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Strength and Drying Shrinkage of Concrete Used Recycled Aggregate

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Synopsis

The influence of recycled aggregate on concrete properties is not clear; therefore, at present, the conventional concept is to use recycled aggregate for only low-strength concrete. In order to expand the usage range of recycled aggregate, the influence of qualities of recycled aggregate on properties concrete must be clarified. Therefore, the present study examined strengths and drying shrinkage of normal and high-strength concrete used ordinary aggregate and recycled aggregate. The results show a linear relation between the compression or splitting tensile strength of concrete of a given slump and C/TW in the region of compression strength 30-70 N/mm^2 or tensile strength 3-6 N/mm^2. In addition, the length change rate per unit cement volume shows close correlation with C/TW, in which TW is the sum of water content and total water absorption of fine and coarse aggregate.

KeyWords: recycled aggregate, normal-strength concrete, high-strength concrete, strength, drying shrinkage

1. Introduction

Use of recycled aggregate is expected to increase, in view of consumption of natural aggregate. In addition, Recycling of demolished concrete is effective for reducing environmental impact and land reclamation. As compared with natural aggregate, recycled aggregate has lower density in oven-dried condition and higher water absorption. These tendencies are attributed to cement paste attached the particles. Concrete used recycled aggregate has lower strength and higher drying shrinkage strain than conventional concrete, and the reasons for these are unknown. So, at present, the conventional concept is to employ recycled aggregate only for low-strength concrete. However, the amount of demolished concrete is expected to increase, requiring expansion of the range of application for concrete used recycled aggregate. For that reason, it needs to be clear the influence of qualities of aggregate on properties of concrete. Therefore, the present study investigated relationships between water absorption of aggregate and the strength or drying shrinkage strain of hardened concrete, which of compressive strength was the region of 30 – 70 N/mm^2.

2. Test Procedures

The aggregate used in this study was described in Table 1. As aggregate, we used 2 kinds of natural sand (NSI and NSC) and a crushed stone (NCT). In addition, we used 2 kinds of recycled fine aggregate and one kind of recycled coarse aggregate, called RSa ,RSb, and RCb. RSa was recycled fine aggregate produced in a recycling plant. RSd and RCb were 0.15-2.5 mm and 5-25 mm diameter particles that were crushed from demolished concrete by use of a jaw crusher and a cone crusher. Here, the source of the demolished concrete was a 45-year-old building.

Concrete samples were produced from NSI, NCT, and ordinary portland cement at the mixture proportions in Table 2. When other kinds of aggregate were used, the aggregates were used in the same mixture proportions in volume as the substituted aggregate. Properties of fresh concrete were adjusted to the target values at each W/C by a polycarboxylic acid type super plasticizer, a ligninsulfonic acid type air-entraining agent, a water-reducing admixture, and a supplementary air-entraining agent. Table 2 shows the target values. Concrete was prepared by mixing ordinary cement, fine aggregate, and coarse aggregate in a revolving-paddle mixer for 30 seconds, adding

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Table 1 Kinds and physical properties of aggregates used in this study

Kind of aggregate		Symbol	Density in oven-dried condition (g/cm^3)	Water absorption (%)	Source of raw material
Fine aggregate	Ordinary	NSI	2.52	2.74	River sand from Ibi river
		NSC	2.55	1.65	River sand from Fujian, China
	Recycled	RSa	2.18	8.10	Plant for recycled aggregate
		RSb	1.99	11.4	Building erected in 1957
Coarse aggregate	Ordinary	NCT	2.66	1.07	Crushed stone from Takatsuki city
	Recycled	RCb	2.43	3.40	Building erected in 1957

Table 2 Mixture proportions of NSI and NCT in this study

Water / cement ratio, W/C (%)		50	42	35	25
Cement total water, C/TW		1.68	2.03	2.44	3.44
s/a (%)		42.3	40.7	39.3	45.2
Unit quantity (kg/m^3)	Water content, W	155	162	162	162
	Cement content, C	310	386	463	648
	Fine aggregate content, S	754	693	665	697
	Coarse aggregate content, G	1073	1054	1071	881
	Polycarboxylic acid type super plasticizer or Ligninsulfonic acid type air-entraining agent (weight percent)	Cx0.25*1	Cx0.25*1	Cx0.7*2	Cx2.8*2
	Supplementary air-entraining agent (weight percent)	Cx0.002	Cx0.0025	Cx0.0005	Cx0.0035
Target value of slump or slump flow (mm)		120±20	120±20	180±20	600±50
Target value of air content (%)		5±1	5±1	3±1	3±1

*1 Ligninsulfonic acid type air-entraining agent
*2 Polycarboxylic acid type super plasticizer

influence of recycled fine aggregate, tests were carried out for concrete with NCT at W/C = 25, 35 and 50%.

Properties of hardened concrete were measured; specifically, compressive and splitting tensile strength, and length change under dried condition. Dimensions of concrete specimens were Ø100 x 200mm for compressive strength measurement, Ø150 x 150mm for splitting tensile strength measurement, and 100 x 100 x 400mm for length change measurement. All specimens were cured in water at 20oC. Strengths were measured after curing for 28 days. In addition, in the test of length change under dried conditions, the specimens were dried at 20oC and 60% humidity after curing for 7 days, and strain of the specimens by drying was measured.

3. Results and Discussions about Compressive and Splitting Tensile Strengths

Fig.1 shows the relationship between C/W and compressive strength. In spite of kinds of fine aggregate, compressive strength increased with increasing C/W. In each case, the relationship was almost expressed by a straight line. In addition, the water absorption of aggregate has great influence on compressive strength.

Therefore, an appropriate index was introduced. The quantity of water absorbed by all aggregate in concrete was calculated. The result was added to water content, yielding the total quantity of water in concrete, called TW. The ratio of Cement content to TW was defined as cement / total water ratio (C/TW). Expression (1) shows the calculation of C/TW.

$$TW = W + s \times Ds \times ws + g \times Dg \times wg \qquad (1)$$

Where, *TW* is total water content, *W* is water content, *s* is content by volume of fine aggregate, *Ds* is density of fine aggregate in the oven-dried condition, *ws* is water absorption of fine aggregate, *g* is content by volume of coarse aggregate, *Dg* is density of coarse aggregate in the oven-dried condition, and *wg* is water absorption of coarse aggregate.

Fig.2 shows the relationship between C/TW and compressive strength. In both case, the relationship was linear when compressive strength was 30 - 70 N/mm^2. The kind of aggregate had no influence to the relation. However, when compressive strength exceeds 70 N/mm^2, the compression strength of concrete used recycled coarse aggregate decreased to approximately 80% that using ordinary coarse aggregate. The supposed reason was thought that recycled coarse aggregate was inferior to ordinary coarse aggregate in particle strength. In other words, it is desired that high particle of strength coarse aggregate is used in high-strength concrete.

Similarly, as shown in Fig.3, the splitting tensile strength showed a linear relationship with C/TW, when splitting tensile strength was 3 - 6 N/mm^2.

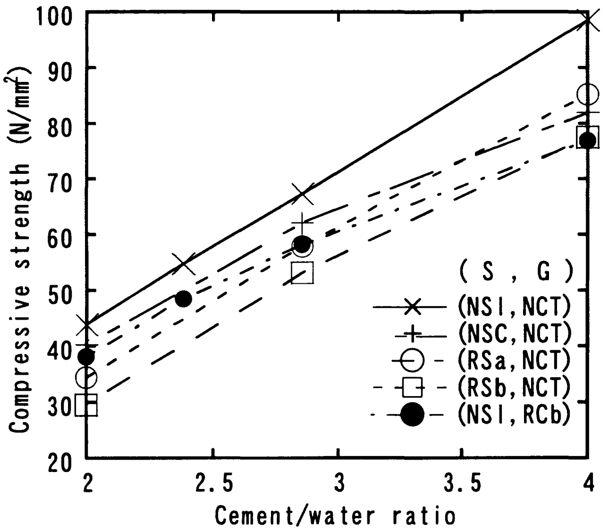

Fig.1 Relationship between compressive strength and cement / water ratio

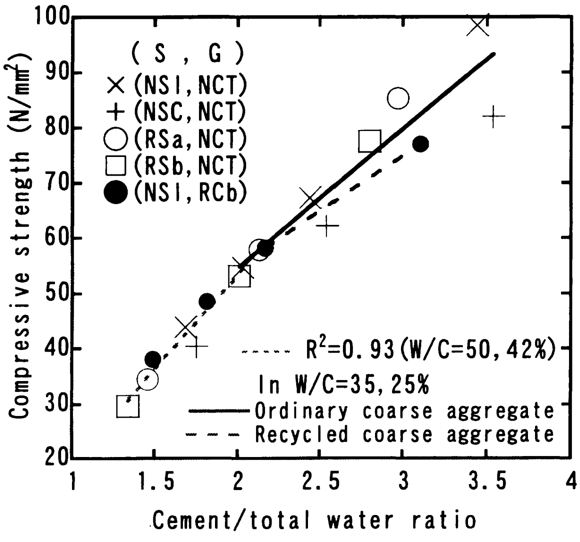

Fig.2 Influence of cement / total water ratio on compressive strength

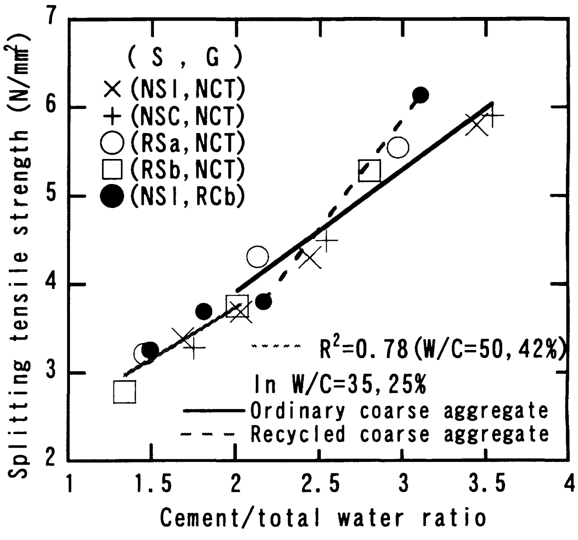

Fig.3 Relationship between splitting tensile strength and cement / total water ratio

4. Results and Discussion about Drying Shrinkage

Next, the drying shrinkage of recycled concrete was investigated. As shown in Fig.4, length change rate tended to decrease with increasing C/W. As compared with the case where ordinary aggregate was used, when recycled fine aggregate of high water absorption was used, the length change rate became large. According to a previous study, not only water content but also cement content influences drying shrinkage strain. Then, paying attention to the amount of cement, a length change rate per unit cement volume was computed. As shown in Fig.5, the results clarify a strong correlation between C/TW and length change per unit cement volume. The above results suggest that the properties of hardened concrete used recycled fine and coarse aggregate are greatly influenced by C/TW, which takes into consideration the amount of water absorption of aggregate.

As the result of this study, if amount of water absorbed to aggregate is considered, a part of properties of concrete used recycled fine and coarse aggregate will be able to be controlled. So, the recycled aggregate can be used for normal-strength concrete. But, in case of high-strength concrete, it is difficult to use recycle coarse aggregate because particle strength influenced concrete strength.

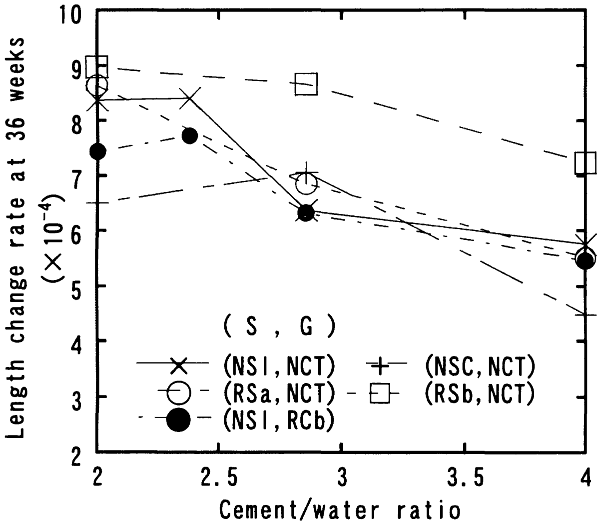

Fig. 4 Change in length change rate with increase in cement / water ratio

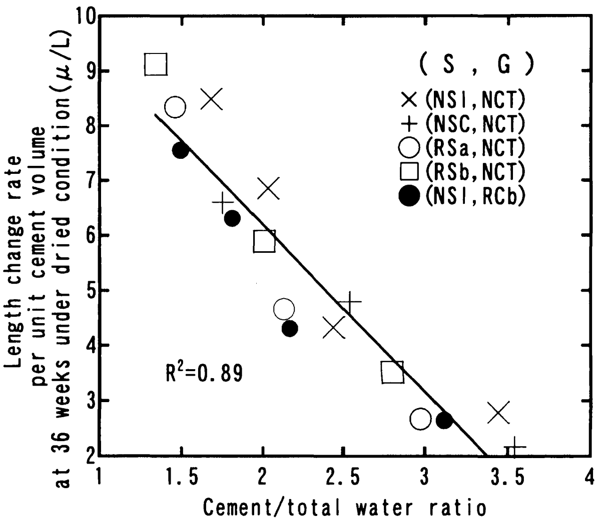

Fig.5 Influence of cement/total water ratio on length change per unit cement volume

5. Conclusion

1) A linear relation existed between the compression or splitting tensile strength of concrete of a given slump and the ratio of cement content to amount of total water in concrete (C/TW), within the compression strength range of 30-70 N/mm^2 or tensile strength 3-6 N/mm^2.
2) The length change per unit cement volume was closely correlated with C/TW.

References

1) Takayuki FUMOTO, etc.: Influence of Quality of Recycle Fine Aggregate on Properties of Concrete , No.24, Vol.1, pp.1233-1238, 2002.
2) Kenji Izumo: Drying shrinkage of various mortar, Proceeding of Annual Conference of the Japan Society of Civil Engineers No. 57, V-651, pp.1301-1302, 2002.