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EFFETS OF HIGH-QUALITY RECYCLED AGGREGATE ON THE PROPERTIES OF CONCRETE FOR NUCLEAR POWER PLANTS

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ABSTRACT

This paper described the characteristics of recycled coarse aggregates aggregate produced by a wet treatment system, and the properties of concrete with it.

High-quality recycled coarse aggregate produced by this system, which consisted of two mills and a density sorter, met the specification of JIS A 5021.

Adhered mortar amount of recycled aggregate in this study was higher than that of the previous report, it was why the quality of recycled aggregate was lower. The compressive strength of concrete with recycled aggregate did not obviously become low due to crushed stone as the original stone.

The recycled aggregate was effective in reducing the drying shrinkage of concrete, it was suggested the recycled aggregate adhered mortar had high water absorption, and would probably store water at an earlier curing stage.

INTRODUCTION

In Japan, 4 kinds of recycled aggregates are specified according to the quality of the aggregate. Their recycled aggregates are classified into JASS 5N (Japanese Architectural Standard Specification JASS 5N Reinforced Concrete Work at Nuclear Power Plants), JIS A 5021” Class H” (Japanese Industrial Standard), JIS A 5022” Class M” and JIS A 5023” Class L”. The recycled aggregate of JASS 5N can be used as concrete materials of NPP, Class H is used for buildings. The usage of Class M is allowed for building materials in reinforced concrete that does not require the durability of dry shrinkage. Class L is used for unreinforced concrete.

The previous report "Kasami H., et al. (2019)" presented the basic properties of recycled concrete with high-quality recycled aggregates produced by 4 types of dry treatment system was almost the same as concrete with original stone.

In this study, a recycled coarse aggregate was produced by a different method using a wet treatment system, The compressive strength, shear strength, tensile strength and dry shrinkage of concrete using the recycled aggregate was investigated.

MANUFACTURING OF RECYCLED AGGREGATE AND MAIN APPLICATIONS

(1) MANUFACTURING PROCESS

This process is a treatment system consisting of 3 sections, The first section has two mills and a density separator for Recycled coarse aggregate, the second has a high-mesh separator for recycled fine aggregate, the third has a thickener and a filter press for sludge cake. Fig.1 shows Manufacturing of recycled aggregate, and Fig.2 shows in appearance of the facilities using in this study.

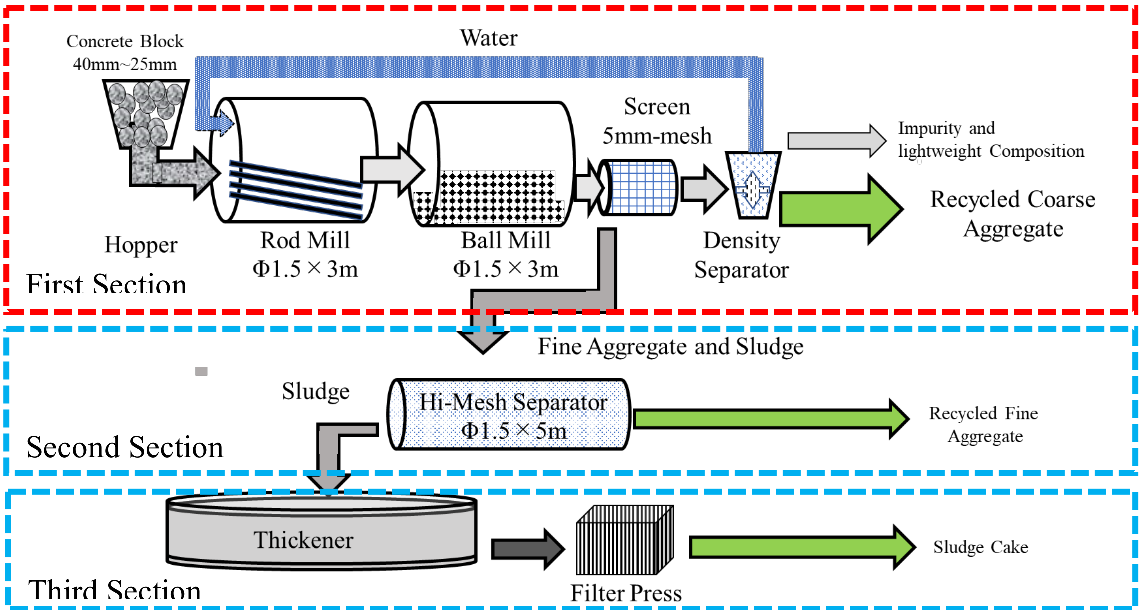
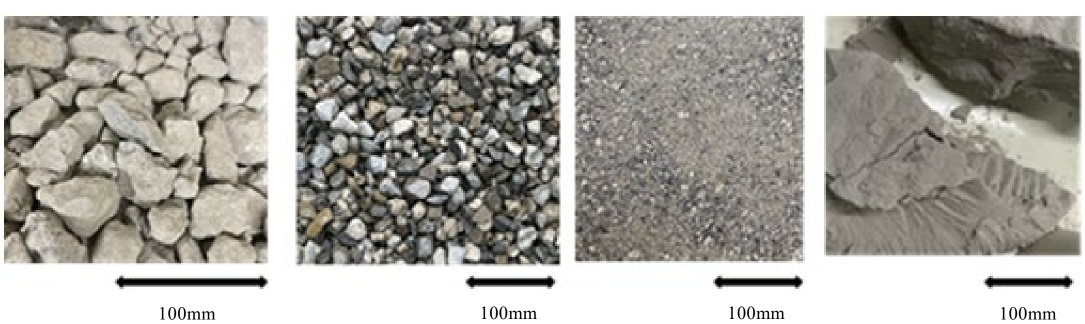


Fig.1 Wet treatment system in the production of recycled aggregates for concrete recycle

(a) Mill (b) Density separator (c) High-mesh separator

Fig.2 Facilities appearance using in this study



(a) Concrete block (b) Coarse aggregate (c) Fine aggregate (d) Sludge

Fig.3 Productions of this treatment system

THE FIRST SECTION

The raw material was demolished concrete in the suburbs of Tokyo. The block of demolished concrete was crushed to 40cm in size with a jaw crusher.

2 types of the mill were a rod mill and a ball mill, Fig.2 (a) shows in the facility appearance of the mill.

The rod mill was a cylindrical shape of 1.5m in diameter and 3m long, and had enough steel rods. A ball mill was the same shape as a rod mill, had dozens of steel balls.

Concrete block was fed into the rod mill from a hopper to the rod mill, large concrete was granulated so that the original stone would not be broken by the rod. Next, the adhered mortar and mortar particles were grounded with the ball mill. It was important to control the operating conditions so that only the mortar was rubbed and prevented the original stone from cracking, The controllable conditions were size and weight of balls, rotational speed, feed rate, and so on.

After separating between coarse and fine aggregate that contained sludge, a larger composition than 5mm was fed into a density separator. A lightweight composition as wood, plastic, and mortar particles was removed. The density separator is shown in Fig.2 (b).

THE SECOND SECTION

Rotor blade stirred the water involved fine aggregate and sludge, water with sludge was drained, the heavier composition was collected as recycled fine aggregate. The high-mesh separator is shown in Fig.2 (c).

THE THIRD SECTION

Sludge involved powder of cement hydration and stone was fed into a thickener. The sludge particles were less than 0.75 mm, and were cement hydration and stone powder. The sludge was pressed into a cake after concentration. Demolished concrete as raw materials, 2 kinds of recycled aggregates and sludge are shown in Fig.3.

(2) QUALITY OF RECYLED COARSE AGGREGATE "CLASS H"

In this study, the water absorption of the recycled coarse aggregate was 2.52%, surface -dry density was 2.52g/cm^3. The quality of this recycled aggregate was lower than in the previous study. Fig. 4 shows the water absorption and oven drying density of current and previous studies. It met the specification of JIS A 5021 "CLASS H".

The amount of adhered mortar was obtained by oven-drying the recycled coarse aggregate, dissolving it in 10% HCl aq., separating it by a 5 mm mesh, and weighing the aggregate above 5 mesh. The relationship between water absorption and adhered mortar is shown in Fig.5.This indicates that the recycled aggregate used in this study not only has a high-water absorption but also a high adhered mortar.

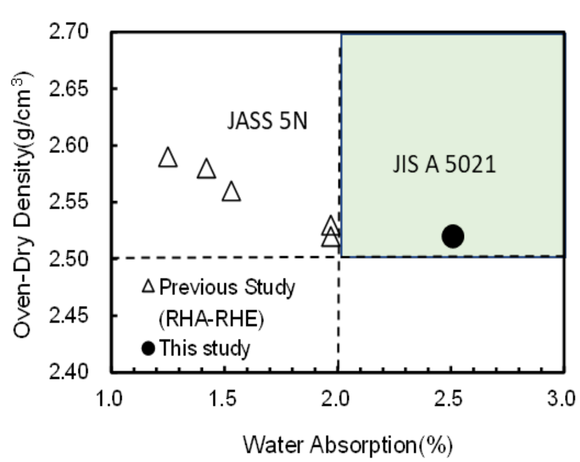


Fig.4 Relationship between water absorption and oven-dry density

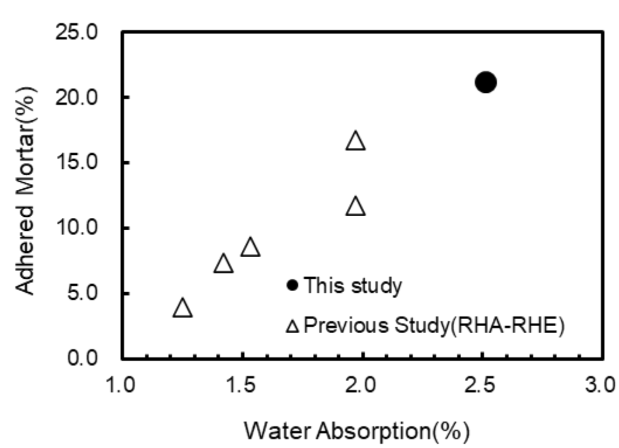


Fig.5 Relationship between water absorption and adhered mortar

(3) DIFFERENCE BETWEEEN THIS STUDY AND PREVIOUS STUDY

Table 1 shows the comparison of experimental conditions between this study and the previous study The quality of this recycled aggregate was lower than in previous studies. Also, the unit water was kept constant in this study. On the other hand, in the previous study, the unit water was determined according to the characteristics of the recycled aggregate.

Table 1 Comparison of experimental conditions

Materials		This study	Previous study
Recycled coarse aggregate	Type of manufacturing	Wet method	Dry methods
	Original aggregate	Several kinds of crushed stone	One kind of river stone
	Water absorption(%)	2.52	1.25-1.97
	Oven-dry density(g/cm^3)	2.52	2.52-2.59
	Adhered mortar (%)	21.2	4.0-16.7
	Compatible standerd	JIS A 5021*	JASS 5N**
Cement	Type	Moderate-Heat Poltland Cement	Fly ash cement
Mix proportion	Unit water (kg/m^3)	Constant 178	Appropriate 149-157

*:Japan Industrial Standard

**:Japanese Architectural Standard Specification

EXPERMENTAL OVERVIEW

MATERIALS AND MIX PROPRTION

The quality of aggregates and materials are shown in Table 1. Concrete was mixed with a 50L paddle mixer in a laboratory at 20°C. All materials were kept at 20°C. The mix proportion and results of fresh concrete are shown in Table 2.

Table 2 The quality of aggregates and materials

Materials	Symbol	Kind of Materials	Water Absorption (%)	Surface-Dry Density (g/cm^3)	Oven-Dry Density (g/cm^3)	Max Size (mm)	F.M.	Solid Volune (%)
Coarse Aggregate	RG	Recycled Aggregate	2.52	2.58	2.52	20.00	6.7	60.5
	G	Crushed Rock	0.69	2.64	2.62	20.00	6.8	59.1
	JIS A 5021		≦3.0		≧2.5	-	-	-
Fine Aggregate	S	Land Sand	1.65	2.58	2.54	5.00	2.7	-

Materials	Symbol	Kind of Materials	Density (g/cm^3)	-
Cement	MPC	Moderate-Heat Poltland Cement	3.21	-
Admixture	Ad	AE Water- Reducing Agent Standerd I	1.09~1.13	-
Admixture	AE	Air-entraining Agent (Potasium Rosiate)	1.03~1.05	-
Admixture	DF	Anti-foarming Agent (Noninic Surfactant)	0.96~1.00	-

Table 3 The mix proportion and results of fresh concrete

Symbol	Aggregate		W/B (%)	Unit bulk volume of coarse aggregate	s/a (%)	Unit of weight (kg/m^3)					Ad (MPC×%)※	AE (MPC×%)※	Slump (cm)	Air (%)
	Coarse	Fine				W	MPC	S	G	RG				
G60	G	S	60	0.62	46.9	178	297	828	960	-	1.250	0.015	19.0	5.5
RG60	RG	S	60	0.60	46.9	178	297	828	-	938	1.175	0.010	20.0	5.3
G50	G	S	50	0.62	45.4	178	356	781	960	-	1.250	0.012	19.7	5.5
RG50	RG	S	50	0.60	45.4	178	356	781	-	938	1.050	0.010	19.5	5.9

EXPRIMENTAL ITEM AND CURING METHODS

Compressive strength and Young's modulus: The concrete specimen was a cylinder with a diameter of 10 cm and a length of 20 cm. There were 3 kinds of curing conditions.

One condition (28day Standard curing) was submerging and keeping in a water tank at 20℃ for 28days until the date of testing. Another (13 weeks Sealed curing) was sealed double plastic sheet and stick vinyl taped to the top of the mold containing the specimen for 13 weeks. The other (26weeks Air after sealed curing) was to cure for 13 weeks while exposed 60% R.H. and 20℃, after keeping for 13 weeks at 20℃ under sealed curing.

Shear strength: Specimen size was 100×100×200mm, measurement span length was 100mm. The load rate was constant at 0.06 N / mm^2 as the rate of increase in strength. Shear strength method was based on “Test method for shear strength of steel fibber reinforced concrete” by Japan Society of Civil Engineers.

Tensile strength: Specimens were 100mm cubic of the central block remaining after shear strength test. This method was performed using the same method as specified in “BS-1881 Part-117 Method for determination of tensile splitting strength”. Shear strength is shown in Fig.6.

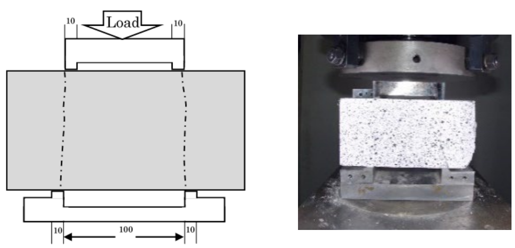


Fig.6 Shear Strength Test

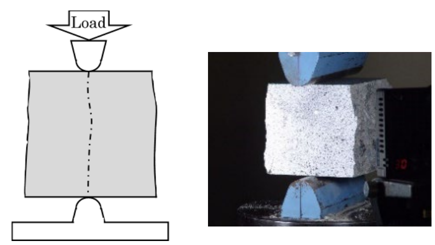


Fig.7 Tensile Strength Test

Dry-shrinkage: The size of the specimen was 10×10×40cm. It consisted of measuring the change in the size of the specimen when dried in a laboratory room at 20℃ and 60% relative humidity until 26 weeks. The initial length was the data measured when the module was removed and then cured in water tank at 20 ° C for 6 days. Tensile strength is shown in Fig.7.

EXPRIMENTAL RESULTS

(1) COMPRESSIVE STRENGH AND YOUNG’S MODULUS

The results of Compressive strength and Young’s modulus are shown in Fig.8,9. The compressive strength of water-cement ratio 60% between concrete with crushed stone and with recycled aggregate was not obviously different. At the water-cement ratio 50%, the compressive strength of concrete using recycled aggregate was lower than that of crushed stone, and this tendency was implied especially in the sealed curing state. The Young's modulus of concrete with crushed stone and with recycled aggregate was similar regardless of the water-cement ratio.

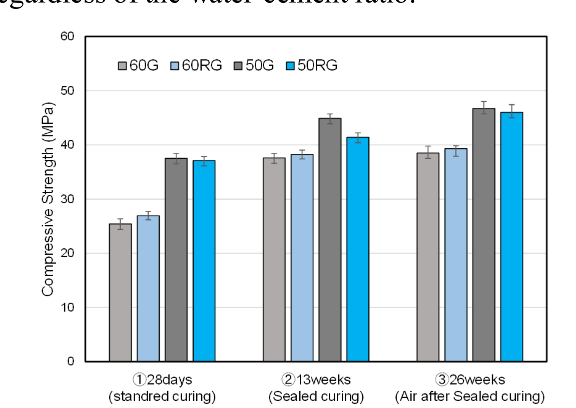


Fig.8 Compressive strength of concrete

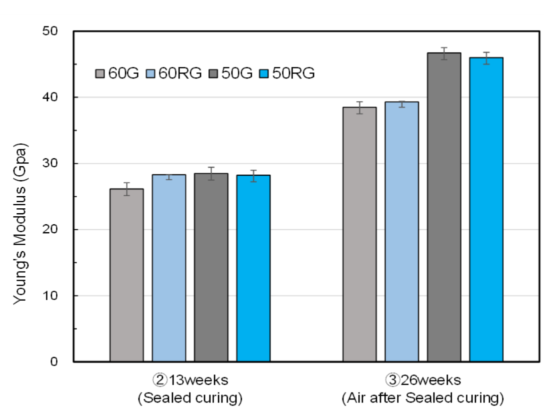


Fig.9 Young’s modulus of concrete

(2) SHEAR STRENGTH AND TENSILE STRENGTH

The results for shear strength and tensile strength are shown in Fig.10, 11.

In the case of a water-cement ratio of 60%, the shear strength of concrete was almost the same, even which was used recycled aggregate. At a water-cement ratio of 50%, the shear strength of concrete using recycled aggregate was lower and the tendency was the same for both curing conditions.

Fig.12 shows the shear plane of concrete.

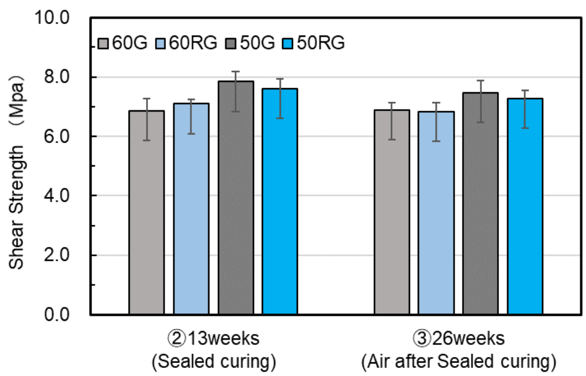


Fig.10 Shear strength of concrete

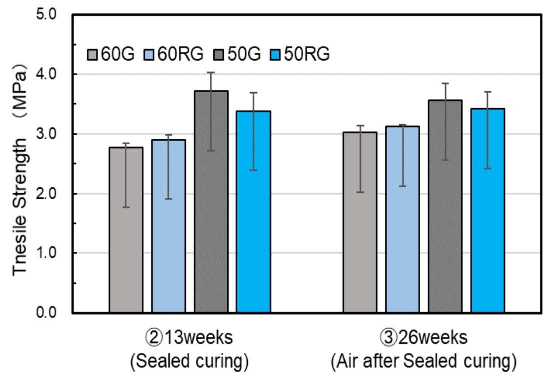
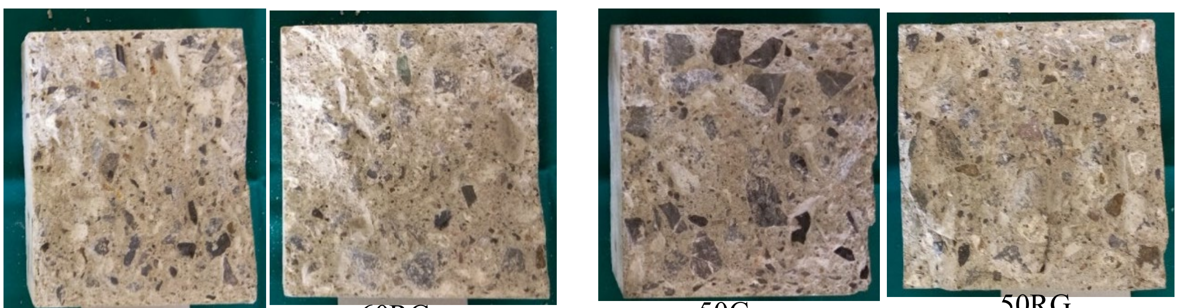


Fig.11 Tensile strength of concrete



60G 60RG 50G 50RG

Fig.12 Shear plane of concrete at the curing condition [③26weeks]

In the water-cement ratio 60%, the concretes with crushed stone and recycled aggregate also sheared on the boundary between aggregate and cement hydration.

In the water-cement ratio 50%, the surface of the stone broken by shear failure could be identified on the shear plane of concrete containing crushed stone. On the other hand, the fractured surface of the stone was not found in concrete with recycled aggregate. This indicates that the concrete with recycled aggregate sheared at the boundary between recycled aggregate and cement hydration and would not fracture an aggregate itself. The effect of recycled aggregate on the tensile strength of concrete was like that of shear strength.

The adhered mortar of recycled aggregate absorbed water from the concrete, inhibiting hydration at the boundary and weakening the bond strength around the aggregate.

(3) DRY SHRINKAGE

The dry shrinkage of concrete is shown in Fig.13. The dry shrinkage of concrete with recycled aggregate was smaller than that of crushed stone, and this tendency became stronger at a water-cement ratio 50%.

The decrease of concrete weight is shown in Fig.14. On the whole, the decrease of concrete weight lied on the water-cement ratio, and that of concrete with recycled aggregate was smaller than with crushed stone when the water-cement ratio was constant. Thus, concrete with recycled aggregate had smaller dry shrinkage and weight reduction ratio than the concrete with crushed stone.

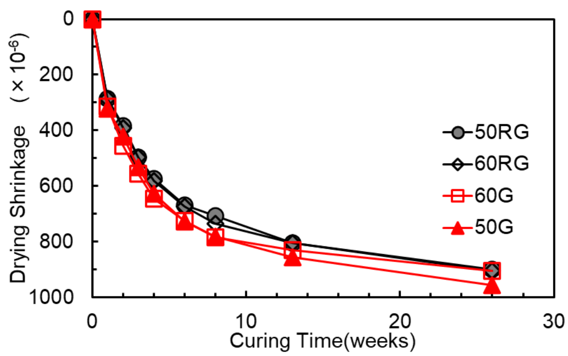


Fig.13 Effect recycled aggregate on dry shrinkage of concrete

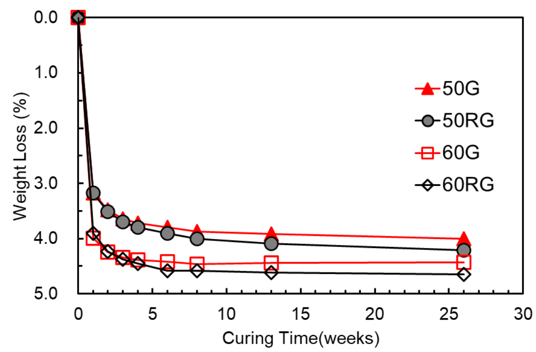


Fig.14 Effect recycled aggregate on weight of concrete

CONCLUSION

We have researched and studied characteristics of recycled aggregate and the performance of recycled concrete for 3 decades. The latest report described that the production of high-quality recycled aggregate had been developed and that the quality of said aggregate was the same as that of the original stone. Unit water content of concrete with a round recycled aggregate was lower than that with crushed stone. Compressive strength of concrete with recycled aggregate was slightly lower than that of crushed stone with the same water cement ratio. The shrinkage of concrete with recycled aggregate was obviously smaller than that with crushed stone.

At this time, the recycled aggregate which met JIS standards was produced by a different method, and the effect of recycled aggregate quality on the strength and drying shrinkage of concrete was experimentally investigated.

This study shows a comparison between compressive strength, shear strength, and dry shrinkage of concrete with recycled coarse aggregate and that of crushed stone. As a result, the following conclusions were reached.

(1) The recycled coarse aggregate produced by a wet system consisting of multiple mills and a density separator met the specification of JIS A 5021 "Class H"
(2) The compressive strength of concrete with recycled aggregate was not lower than expected. It was because the original stone was crushed stone.
(3) The Young's modulus of concrete containing crushed stone and concrete containing recycled aggregate was similar regardless of the water-cement ratio.
(4) The shear strength of concrete containing recycled aggregate was lower than that contained crushed stone. It suggested that the cement hydration around an adhered mortar would be inhibited. The study of clarifying the mechanism is ongoing.
(5) The effect of recycled aggregate on drying shrinkage in this study was smaller than that in the previous study because the shape of the recycled aggregate had an additional water-reducing effect in the previous study. In this study, the recycled aggregate itself was effective in reducing the drying shrinkage of concrete, possibly because the recycled aggregate itself absorbed water at early curing.

REFERENCES

Kasami, H., Tateyashiki, H., et al.(2019).”Research and standardization of high-quality recycled aggregates for concrete in nuclear power plants”, SMiRT25, Charlotte, USA