Basic research on GRC recycling

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Summary

In order to build a resources recycling society, various trials for recycling have been conducted in the concrete industry. The use of reclaimed aggregates especially, obtained by crushing wasted concretes, was widely investigated and formed into the Japanese Industrial Standard (JIS) in Japan. Under such circumstances, the requirement for glassfibre-reinforced concrete (GRC) recycling has been enhanced in Japan.

We, at NEG, have conducted a series of tests and issued reports on GRC properties over recent years, which employed industrial by-products in the GRC matrix such as fly ash and slag. In this paper, GRC recycling was examined. GRC was crushed after accelerated aging tests. Crushed granulated and fine GRC material was added into the GRC and concrete mixes. Typical physical properties of GRC and concretes were measured and summarised. As a result of this examination, it was found that crushed GRC can be successfully used in GRC and concrete mix, replacing fine aggregate or cement.

Keywords: GRC, recycle, concrete, crush

Introduction

Various recycling trials have been examined in the concrete industry with a view to building a resource recycling society. In particular, research of the reclaimed aggregate obtained by crushing waste concrete was examined from various aspects; as a result, JIS A 5021 (recycled aggregate for concrete) was established.

The demand for recycling of glassfibre-reinforced concrete (GRC) has grown, and it is now widely used as a building material thanks to its lightness and excellent form. For several year we have reported on the basic physical properties of GRC with the addition of material recycled from industrial waste .

In the current research, GRC recycling was examined. GRC was crushed after accelerated aging tests. Crushed granulated and fine GRC material was added into GRC and concretes mix. Typical physical properties of the GRC and concretes were measured and summarised. As a result of this examination, it was found that crushed GRC can be used in GRC and concrete mix, replacing fine aggregate or cement.

CRUSHING GRC

Aged GRC

Table 1 shows the mix proportions of aged GRC for recycling that was crushed in this study. The aged GRC was prepared from a GRC panel that corresponded to 25-year outdoor exposure. Test pieces were made by direct spray method (l = 31 mm) in GRC thickness of 40 mm, and were cut out from the GRC in sizes of 100×100 mm, and were immersed in 80°C water at the age of 28 days for ten days. It is said that the bending strength of GRC after one day of immersion in water at 80°C is estimated to be equivalent to about 2.5 years of outdoor exposure in Tokyo [2].

Ordinary Portland cement	100
Silica sand No.6	80
Water reducer	0.7
Water	34
Glass fiber content (wt%)	5

Table 1. Mix proportions of aged GRC

Crushability

Photograph 1 shows the jaw crusher that was used for crushing GRC in this examination. The crusher's jaw opening was adjusted to 15 mm and the aged GRC pieces were crushed once. Photograph 2 shows crushed GRC just after the first crushing operation; 20% of the once-crushed GRC passed a 5 mm sieve. Table 2 shows the screening results of this 20% passed crushed GRC.

Photograph 1. Jaw crusher

Photograph 2. Crushed GRC

Particle size (mm)	5~2.5	2.5~1.2	1.2~0.15	0.15~
weight (%)	26	18	41	15

Table 2. Screening results

Some 50% of crushed GRC under 5 mm was smaller than 1.2 mm, although the jaw opening was 15 mm. Moreover, the glass fiber included in the crushing GRC had been crushed fine. It seems that GRC can be crushed easily compared to other organic fibre-reinforced concrete due to glass fibre's high degree of elasticity.

Properties of crushed GRC

Figure 1 shows the crushing process flow chart applied in this experiment. As shown in Figure 1, crushed GRC was divided into the grading range 5–0.15 mm as recycled fine aggregate (RFA) and the grading range less than 0.15 mm as recycled powder (RPW).

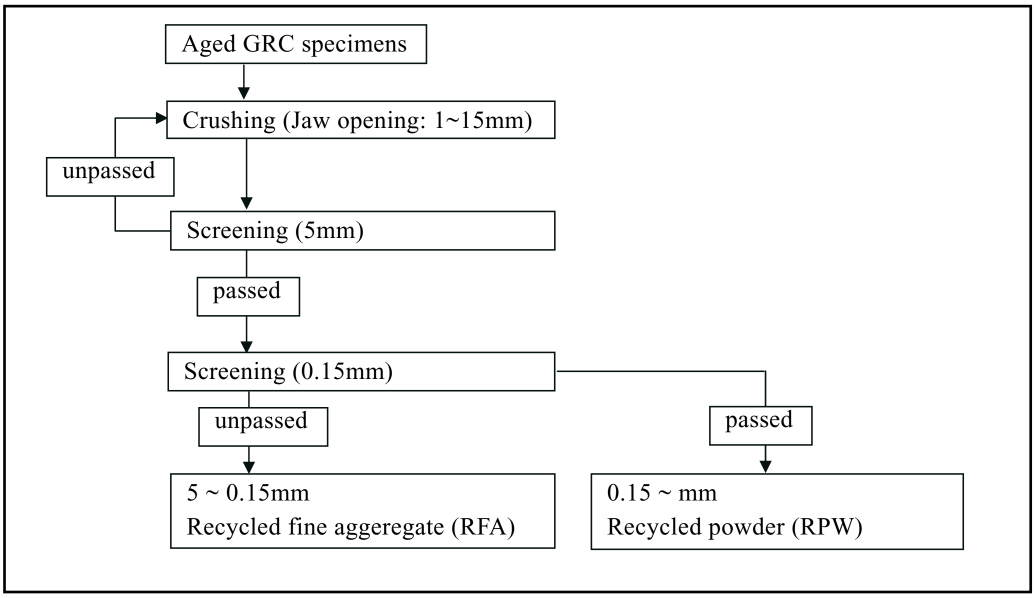

Figure 1 Crushing process flow chart

Figure 2 shows grading of recycled fine aggregate and Table 3 shows properties of RFA. A sieving test was conducted by JIS A 1102 (Method of test for sieve analysis of aggregate). The broken lines mean grading specifications of fine aggregate specified in JIS A 5005 (crushed stone and manufactured sand for concrete) and the solid line shows sieve analysis results of RFA. The fineness modulus was 3.12. RFA met JIS A 5005 grading requirements but it was coarser compared to the mean value. The density of RFA is similar to that of aged GRC and did not meet JIS A 5005. Absorption of RFA is similar to that of aged GRC and also did not meet JIS A 5005.

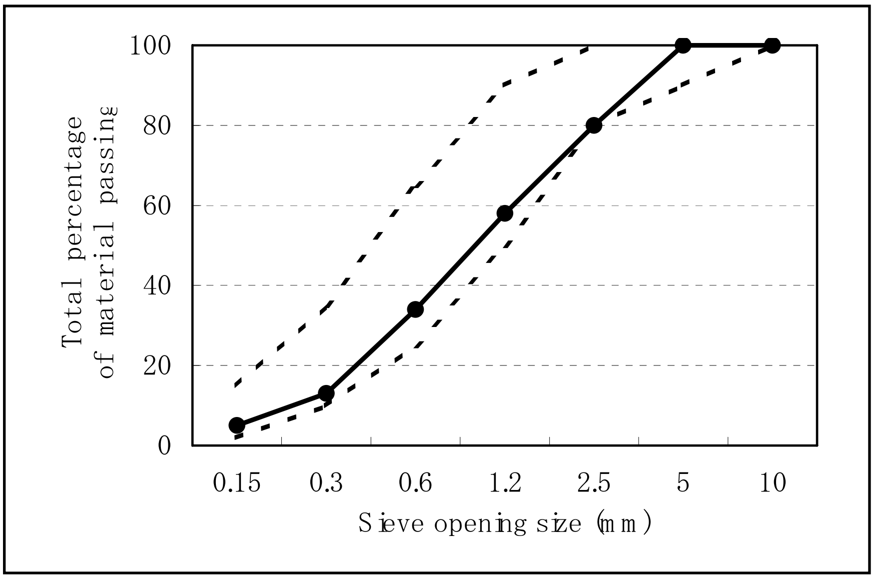

Figure 2. Grading of RFA

Item	Air dried density (g/cm^3)	Oven-dried density (g/cm^3)	Absorption (%)	Fineness modulus
Specification	-	more than 2.5	less than 3.0	-
Measured value	2.28	2.05	11.1	3.12

Table 3. Properties of RFA

Crushed GRC for recycling

RFA which is shown in Figure 1 and Table 3 is used for recyclability evaluation by adding to the conventional concrete. RPW, with particle size less than 0.15 mm, was used for the same evaluation by adding to the GRC.

TEST METHODS

Mortar flow value

The left–hand side of Figure 3 shows the test method for fresh mortar flowability. A flow cylinder 55 mm in diameter and 50 mm high was placed on a plate. It was filled with fresh mortar and then held vertical and the fresh mortar flowed onto the plate. The diameter of the fresh mortar was measured as a mortar flow value.

GRC flow value

The right-hand side of Figure 3 shows the test method for fresh GRC mortar flowability. A GRC flow value of fresh GRC mortar (including glass fibre) was measured by flow test of the physical testing method for cement provided in JIS A 5201. A flow cone of 70 mm upper diameter, 100 mm lower diameter and 70 mm high was placed on a flow table. It was filled with fresh GRC mortar and pulled vertical. The GRC mortar was given a 10 mm dropping movement 15 times in 15 seconds by rotating handle. The diameter of flowed GRC mortar was measured as a GRC flow value.

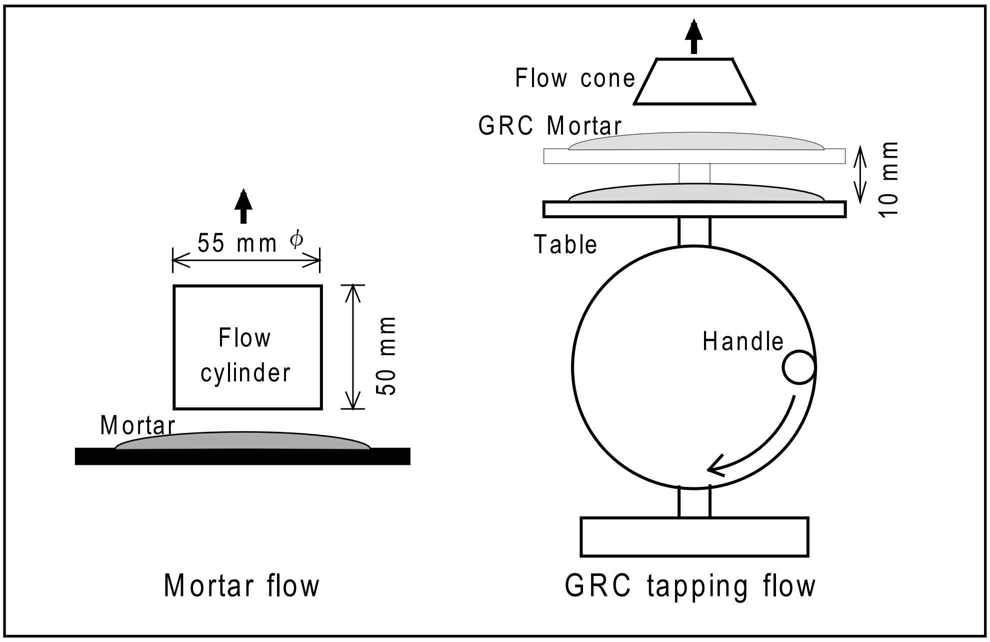

Figure 3. Test methods for flowability

GRC bending test

Bending strength, strain to failure and modulus of elasticity were measured by the bending test prescribed by the Japan GRC Association, test conditions of which are shown in Table 4. Specimens for the bending test were remoulded at the age of one day and stored in a curing room at 20°C, 60% relative humidity (RH) until the age of 28 days.

Dimensions of specimen (mm)	Bending span (mm)	Test speed (mm/min)	Loading method
275 X 50 X 15	225	2	3-point

Table 4. Bending test conditions

Accelerated aging test for GRC

The accelerated aging test was conducted by immersing specimens in water at 70°C after curing at 20°C, 60% RH for 28 days. The durability of GRC was evaluated by the bending test after the accelerated aging test. It is said that the bending strength of GRC after one day of immersion in water at 70°C is estimated to be equivalent to about one year of outdoor exposure in Tokyo [2].

Drying shrinkage of GRC

Drying shrinkage was measured by the contact gauge method provided in JIS A 1129-2 (Method of test for length change of mortar and concrete – Part 2: Method with contact-type strain gauge).
Base lengths were measured at the age of one day and drying shrinkage was then measured at specified intervals.

Freeze–thaw test of GRC

Plate specimens were attached to a piece of rectangular normal concrete of size 80 × 80 × 400 mm, as shown in Figure 4. The overall size is the same as the rectangular specimens defined in the JIS. According to JIS A 1148 (Method of test for resistance of concrete to freezing and thawing), freeze–thaw tests are conducted on combined plate specimens. Specimens were frozen at –18°C and thawed at 5°C 300 times. Bending tests were conducted on the specimens before and after the freeze–thaw test.

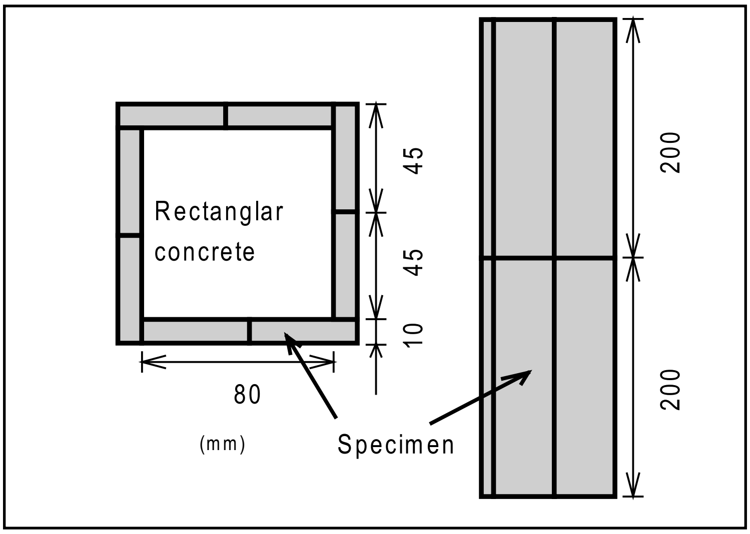

Figure 4. Test specimens for freeze–thaw test and its setting

Test methods for concrete

Slump	Air content	Compressive strength	Density and absorption of RAF
JIS A 1101	JIS A 1128	JIS A 1108 100(d) X 200(h) mm	JIS A 1109, 1110

Table 5 shows the test methods for concrete.

ADDITION OF RPW TO GRC

RPW was incorporated into mix proportions by replacement of cement or silica sand and both mixes were evaluated on the above properties.

Replacement of cement

Properties of fresh GRC mortar

Mix proportions, properties of fresh condition and air-dried densities of GRC with cement replaced by RPW are shown in Table 6. Figure 5 shows the relationship between replacement ratio of RPW and flowability. The density of fresh GRC mortar should decrease if a large proportion of cement is replaced by RPW, because the density of RPW is lower than that of ordinary Portland cement. On the other hand, flowability decreased with increased proportion of RPW because of its particle size and absorption.

No.	1	2	3	4
Ordinary Portland cement	100	90	80	70
RPW	0	10	20	30
Silica sand No.5	100			
Air-entraining and high-range water-reducing admixture (AEHR)	0.6			
Water	32			
ACS19PH-901X	7.0 (3.0 wt% against mortar)			
GRC fresh density	2.15	2.14	2.09	2.05
GRC air-dried density	2.10	2.06	2.05	2.02
Air content (%)	7.4	8.0	8.2	6.7

Table 6. Mix proportions and properties of fresh GRC and air-dried density

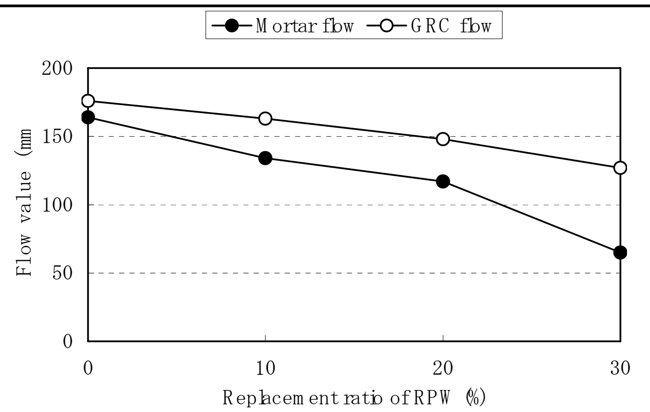

Figure 5 Relationship between replacement ratio of RPW and flowability

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Bending strength

Figure 6 shows the relationship between replacement ratio of RPW and bending strength. The GRC bending strength should decrease if a large proportion of cement is replaced by RPW, because the total amount of cement in the GRC is lower than that of GRC without replacement.

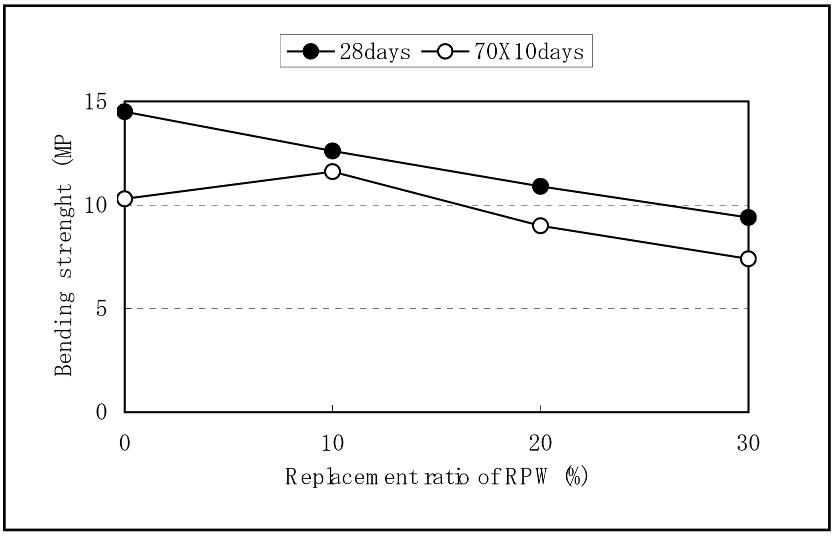

Figure 6. Relationship between replacement ratio of RPW and bending strength

Drying shrinkage

Figure 7 shows the relationship between replacement ratio of RPW and drying shrinkage. There are no significant differences in the four specimens.

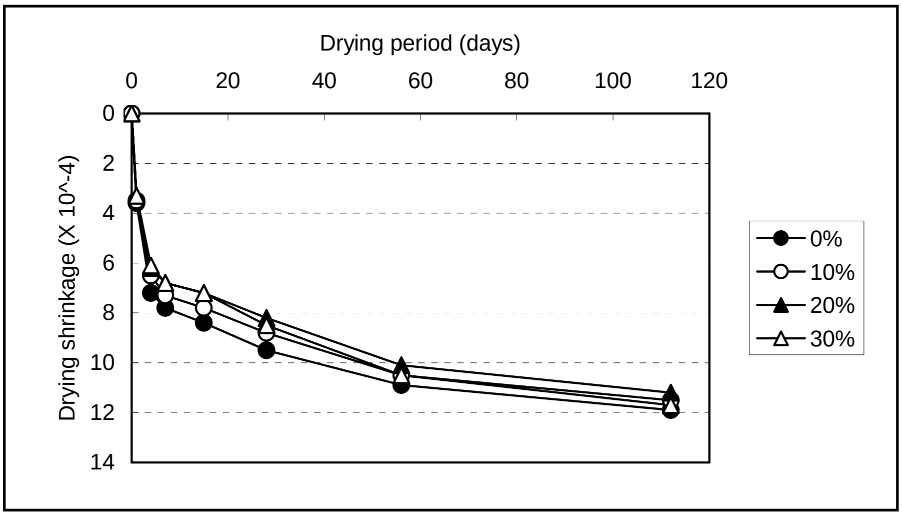

Figure 7. Relationship between replacement ratio of RPW and drying shrinkage

Replacement of silica sand

Properties of fresh GRC mortar

Mix proportions, properties of fresh condition and air-dried densities of GRC with replacement of silica sand by RPW are shown in Table 7. Figure 8 shows the relationship between replacement ratio of RPW, additional rate of AEHR (air-entraining and high-range water-reducing admixture) and flowability. The density of fresh GRC mortar should decrease if a large proportion of silica sand is replaced by RPW, because the density of RPW is lower than that of silica sand. Flowability decreased with increasing the proportion of RPW. It is necessary to increase the dosage of AEHR to obtain the same mortar flow value as for non-replacement GRC. In the case of adjusting the flow value by changing the dosage of AEHR, GRC flow value tends to be high even if mortar flow value is the same. This is because GRC mortar with silica sand replaced by RPW is more consistent than non-replaced GRC mortar. Material segregation was observed in GRC mortar with replacement of silica sand by RPW at the rate of 60%. The dosage of AEHR was out of range of the manufacturer's recommended dosage The above results suggest that the maximum replacement ratio of silica sand is 60%.

No.	5	6	7	8
Ordinary Portland cement	100	100	100	100
RPW	0	20	40	60
Silica sand No.5	100	80	60	40
AEHR	0.6	1.0	1.9	4.3
Water	32			
ACS19PH-901X	7.0 (3.0 wt% against mortar)			
GRC fresh density	2.14	2.08	2.05	1.98
GRC air-dried density	2.12	2.06	2.02	1.97
Air content (%)	8.5	10.0	9.4	more than 10.0
Segregation	good	good	good	bad

Table 7. Mix proportions, properties of fresh GRC and air-dried density

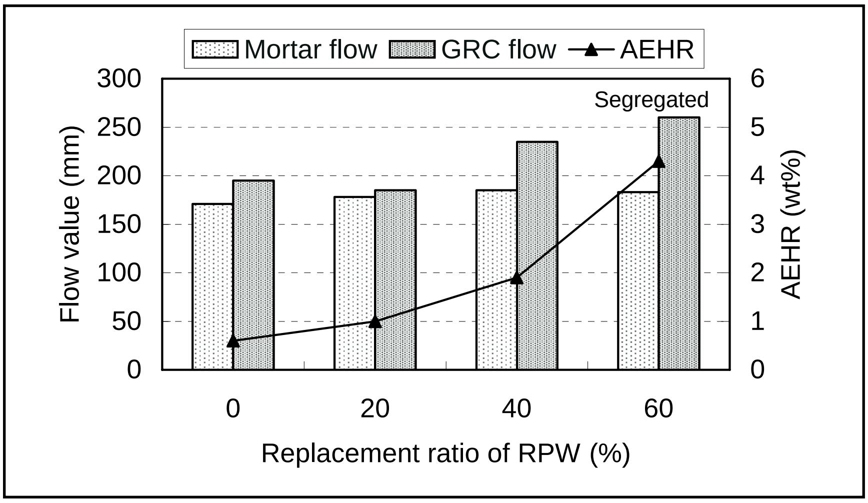

Figure 8. Relationship between replacement ratio of RPW, AEHR and flowability

Bending strength

Figure 9 shows the relationship between replacement ratio of RPW and bending strength. GRC bending strength should increase if a large proportion of silica sand is replaced by RPW, because RPW includes the reactive ingredient cement.

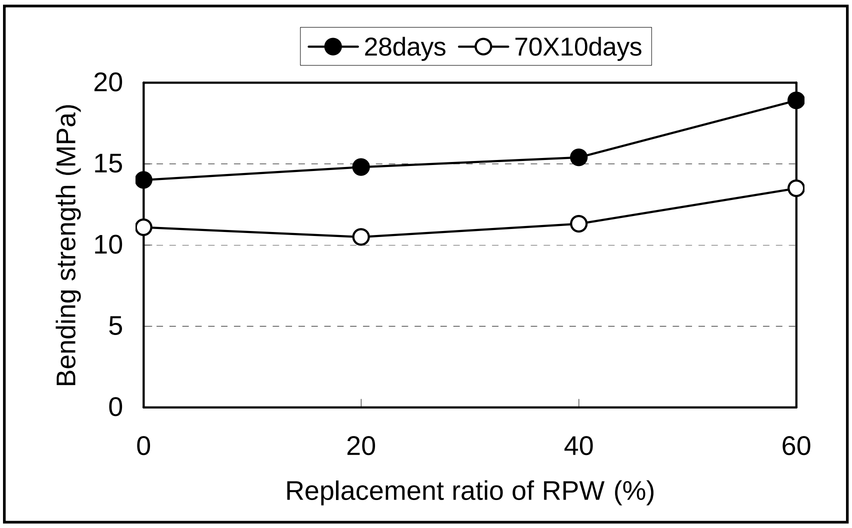

Figure 9. Relationship between replacement ratio of RPW and bending strength

Drying shrinkage

Figure 10 shows the relationship between replacement ratio of RPW and drying shrinkage. There are significant differences in four specimens. Drying shrinkage should increase if a large proportion of silica sand is replaced by RPW. This reason is the same as that for bending strength.

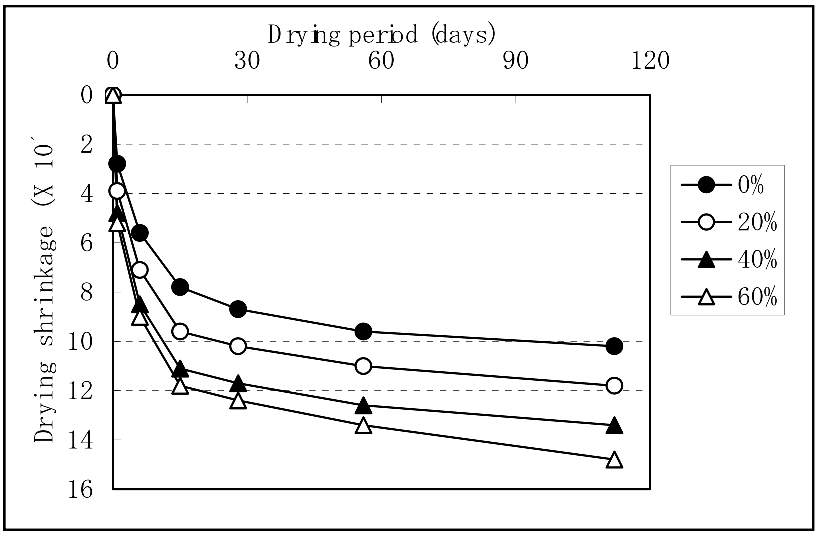

Figure 10. Relationship between replacement ratio of RPW and drying shrinkage

Freeze–thaw test results

GRC samples with replacement of both cement and silica sand by RPW were subjected to freeze–thaw tests for 300 cycles. Mix proportions and void content of GRC with replacement of silica sand or cement by RPW are shown in Table 8. Photograph 3 and Photograph 4 show typical specimens after freeze–thaw testing. Figure 11 shows the retention ratio of bending elastic modulus after freeze–thaw testing.

Freezing and thawing resistance of GRC with replacement of silica sand or cement by RPW were worse than non-replaced GRC. On the other hand, the resistance of high replacement ratio specimens such as No. 12 and13 were better than any other specimens because of higher void content generated by AEHR. From these results the resistance of GRC using RPW can be improved by adding entrained air by AE agent or any other chemical admixture.

No.	9	10	11	12	13	14
Replaced object	Silica sand					Cement
Ordinary Portland cement	100	100	100	100	100	90
RPW	0	10	20	30	40	10
Silica sand	100	90	80	70	60	100
AEHR	0.6	0.9	1.3	1.6	1.9	0.6
Water	32					
ACS19PH-901X	7.0 (3.0 wt% against mortar)					
Air content (%)	8.0	7.6	8.4	9.0	9.0	7.2
Scaling	from 20 many	from 100c many (Photo 3)	from 100c many	at 300 few	at 300 few (Photo 4)	from 100c many

Table 8. Freeze–thaw test results

Photograph 3. Freezing and thawing test specimen (No.10, 100c)

Photograph 4. Freezing and thawing test specimen (No.13, 300c)

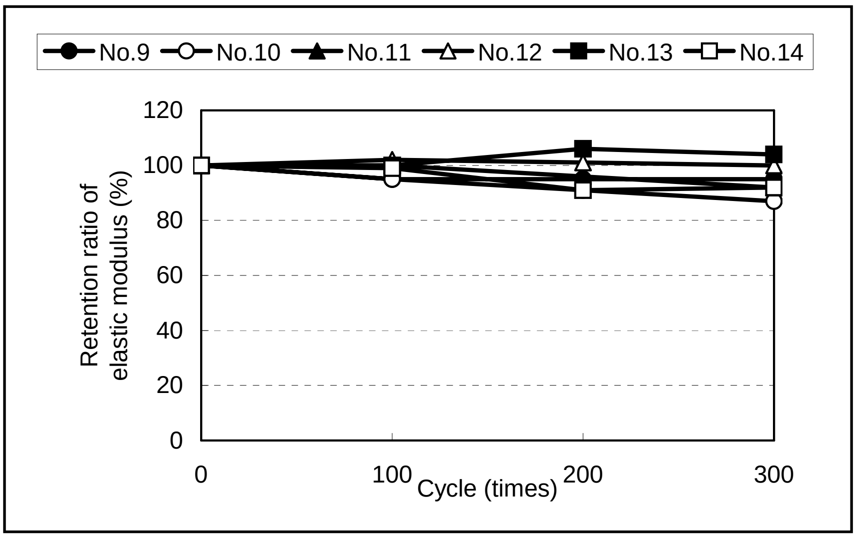

Figure 11. Retention ratio of elastic modulus after freezing and thawing test

ADDITION OF RFA TO CONVENTIONAL CONCRETE

Properties of fresh concrete

Mix proportions, slump and air content of concrete with replacement of fine aggregate by RFA are shown in Table 9. Slump was adjusted to 18 cm by changing the dosage of AEHR. The flowability of concrete decreased with increasing proportion of RFA. More AEHR was needed to obtain the same flowability (slump) when RFA was used, whose dosage was in the range of that recommended by the manufacturer. Air content increased with increasing proportion of AEHR.

No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
W/C(%)	42.7					47.8					52.6				
C/W	2.34					2.09					1.90				
Replacement ratio (%)	0	20	40	60	100	0	20	40	60	100	0	20	40	60	100
Sand-total aggregate ratio	47.1	47.8	48.4	49.0	50.2	47.1	47.8	48.4	49.0	50.2	47.1	47.8	48.4	49.0	50.2
Quantity (kg/m^3)															
Water	190														
Cement	445					398					361				
Fine aggregate	764	611	458	306	0	783	626	470	313	0	796	637	478	318	0
RFA	0	153	306	458	764	0	157	313	470	783	0	159	318	478	796
Coarse aggregate	891					913					930				
AEHR (against cement %)	0	0	0.17	0.17	0.22	0	0	0.13	0.13	0.25	0	0	0.14	0.14	0.24
Air content (%)	0.9	1.3	2.7	1.8	2.8	1.0	1.3	1.7	2.0	2.7	0.8	1.2	2.7	2.3	3.0
Slump (cm)	19.5	19.0	18.5	19.5	18.0	19.0	18.5	19.0	18.0	18.0	20.0	20.0	18.0	18.0	20.0

Table 9. Mix proportions, slump and air content of concrete

Compressive strength

For replacement ratio less than 40%, compressive strength increased in proportion to the water/cement (w/c) ratio. But in the case of more than 60%, compressive strength and c/w were not correlated.

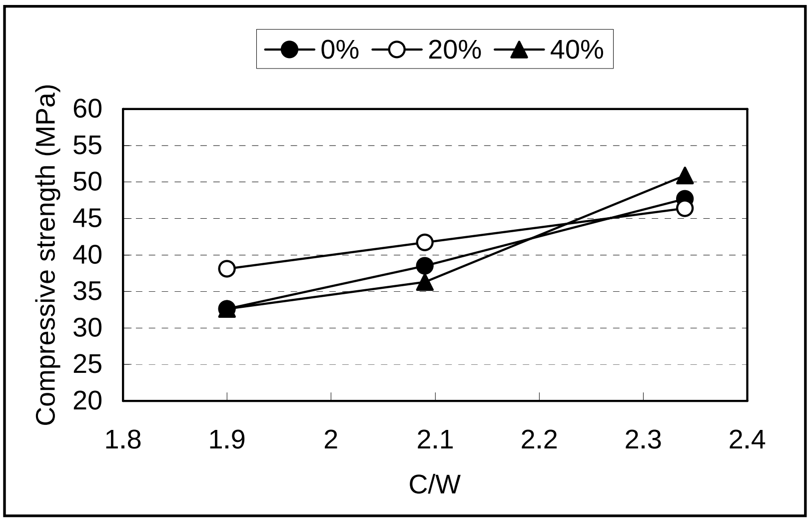

Figure 12. Relationship between compressive strength and w/c ratio (0, 20, 40%)

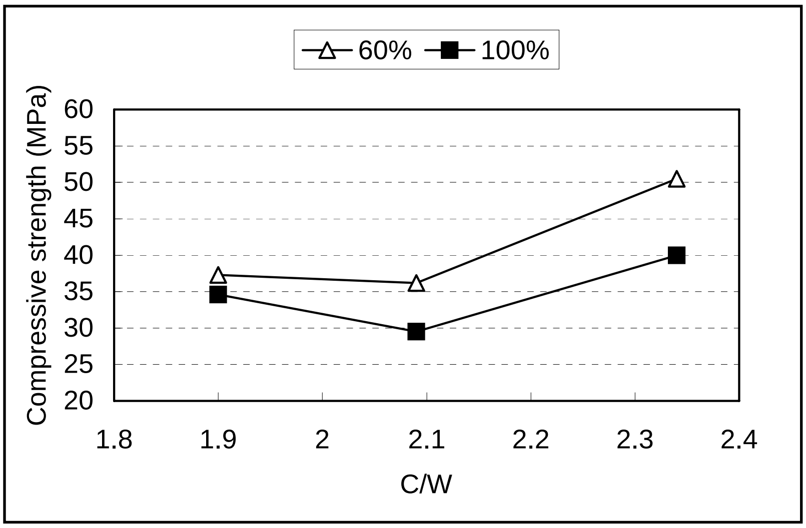

Figure 13. Relationship between compressive strength and w/c ratio (60, 100%)

CONCLUSIONS

- GRC has good crushability compared to organic fibre-reinforced concrete because of the high elasticity of glass fibre.
- It is possible to make recycled fine aggregate which meets the grading of JIS A 5005. However, the density and absorption do not meet that specification.
- In the case of replacement of cement by RPW, the density, flow value and bending strength of GRC decreased. Maximum replacement ratio of cement by RPW seems to be 10%.
- In the case of replacement of silica sand by RPW, the bending strength was increased and drying shrinkage became large. At high replacement ratio, material segregation occurs if the same flowability is needed. The maximum replacement ratio of silica sand by RPW seems to be 40%.
- The freeze–thaw resistance of GRC including RPW reduced. The resistance can be improved by adding suitably entrained air by air-entraining agent or any other chemical admixture.
- Concrete including RFA requires more water-reducing agent to adjust flowability. In the case of replacement ratio less than 40%, compressive strength increases in proportion to c/w.

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