STATISTICAL ANALYSIS OF STRENGTH VARIATION IN CONCRETE UTILIZING LOW-GRADE RECYCLED AGGREGATES

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1. Introduction

Past research works have shown that the usage of recycled aggregate in new concrete reduces performance such as workability, strength, and durability. However, the effect of recycled aggregate quality and variation on the variation in concrete properties has not been widely investigated. In a previous study on the effect of recycled aggregate quality on the variation of compressive strength, it was found that the coefficient of variation did not increase greatly between different recycled aggregates [1]. However, when combining aggregate types the variation in strength was greater than when either of the types was utilized alone. This paper follows up on these results by conducting statistical analyses of aggregate quality and strength variation using a statistical hypothesis test (t-test) and examines the effects of mixing aggregate types.

2. Experimental program

2.1. Materials

Four types of coarse aggregates were used in this investigation. Saturated surface dry (SSD) density and absorption were measured following JIS A 1109 ten times for each aggregate type, with the means and coefficients of variation (C.V.) reported in Table 1. Water (W), type-I portland cement (C), river sand (S), and air-entraining admixtures were also used for preparing concrete.

2.2. Mix proportions and specimens

Concrete mix proportions are given in Table 2. The water-cement ratio was set at 0.50, and the effect of recycled aggregates was examined by replacing 100% of the normal coarse aggregates with recycled aggregates. Two combinations of aggregates (N-R1, R1-R3), split evenly by volume, were also investigated.

Cylinder specimens were cast for each concrete mix following JSCE-F 552. Specimens were cured in the molds for 24 hours then placed in water curing at 20°C.

2.3. Testing and statistical analysis

Compressive strength testing of 30 specimens per series was conducted 28 days after casting following JIS A 1108, and the mean, standard deviation, and coefficient of variation were calculated for each series. In order to determine whether the properties of the aggregates and concretes actually differed, a two-sample, two-tailed t-test with unequal variance was utilized which tested the null hypothesis that the means of two distributions were the same at a significance level of 5% (α = 0.05).

3. Experimental and analysis results

3.1. T-test of recycled aggregates

The t-test was applied to the distribution of recycled aggregate properties in order to verify that the recycled aggregates, which were acquired from different sources, could be labeled as statistically different. Results showed that the means of the density and absorption were different for all aggregate types except for the mean absorptions of R2 and R3, which were statistically the same at α = 0.05.

Table 1 Properties of coarse aggregates

Type	Density (g/cm3) [C.V.]	Absorption (%) [C.V.]	Grade (JIS A 5002)
Normal (N)	2.71 [0.14]	0.78 [9.76]	-
Recycled 1 (R1)	2.45 [0.53]	5.66 [6.32]	Low
Recycled 2 (R2)	2.38 [0.59]	7.53 [3.32]	< Low
Recycled 3 (R3)	2.36 [0.49]	7.91 [4.02]	< Low

Table 2 Concrete mix proportions

Series name	(kg/m^3)						
	W	C	S	N	R1	R2	R3
N	177	353	742	1042	-	-	-
R1	177	354	785	-	897	-	-
R2	166	332	771	-	-	932	-
R3	176	352	787	-	-	-	866
N-R1	175	350	789	503	453	-	-
R1-R3	177	353	749	-	466	-	448

Keywords: recycled aggregate, compressive strength, t-test, coefficient of variation
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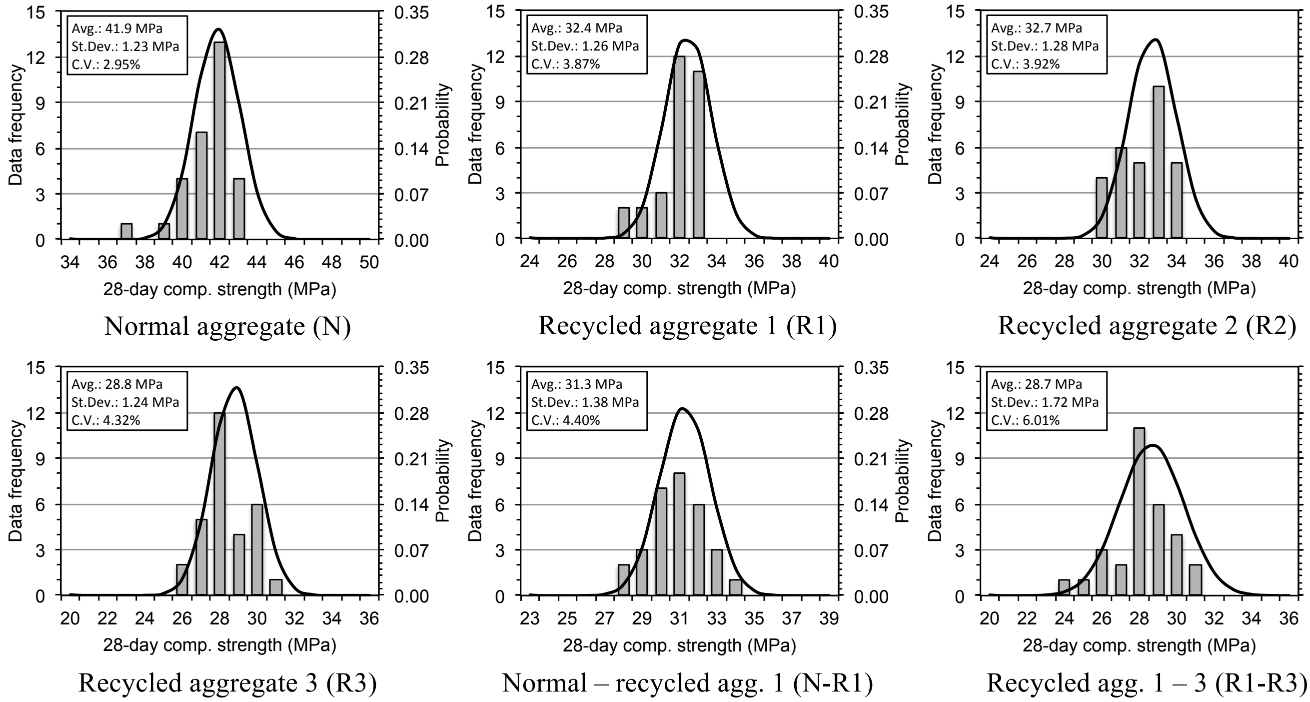

Figure 1 Data frequency and probability distributions

3.2. Compressive strength results & distributions

The frequency distributions of compressive strength results are shown in Figure 1 along with the means, standard deviations, coefficients of variation, and the calculated normal probability curves. As reported previously, replacing normal aggregates with recycled aggregates increases C.V., but when combining types the C.V. is greater than when either aggregate is used alone.

3.3. T-test of compressive strength

When applying the t-test to the compressive strength results it was determined that, at $\alpha = 0.05$, the mean values were statistically different for all test series except for concretes using R1 and R2 and concretes using R3 and R1-R3, which were found to be statistically the same. However, the t-test of aggregate properties showed R1 and R2 to be different; therefore, it can be said that, even though aggregates R1 and R2 were different, the compressive strength of concrete using these aggregates was the same, so the difference in aggregate quality did not have an affect on the concrete strength. In the case of the concretes using R3 and R1-R3, it is not possible to make a similar conclusion because the properties for the combination of recycled aggregates were not measured.

3.4. Estimating the coefficient of variation

Combining different types of aggregates was found to increase the variation in concrete strength. Therefore, it is possible that combining aggregate types has an amplifying effect on strength variation. To test this theory, the relationship between the number of bonding surfaces and the coefficient of variation was examined. In this case, the number of bonding surface refers to where mortar bonds to the aggregate. In the case of normal aggregates, the bond between the aggregate and the fresh mortar can be assumed to be uniform, so the number of bonding surfaces is "1." However, for recycled aggregates, the number is "3": the bond between the residual mortar and the original aggregate, between the fresh mortar and the original aggregate, and between the fresh mortar and residual mortar.

The relationship between the number of bonding surfaces and the coefficients of variation is shown in Figure 2. A positive linear relationship can be seen with an R^2 value of 0.79, indicating that this may be one way to estimate the coefficient of variation when combining different types of aggregates.

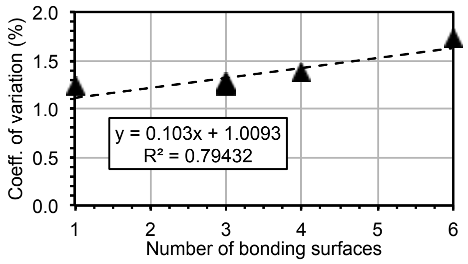

Figure 2 Relationship between number of bonding surfaces and strength coefficient of variation

References

[1] Henry, M., Hagiwara, K., Nishimura, T., Kato, Y., "Effect of recycled aggregate quality on variation and estimation of concrete strength," Proceedings of the Japan Concrete Institute, Vol. 33 No. 1, pp. 1535-1540, 2011.