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Research Paper

Material Design for Concrete Using Low-Quality Recycled Aggregate

Nguyen Anh Duc [a,*], *Dosho Yasuhiro* [b], *Nishikigi Kenji* [a], *Dinh Van Linh* [a]

[a] *Graduate School of Science and Technology, Meijo University, Nagoya, Japan*

[b] *Prof. Dept. of Environmental Technology, Meijo University, Nagoya, Japan*

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ABSTRACT

Since the 19th century, concrete has been a fundamental construction material. It is the most popular manmade material in the world because of its more reliable workability, greater durability, and lower cost compared with other construction materials. However, because of its durability, demolishing or renovating old structures generates a huge amount of concrete waste, which, if not properly treated or reused, can adversely affect the environment. Therefore, the development of concrete-recycling technology is a necessary and pressing requirement for all the countries. This study concerns material design with concrete using low-quality recycled aggregates prepared via an aggregate replacement method. To evaluate the quality of the aggregates in recycled aggregate concrete, experiments were conducted using specimen groups characterized by various mix proportions. Accordingly, when low-quality recycled aggregate is used, by employing the relative quality index method for material design, the manufacturing of recycled aggregate concrete with required performance could be achieved.

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1 Introduction

Vietnam is a developing country located in Southeast Asia. In the 21st century, Vietnam has achieved great economic and social progress. Simultaneously, the infrastructure has been quickly constructed to satisfy the demands of development. Concrete is still the most popular construction material in Vietnam owing to its more reliable workability, greater durability, and lower cost compared to other construction materials. However, owing to its durability, demolishing or renovating old structures generates the huge amounts of concrete waste, which is very difficult to recycle effectively.

In Hanoi, the capital of Vietnam, the amount of construction waste generated will reach (in tons per day) 2,100 in 2020, 3,400 in 2030, and 4,800 in 2050, according to forecasts [1]. Currently, construction waste in Vietnam is not effectively treated or recycled, which can adversely affect the environment.

* *Corresponding author. Tel.: +81 52-832-1151.*
E-mail address: 203443501@ccmailg.meijo-u.ac.jp

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In contrast, Japan’s Building Contractors Society has been studying recycled aggregate concrete since the 1973 oil crisis [2]. Therefore, to promote and disseminate recycled aggregate concrete, Vietnam’s Government must increase research in this field and enact policies to encourage the use of recycled construction waste for people and enterprises.

This study applied material design using relative quality index method to produce recycled aggregate concrete-class M in accordance with Japanese Industrial Standard JIS A 5022. Experiments for concrete specimen groups that used low-quality recycled aggregate in different replacement ratios were conducted. Consequently, when mixing low-quality recycled aggregate with normal aggregate using the employing the relative quality index method for material design, the manufacturing of recycled aggregate concrete with required performance could be achieved.

2 Outline of experiment

2.1 Material

2.1.1 Cement

Ordinary Portland cement (N) was used in accordance with JIS R 5210.

2.1.2 Aggregate

As shown in Table 1, river sand (NS) and crushed sand (CS) were used as normal fine aggregates and crushed stone 2005

Table 1 – Quality of aggregate.

Item		Test method	NS*1		CS*2	NG*3		RLS		RLG*4	
Density in oven-dry condition (g/cm^3)		JIS A 1109	2.60	2.60	2.52	2.61	2.61	2.14	2.06	2.27	2.22
Absorption (%)		JIS A 1110	1.46	1.44	1.60	1.17	1.21	8.45	10.25	5.66	6.84
Fineness modulus (F.M.)		JIS A 1102	2.55	2.74	2.63	6.60	6.57	3.37	3.09	6.57	6.46
Materials finer than 75-µm sieve (%)		JIS A 1103	1.9	1.6	4.5	1.1	1.7	5.5	7.0	0.3	0.6
Solid content (%)		JIS A 1104	62.8	64.8	67.1	60.6	58.6	65.2	69.8	61.0	61.6
Solid content in aggregate (%)		JIS A 5005	-	-	58.2	59.8	58.3	60.3	66.1	59.9	63.2
Amount of contained impurities*5 (mass %)	A	JIS A 5023	-	-	-	-	-	0	0	0.3	0.1
	B							0	0	0	0
	C							0	0	0	0
	D							0	0	0	0
	E							0	0	0	0
	F							0	0	0	0
	G							0	0	0	0
	Total							0	0	0.3	0.1

*1 NS: Sand from Ibi River. *2 CS: Crushed sand from Shinshiro. *3 NG: Crushed stone from Shinshiro. *4 RLG is mixed by 15 to 5 mm recycled coarse aggregate class L and 20 to 15 mm recycled coarse aggregate class L with the same weight. *5 Classification of A~G according to JIS A 5023.

(NG) was used as the normal coarse aggregate. Recycled coarse aggregate class L 2005 (RLG) and recycled fine aggregate class L (RLS) were produced that satisfied JIS A 5023. In this study, RLG and RLS were mixed with normal aggregates with various replacement ratios as an aggregate replacement method to prepare recycled aggregate Concrete-Class M in accordance with JIS A 5022.

2.2 Mix proportions

Table 2 – Mix proportion.

Specimen[*1]	Mix proportion					Unit weight (kg/m^3)							Ad[*3] ($C\times\%$)
	Cement	Replacement ratio (%)		W/C (%)	s/a (%)	W	C	NS	CS	NG	RLS	RLG	
		RLG[*2]	RLS										
NGNS-45	N	0	0	45	43.5	183	407	736	-	960	-	-	1.00
NGRLS100-45		0	100	45	43.5	183	407	-	-	960	649	-	1.00
RLG50NS-45		50	0	45	43.5	183	407	736	-	480	-	436	1.00
RLG50RLS30-45		50	30	45	45.3	183	407	-	523	464	199	417	1.00
RLG50RLS50-45		50	50	45	43.5	183	407	368	-	480	324	436	1.00
RLG100NS-45		100	0	45	43.5	183	407	736	-	-	-	872	1.00
NGCS-55		0	0	55	47.6	180	327	-	819	928	-	-	1.00
NGNS-55		0	0	55	45.8	180	327	810		960	-	-	1.00
NGRLS30-55		0	30	55	47.6	180	327	-	573	928	218	-	1.00
NGRLS50-55		0	50	55	45.8	180	327	405	-	960	357	-	1.00
NGRLS100-55		0	100	55	45.8	180	327	-	-	960	714	-	1.00
RLG50CS-55		50	0	55	47.6	180	327	-	819	464	-	417	1.00
RLG50NS-55		50	0	55	45.8	180	327	810	-	480	-	436	1.00
RLG50RLS30-55		50	30	55	47.6	180	327	-	573	464	218	417	1.00
RLG50RLS50-55		50	50	55	45.8	180	327	405	-	480	357	436	1.00
RLG100NS-55		100	0	55	45.8	180	327	810	-	-	-	872	1.00
NGNS-65		0	0	65	47.4	177	272	863	-	960	-	-	1.00
NGRLS100-65		0	100	65	47.4	177	272	-	-	960	761	-	1.00
RLG50NS-65		50	0	65	47.4	177	272	863	-	480	-	436	1.00
RLG50RLS30-65		50	30	65	49.2	177	272	-	610	464	232	417	1.00
RLG50RLS50-65		50	50	65	47.4	177	272	432	-	480	381	436	1.00
RLG100NS-65		100	0	65	47.4	177	272	863	-	-	-	872	1.00

*1 Specimens were named by type of recycled aggregate used, replacement ratio, and W/C ratio. *2 RLG is mixed by 15 to 5 mm recycled coarse aggregate class L and 20 to 15 mm recycled coarse aggregate class L with the same weight. *3 Ad: Air-entraining and water-reducing admixture.

Table 2 shows the mix proportions used in the experiment. The water-cement ratios (W/C) were 45%, 55%, and 65%.

Furthermore, the recycled aggregate replacement ratios were 0%, 30% (only RLS), 50%, and 100%. In total, 22 specimen groups were made and divided into three groups of W/C ratio. For all the specimen groups, a target slump of 18.0 ± 2.5cm and a target air content of 4.5 ± 1.5% were selected.

2.3 Experiments and test methods

Implemented experiments and test methods are shown in Table 3.

Table 3 – Experiment and test method.

Type	Experiment	Test method	Remark
Fresh concrete	Slump	JIS A1101	-
	Air content	JIS A 1128	-
	Density	JIS A 1116	-
	Temperature	JIS A 1156	-
	Chloride ion content	JIS A 5308 JASS 5 T-502	Electrode current method and Mohr method
Hardened concrete	Compressive strength	JIS A 1108	Standard curing method 4 weeks,13 weeks
	Static modulus of elasticity	JIS A 1149	
	Drying shrinkage	JIS A 1129-3	At 26 weeks
	Accelerated carbonation depth	JIS A 1153	-
	Durability factor	JIS A 1148	Experiment method A

3 Experiment result

3.1 Fresh concrete

Table 4 shows the experiment results for fresh concrete.

3.1.1 Slump and air content

All specimens satisfied the experiments target slump of 18.0 ± 2.5 cm and target air content of 4.5 ± 1.5%. Furthermore, the aggregate correction factor for air content was larger when the replacement ratio of RLS increased.

3.1.2 Density and chloride ion content

Density tended to be lower when the replacement ratio of RLG and RLS increased. Furthermore, the chloride ion content of all specimens satisfied the value established in JIS A 5308 ($\leq$0.30 kg/m^3).

Table 4 – Experiment result of fresh concrete.

Specimen	Slump (*cm*)	Air content (*%*)*1	Density (*kg/m³*)	Temperature (℃)	Chloride ion content (*kg/m³*)*2
NGNS-45	19.5	4.4(0.2)	2299	28.0	0.03
NGRLS100-45	16.5	3.9(1.6)	2250	25.8	0.12
RLG50NS-45	19.0	4.2(0.3)	2277	24.1	0.10
RLG50RLS30-45	20.5	3.6(0.4)	2251	27.6	0.14
RLG50RLS50-45	18.0	4.4(0.6)	2226	24.8	0.11
RLG100NS-45	20.0	5.0(0.5)	2184	28.0	0.06
NGCS-55	18.5	4.4(0.0)	2318	26.0	0.04
NGNS-55	18.0	4.1(0.2)	2336	28.4	0.02
NGRLS30-55	20.0	3.9(0.4)	2274	28.7	0.12
NGRLS50-55	19.5	4.3(0.5)	2234	29.5	0.05
NGRLS100-55	19.0	5.2(0.9)	2084	30.1	0.09
RLG50CS-55	17.0	3.1(0.6)	2282	28.8	0.12
RLG50NS-55	19.5	4.2(0.4)	2256	28.4	0.09
RLG50RLS30-55	20.0	4.4(0.5)	2206	26.1	0.12
RLG50RLS50-55	19.5	4.1(0.3)	2099	29.2	0.08
RLG100NS-55	16.5	4.6(0.5)	2208	27.7	0.09
NGNS-65	18.0	4.6(0.2)	2288	24.6	0.02
NGRLS100-65	18.0	4.5(1.5)	2142	22.8	0.12
RLG50NS-65	19.0	4.7(0.5)	2221	23.6	0.12
RLG50RLS30-65	20.0	5.3(0.6)	2172	24.3	0.11
RLG50RLS50-65	18.0	4.5(1.2)	2163	23.5	0.11
RLG100NS-65	16.0	4.2(0.5)	2189	22.0	0.10

*1 In ( ) is the aggregate correction factor. *2 Refer to electrode current method. For normal-weight concrete, refer to JIS A 5308.

3.2 Hardened concrete compressive strength and static modulus of elasticity

According to JASS 5 (2018) [3], recycled aggregate Concrete-Class M has specified compressive strength of ≤30 N/mm². In the present study, compressive strengths ranged from 19.2 to 54.1 N/mm². As shown in Figure 1, compared with specimen groups using only normal aggregates, the compressive strength tended to be lower at 4 and 13 weeks when the recycled aggregate replacement ratio and/or W/C ratio increased for three groups that were divided by W/C ratio. An increasing trend in compressive strength was also observed from 4 to 13 weeks. Furthermore, the static modulus of elasticity showed the same trend as compressive strength.

3.2.1 Drying shrinkage

As shown in Figure 2, drying shrinkage tended to be higher when RLG and/or RLS were used at a ≥50% replacement ratio due to recycled aggregate's high absorption. However, almost all specimen groups had drying shrinkage that satisfied the target quality threshold value of ≤8 × 10^{-4}, which is regulated by JASS 5 (2018) [3].

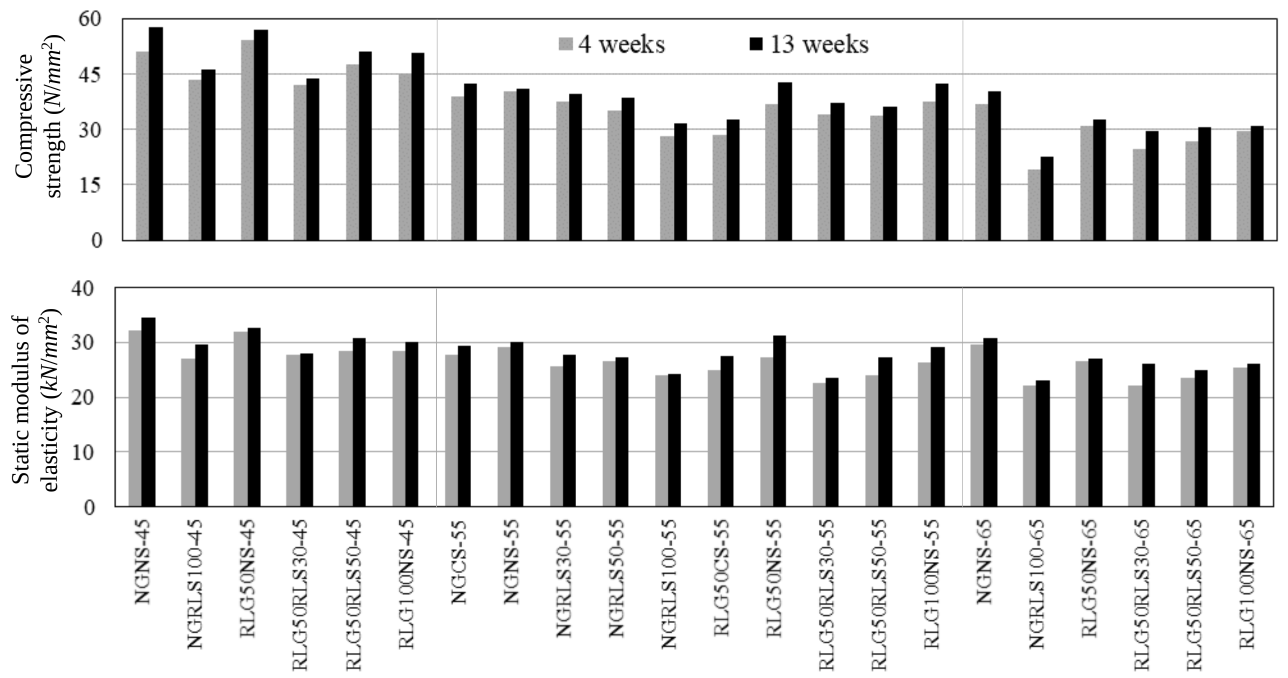


Fig. 1 – Compressive strength and static modulus of elasticity.

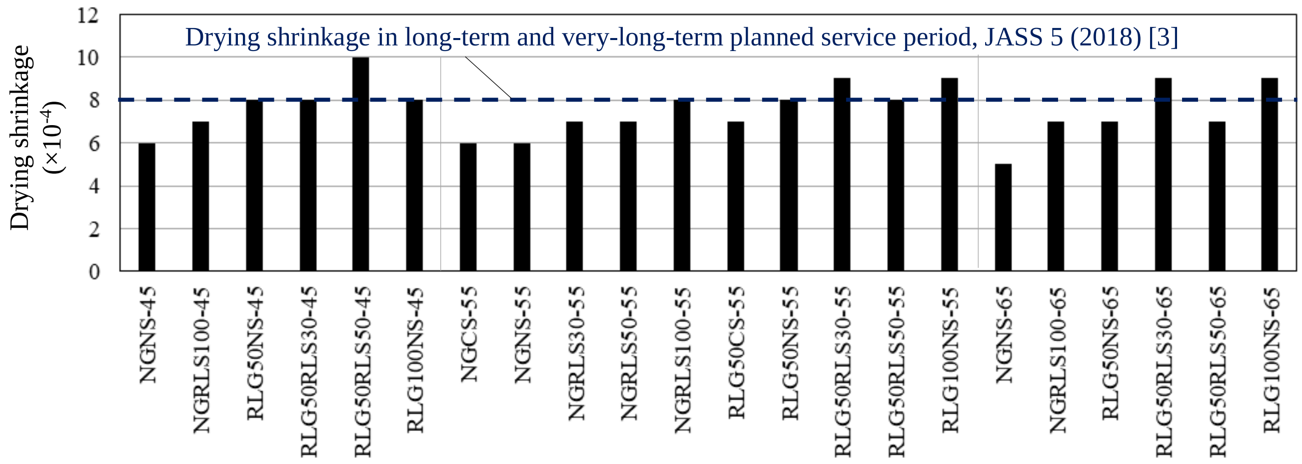


Fig. 2 – Drying shrinkage.

3.2.2 Accelerated carbonation

The carbonation depth target quality threshold value was based on the "Recommendations for design and construction practice of high durable concrete" [4]. Figure 3 shows that carbonation depths were larger when RLG and/or RLS replacement ratios were ≥50%; however, almost all specimen groups were under the 25 mm target quality threshold value.

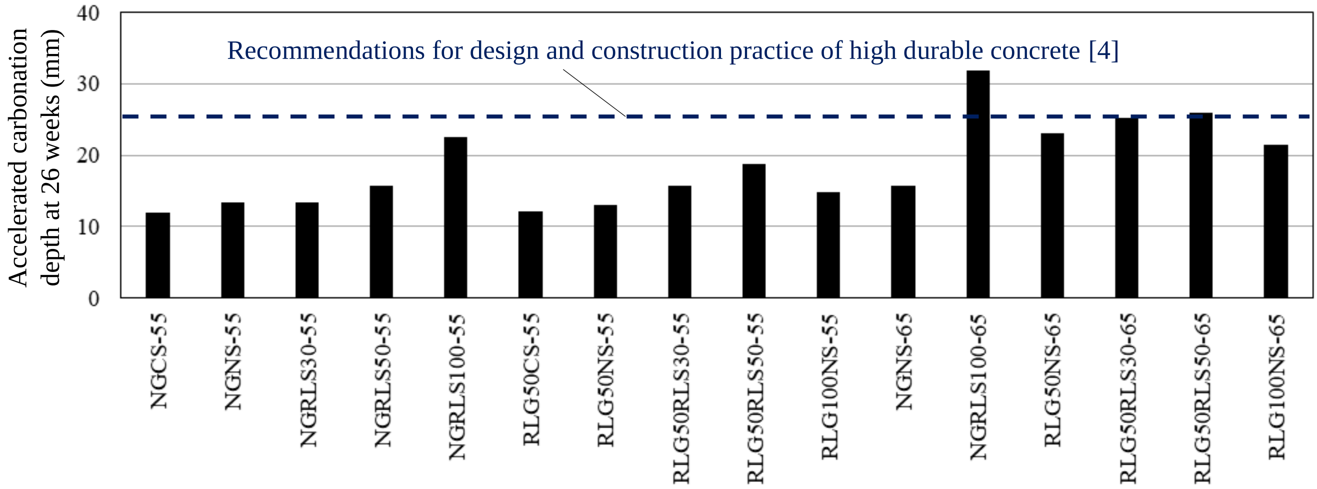


Fig. 3 – Accelerated carbonation depth at 26 weeks.

3.2.3 Durability factor

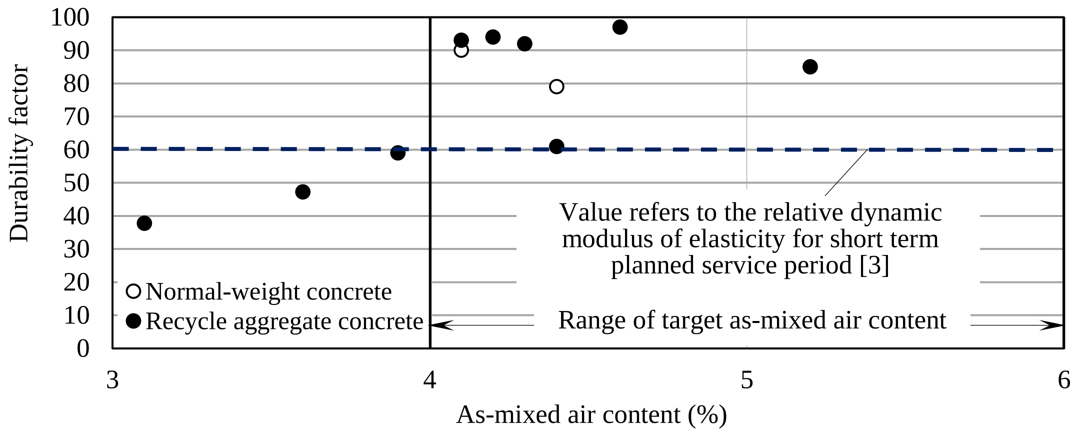


Fig. 4 – Correlation of as-mixed air content and durability factor.

As shown in Figure 4, the specimen groups using RLG and/or RLS with as-mixed air content of 4% to 6% had the durability factor greater than 60.

3.3 Material design by relative quality index method

The relative quality index is calculated based on the recycled aggregate replacement ratio and the aggregate's absorption or density [2]. Evaluation in this study used absorption. This method was used to evaluate correlations of concrete performance and relative absorption. Equation (1) was obtained based on experiment results. The correlations of the relative absorption and recycled aggregate concrete performance were evaluated as shown in Figure 5. For recycled aggregate Concrete-Class M1, when 50% RLG or 100% recycled coarse aggregate class M (RMG) was used, the relative absorption was 4.02%. For class M2, when 50% RLG and 30% RLS were used, the relative absorption was 5.46%, and when 100% RMG and 100% recycled fine aggregate class M (RMS) were used, the relative absorption was 5.87%. Furthermore, the absorption upper limit of normal aggregate and recycled aggregate regulated in JIS were used for calculation.

$$QCt = \frac{QCvG \times a + QCvS \times b + QCrG \times c + QCrS \times d}{a + b + c + d} \quad (1)$$

Where,

QCt: Relative absorption (%);

QCvG: Absorption of normal coarse aggregate (%);

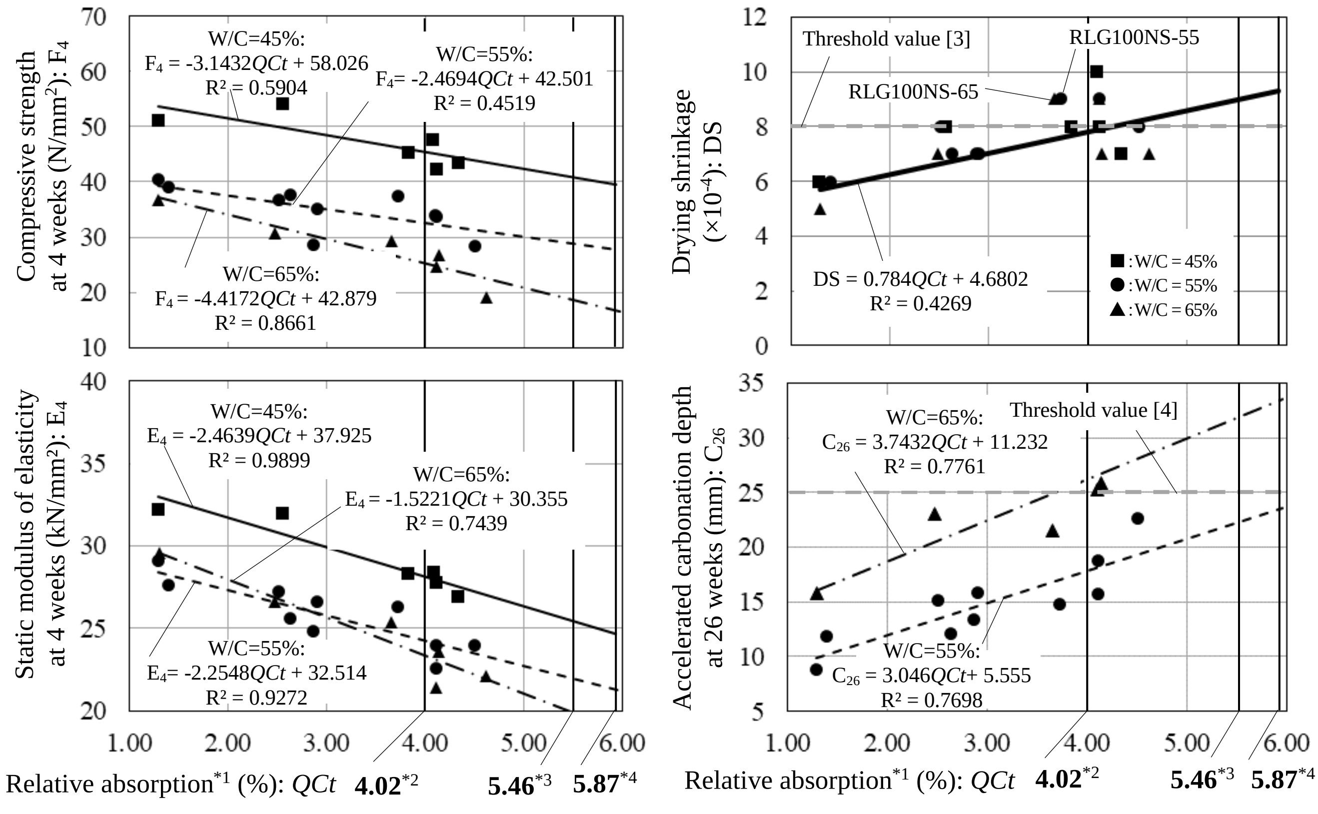
QCvS: Absorption of normal fine aggregate (%);

QCrG: Absorption of recycled coarse aggregate (%);

QCrS: Absorption of recycled fine aggregate (%);

a, b, c, d: Absolute volume of aggregate (L/m^3).

In Figure 5, concrete performance tended to be lower when relative absorption increased. Concrete performance showed some variations, but in general a relative clear correlation was obtained. Furthermore, in case relative absorption ≤4.02%, the target quality threshold values were satisfied except the case when drying shrinkage with the specimen groups used 100% RLG. Therefore, when normal aggregate was mixed with recycled aggregate class L, based on the correlation of relative absorption and recycled aggregate concrete performance, suitable replacement ratio of recycled aggregate, and the use of selected normal aggregate, the manufacturing of concrete with required performance could be achieved.



*1 Upper limit of absorption for NG, CS based on JIS A 5005, NS based on JIS A 5308 were used for calculation. *2 Calculated by upper limit of absorption and replacement ratio of RLG or RMG for recycled aggregate Concrete-Class M1 in accordance with JIS A 5022. *3 Calculated by upper limit of absorption and replacement ratio of RLG and RLS for recycled aggregate Concrete-Class M2 in accordance with JIS A 5022. *4 Calculated by upper limit of absorption and replacement ratio of RMG and RMS for recycled aggregate Concrete-Class M2 in accordance with JIS A 5022.

Fig. 5 – Correlation of relative absorption and concrete performance.

4 Conclusion

- Fresh concrete using low-quality recycled aggregate satisfied the target values even when the replacement ratio of recycled aggregate was large. This was performed by applying a suitable amount of chemical admixture.

- For hardened concrete, when the replacement ratio of recycled aggregate increased, the concrete performance tended to be lower; however, most specimen groups satisfied the target quality threshold values regulated in the Japanese standards. Regarding the freezing thawing experiment, the replacement ratio of recycled aggregate did not affect concrete performance, and by ensuring a suitable as-mixed air content, recycled aggregate concrete could be used for a short term planned service period.

- By applying material design for recycled aggregate concrete, when normal aggregate was mixed with low-quality recycled aggregate, based on the correlation of relative absorption, recycled aggregate concrete performance, a suitable replacement ratio of recycled aggregate, and the use of selected normal aggregate, the manufacturing of concrete with required performance could be achieved.

REFERENCES

[1] - Decision No. 609/2014/QD-TTg, Master plan on solid waste disposal of Hanoi Capital to 2030, with a vision to 2050, 2014.

[2] - Y. Dosho, Development of a Sustainable Concrete Waste Recycling System -Application of Recycled Aggregate Concrete Produced by Aggregate Replacing Method. J. Adv. Concrete Technol. 5(1) (2007) 27-42. doi:10.3151/jact.5.27.

[3] - AIJ, JASS 5 Reinforced Concrete Work, Architectural Institute of Japan, Japanese Architectural Standard Specification, 2018.

[4] - AIJ, Recommendations for design and construction practice of high durable concrete, Architectural Institute of Japan: Japan, 1991.