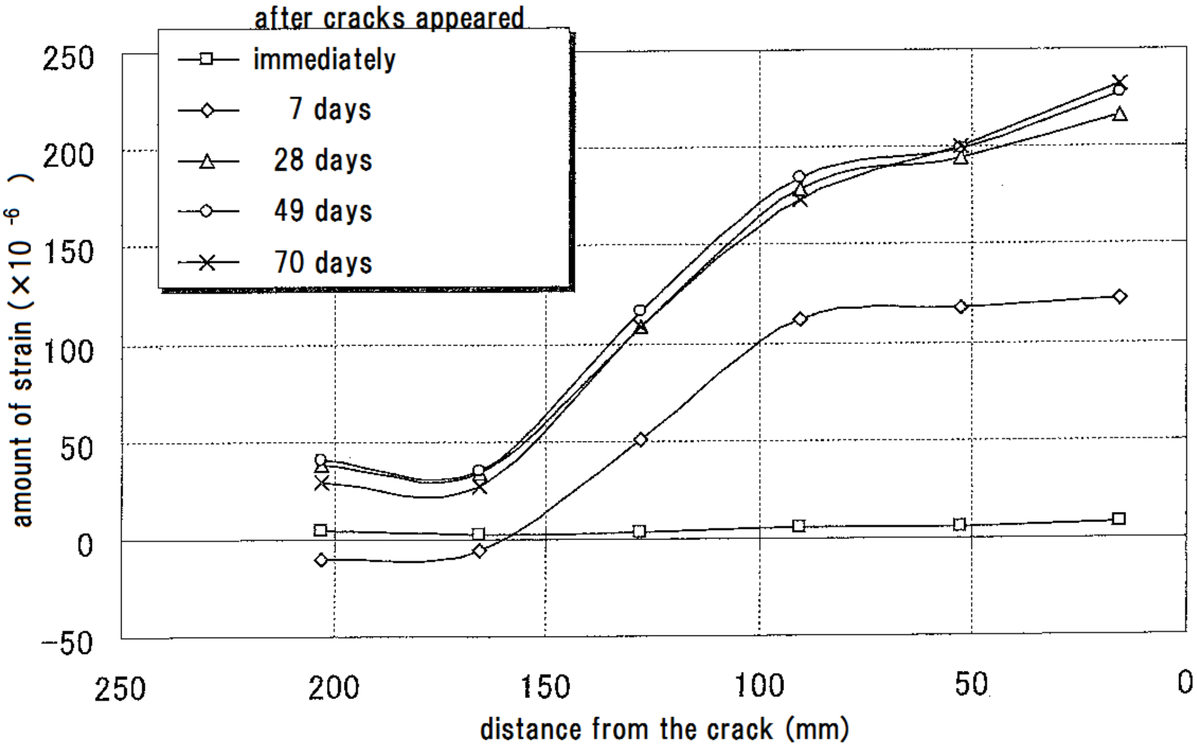



Figure 4.18 distribution of strain at the cracks (reinforcing ・乙)

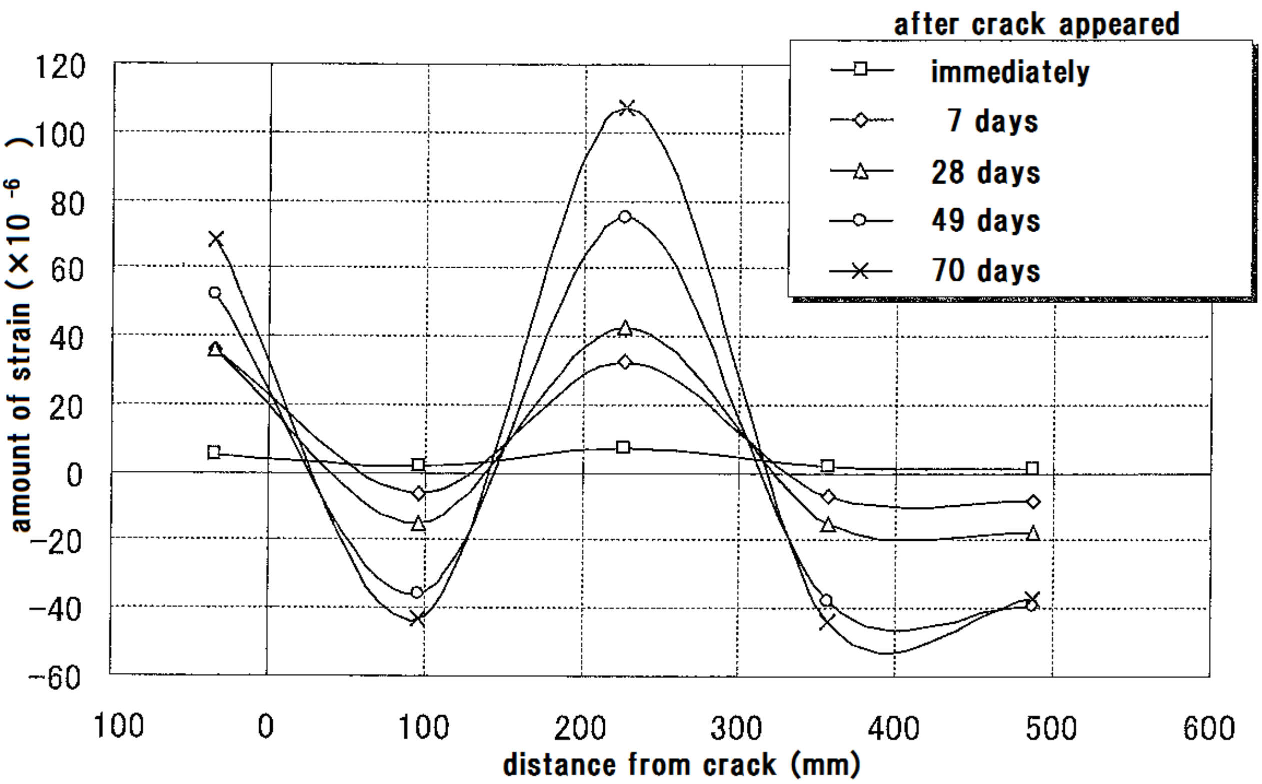



Figure 4.19 distribution of strain at the cracks (upper beam・甲)

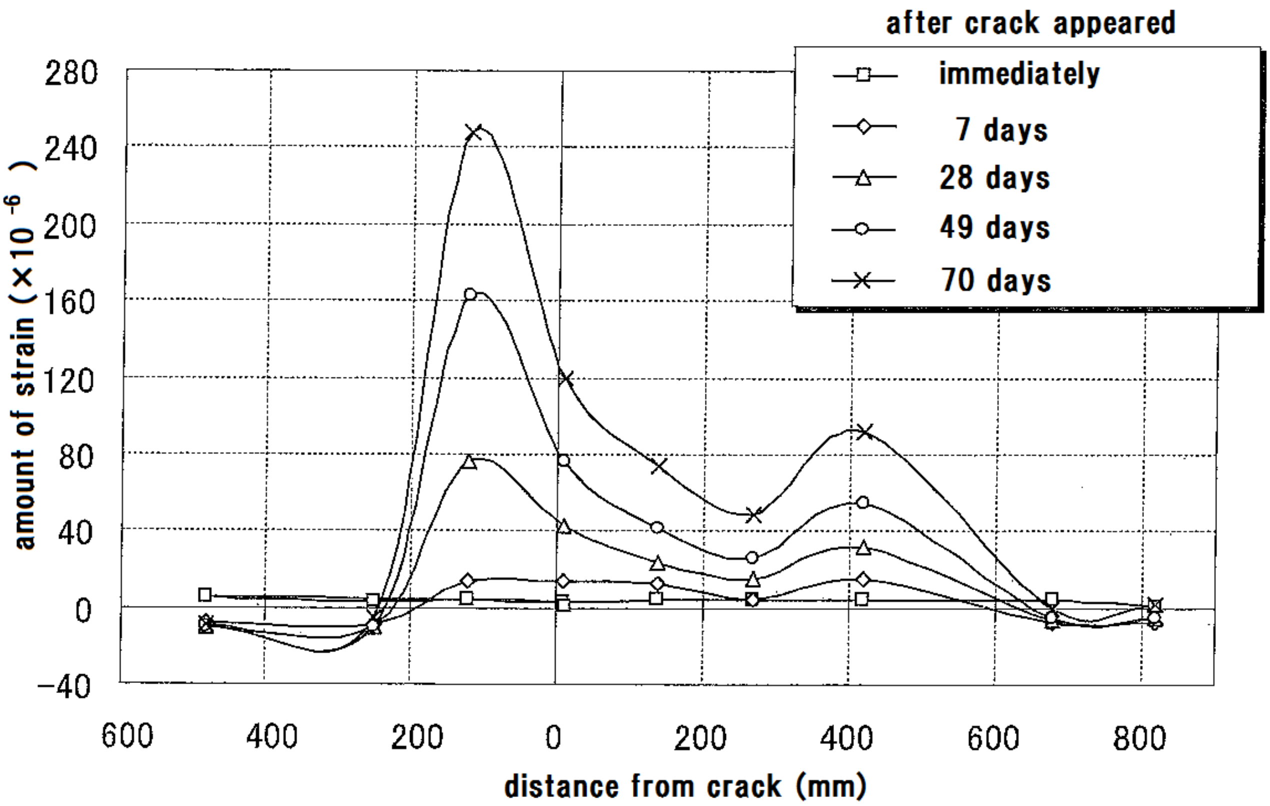



Figure 4.20 distribution of strain at the cracks (lower beam・甲)

i ) Transition of crack range

Figure 4.21 shows the transition of crack range for (⌒)①to⑧ which shown in figure 4.13, 4.14 and 4.15. The crack range of SN1-GN1 is 0.05mm at 65 days of material age and the inspection was carried out using this value as a standard. For SN1-GR1 and SR1-GR1, it is the same as 0.05mm for 120 days of material age. The crack range is not same even the façade and the back are connected, the difference between ① and ② is 0.00025mm, ③ and ④ is 0.0003mm, ⑤ and ⑥ is 0.00025mm and ⑦ and ⑧ is 0.00045mm.

※ The crack range shall be going to spread gradually, we shall observe the progress.

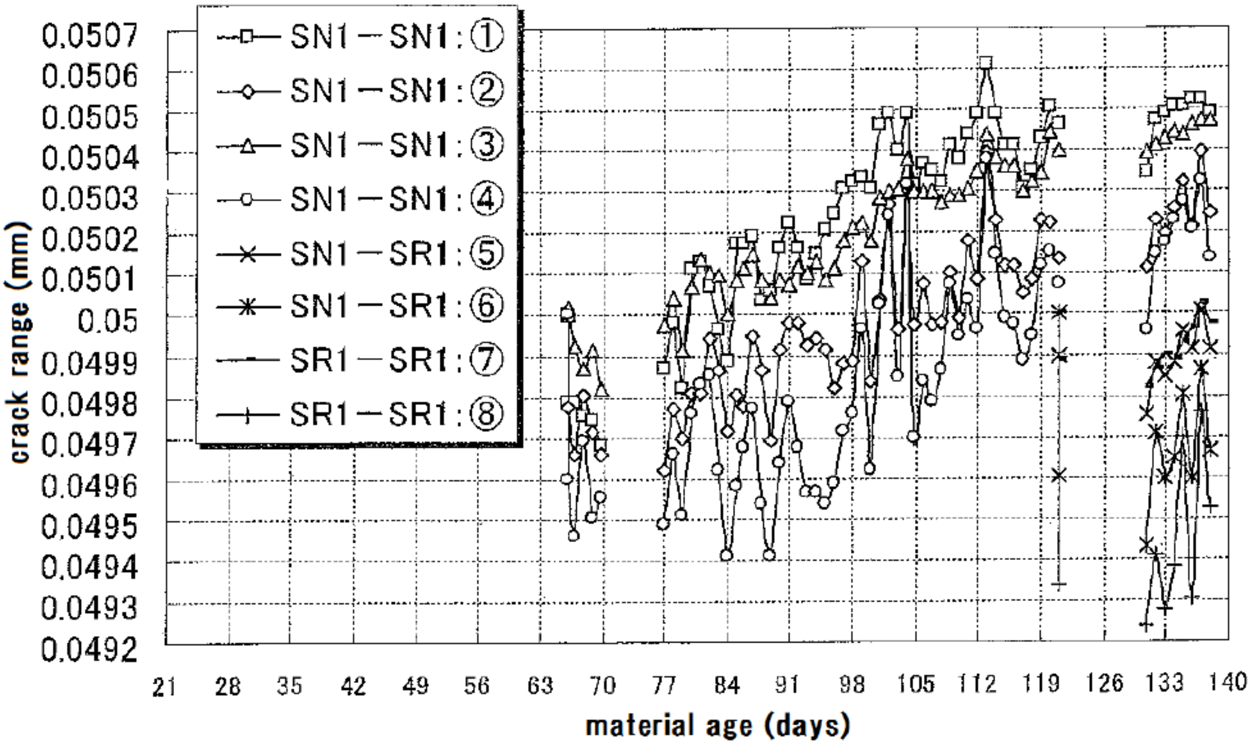



**Figure 4.21 transition of crack range**

j ) Transition of stress meter

Figure 4.22 shows the transition of stress at the edge of wall and the middle of wall of SN1-GN1. The stress at both part are transited through 85 days of material age, however the stress of the edge of wall is suddenly increased. The difference between them at the time is 0.5N/mm$^2$ .

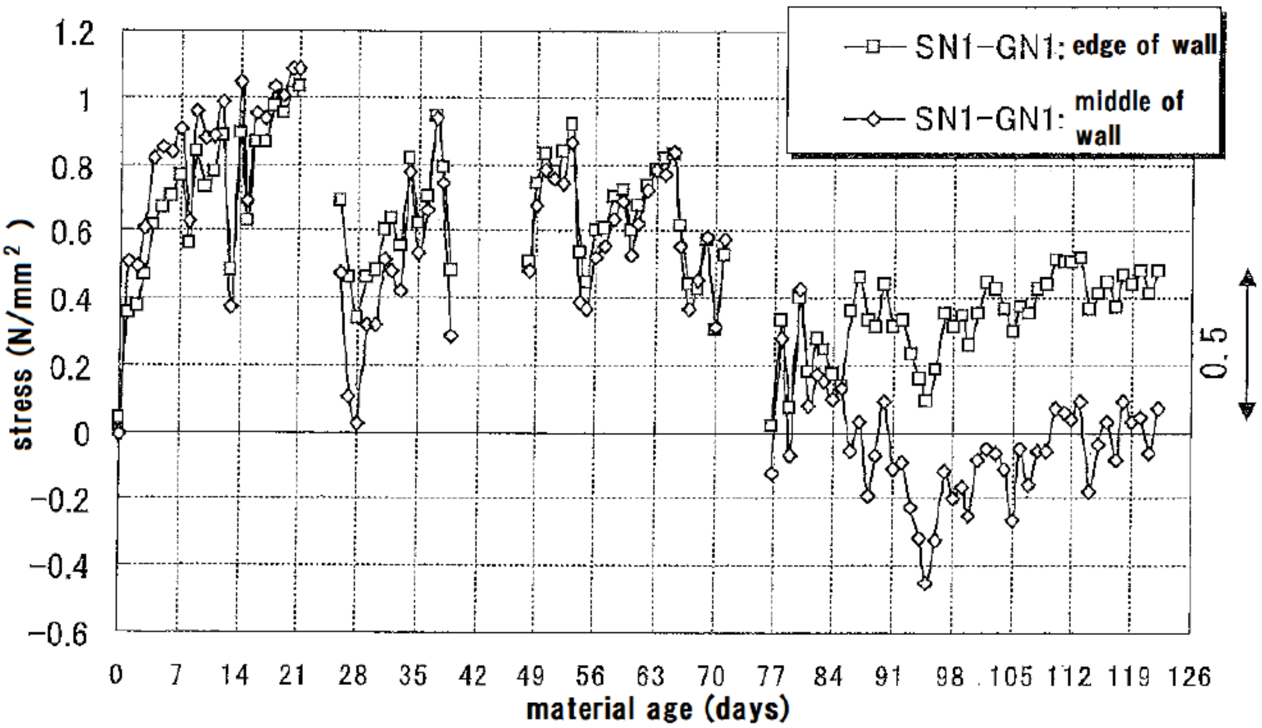



Figure 4.22 transition of stress meter

k) Transition of pie gauge

Figure 4.23 shows the transition of pie gauge placed on the upper left side and in the middle (Ref. figure 4.13). The transition of upper left side is not seen exactly. In the middle, it is suddenly shrinked at the beginning and gradually expanded. The crack is appeared at 31 days of material age and it is the proof of the influence.

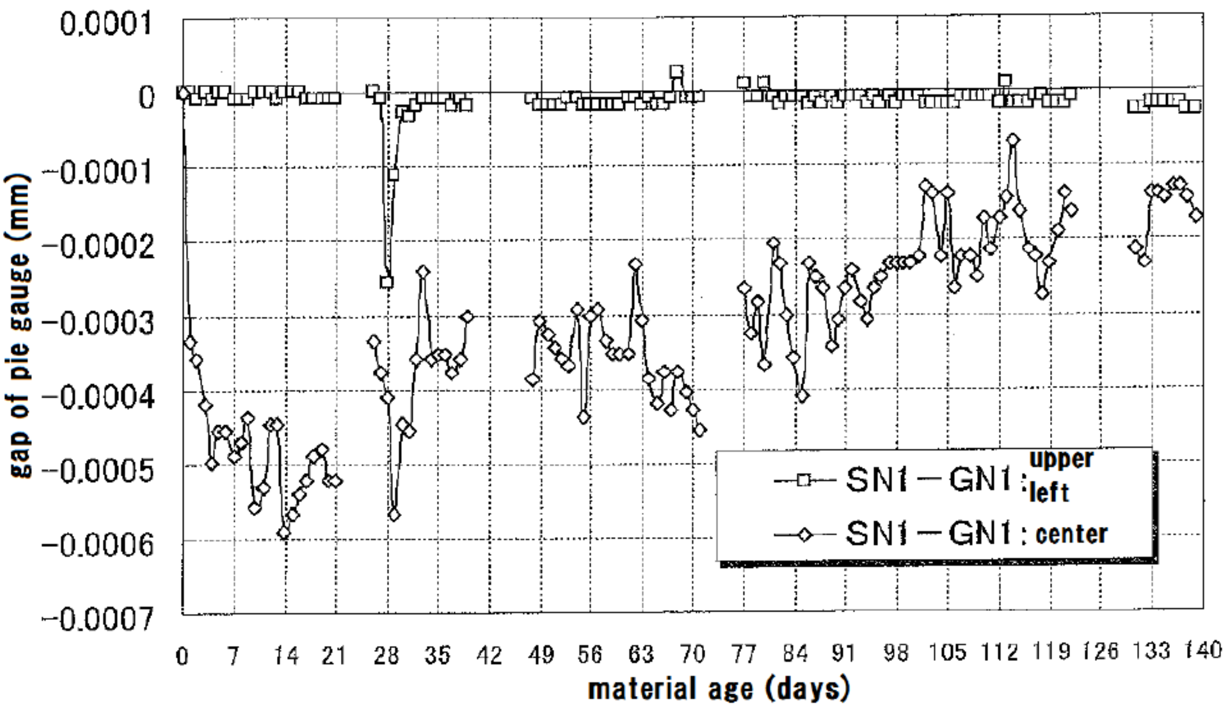



**Figure 4.23 transition of pie gauge**

According to the data for strain which collected in this experiment using actual size specimens, we are planning to analyze and examine for establishing the technology to control shrinkage crack range for the member of concrete wall.

## 5. Recapitulation

According to the experiment, the following observations were obtained.

1. According to the result of compressive strength and Young's modulus, manufacture high strength concrete by using recycled coarse aggregate type 1 shall be possible. However management of materials shall be taken into consideration for manufacturing by actual machine.

2. The compressive strength for concrete using recycled fine and coarse aggregate type 1 shall be almost same level as the concrete using natural aggregate for indoor and using actual machine experiment.

3. For concrete using recycled coarse aggregate type 1, when the water cement ratio is low, the drying shrinkage strain shall be low. When the water cement ratio is same (W/C 50%), the shrinkage strain of concrete using recycled fine and coarse aggregate type 1 shall be smaller than that of concrete using natural aggregate.

4. The carbonation resistance and freeze thaw resistance for concrete using recycled fine and coarse aggregate type 1 shall be almost as same as that of concrete using natural aggregate.

5. On the full size wall specimen, the concrete using recycled fine and coarse aggregate type 1 shall be slower the cracks appeared and less number of cracks than that of concrete using natural aggregate.

The data of strain which collected in this experiment using full size specimen shall be further analyzed with the examination to establish the technology for controlling shrinkage crack range of concrete wall member. According to the indoor and using actual machine experiment, it shall be indicated that the concrete using recycled fine and coarse aggregate type 1 has as same or even better performance than the concrete using natural aggregate. We can conjecture that it shall be the result by means of the effect of improvement for the grain shape of recycled fine aggregate. However we shall continue to explicate the mechanism, collecting data and analyzing for establishment of the performance verification type crack control design.

< References>


1) Web site of Ministry of Land, Infrastructure, Transport and Tourism (http://www.mlit.go.jp/sogoseisaku/region/recycle/refrm.htm)

2) Kenji Nakae : "*The angular stones shall be used by make it round ~ Improvement of grain shape for concrete aggregate at warm dam~"*

3) Japan Concrete Institute : "Concrete Journal" No.6 / 2000 *(Apply for the skeleton of recycled coarse aggregate concrete)*

4) Architectural Institute of Japan : *"Design construction guideline for manufacture high durability reinforced concrete (draft) and commentation"*

5) Architectural Institute of Japan : *"The calculation standard of reinforced concrete structure and commentation"*