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Study on Conversion Formula between Strength of Recycled Aggregate Concrete

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Abstract

In order to study the conversion formulas of splitting tensile strength, flexural strength and cubic compressive strength of recycled aggregate concrete, regression analysis of experimental data in the existing literature was carried out. The results show that the logarithm of splitting tensile strength is approximately linear with the logarithm of cubic compressive strength, and the goodness of fit is 0.712. The flexural strength is proportional to the 0.5 power approximation of cubic compressive strength, and the goodness of fit is 0.967. The average ratios of splitting tensile strength and flexural strength to the calculated values are 1.007 and 0.978, respectively. The standard deviation and coefficient of variation are small, and the formulas in this paper can be used to convert strength indexes.

Keywords

Recycled aggregate concrete, strength, conversion formula, goodness of fit.

1. Introduction

In July 2019, the Ministry of Science and Technology of China issued *the notice of the Ministry of Science and Technology of the people's Republic of China on Issuing the application guide for key projects in 2019, such as the national key R & D plan "solid waste recycling"*, aiming to strengthen the disposal of solid waste and garbage, promote the comprehensive conservation and recycling of resources, and provide scientific and technological guarantee for greatly improving the efficiency of resource utilization in China and supporting the construction of ecological civilization. For the civil engineering industry, as the main solid waste, the waste concrete produced by the demolition and reconstruction of buildings is of great significance. Recycled aggregate concrete (RAC) technology [1] refers to the crushing and processing of waste concrete into recycled aggregate, which is used to replace part of the natural aggregate. On the one hand, it saves the natural aggregate resources, makes the solid waste of construction waste resourceful. On the other hand, it reduces the environmental pollution caused by the transportation of waste concrete and the land occupation caused by the landfill of waste concrete. RAC has a significant effect environmental, economic and social benefits.

In recent years, many scholars have carried out experimental research on the mechanical properties of RAC. For example, A.J. Chen et al. [2] designed a four factor, three level orthogonal test scheme with the content of recycled aggregate (RA), fly ash (FA), water reducer (WR) and fiber type as factors, and the compressive strength, splitting tensile strength, flexural strength and slump as indicators. The results show that RA content is the main significant factor of compressive strength, fiber type is the main significant factor of splitting tensile strength and flexural strength, WR content and fiber type have a significant impact on slump. Considering the workability and strength, the best combination of RAC is A2B3C2D1, that is, RA content is 50%, FA content is 20%, WR content is 0.5%. The test of R. Hai et al. [3] showed that the compressive strength of RAC decreased by 20.7%, 15.3% and

10.6% respectively on the 3d, 7d and 28d, and the tensile strength, flexural strength, tensile compression ratio and flexural compression ratio decreased by 12.7%, 14.2%, 2.4% and 4.2% respectively on the 28d when the content of water reducing agent was 0.45% and the content of recycled aggregate increased from 30% to 50%. J.J. Tang et al. [4] found that when the number of steel fiber spreading layers is 4 and the amount of layer spreading is 2.0 kg/m^2, the compressive strength, splitting tensile strength, tension compression ratio and elastic strength ratio of RAC increased by 0.5%, 17.8%, 17.2% and 13.1% respectively, and the failure of RAC changed from brittleness to plasticity.

At present, considering that most of the researches on the mechanical properties of RAC are focused on the strength (compression, splitting, bending) and the strength ratio (tension compression ratio, elastic strength ratio, bending compression ratio), while the research on the conversion formula between RAC strength is relatively small, and the technical specification for recycled concrete structure (JGJ/T 443-2018) issued by the Ministry of housing and urban rural development in 2018 also lacks the strength conversion formula. Based on this, this paper first selects the test data according to the main influence factors of RAC strength, and then obtains the conversion formula between splitting tensile strength, flexural strength and cube compressive strength by fitting the test data. Finally, the applicability of the conversion formula is analyzed for reliability, which provides reference for the research of RAC mechanical properties.

2. Selection of Test Data

Previous studies have shown that RA substitution rate and water binder ratio are the main influencing factors of RAC strength [5]. Table 1 shows the measured data of compressive strength f_{cu}, splitting tensile strength f_{ts} and flexural strength f_f of some concrete cubes in literature [6-9], wherein the parameters in literature [6, 8, 9] are RA substitution rate, and the variables in literature [7] are RA substitution rate and water binder ratio. In reference [8], there is no RAC flexural strength test data, so the data used to fit the conversion formula between f_{ts} and f_{cu} is 20 groups, while the data used to fit the conversion formula between f_f and f_{cu} is 15 groups.

3. Fitting of Conversion Formula

3.1. Conversion Formula between f_{ts} and f_{cu}

The conversion formula between ordinary concrete splitting tensile strength f_{ts} and cube compressive strength f_{cu} given in *code for design of concrete structures* (GB 50010-2010) is as follows:

$$f_{ts} = 0.19 f_{cu}^{0.75} \tag{1}$$

In this study, formula (1) is used as the model, the logarithm of the measured data of compressive strength and splitting tensile strength in Table 1 is taken, and the scatter diagram is drawn with lnf_{ts} as the Y-axis and lnf_{cu} as the X-axis, and the fitting results are shown in Figure 1.

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Table 1: Test data in reference [6-9]

Data sources	Specimen number	RA substitution rate /%	Water binder ratio	f_{cu}/MPa	f_{ts}/MPa	f_f/MPa
Literature[6]	NC	0	0.43	32.1	2.90	3.50
	RC50	50	0.43	25.5	1.80	2.40
	RC100	100	0.43	25.9	2.20	2.80
Literature[7]	R30-0	0	0.48	37.2	3.05	5.53
	R30-60	60	0.48	40.5	3.50	5.75
	R40-0	0	0.39	47.7	3.69	5.80
	R40-60	60	0.39	53.9	3.94	6.13
	R50-0	0	0.32	59.5	4.16	6.33
	R50-60	60	0.32	59.3	4.04	6.35
Literature[8]	A0	0	0.47	34.4	3.50	/
	A25	25	0.47	33.3	3.50	/
	A50	50	0.47	34.1	2.70	/
	A75	75	0.47	31.1	3.00	/
	A100	100	0.47	27.7	2.30	/
Literature[9]	NC-0	0	0.32	63.8	3.94	7.10
	RC-20	20	0.32	58.4	4.01	5.92
	RC-30	30	0.32	57.1	3.97	5.24
	RC-40	40	0.32	53.7	3.90	5.19
	RC-50	50	0.32	54.5	3.11	4.72
	RC-60	60	0.32	51.7	3.26	3.44

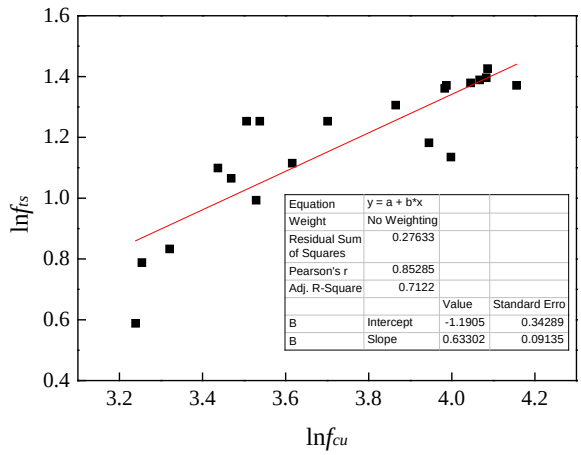

Figure 1: The relationship between f_{ts} and f_{cu}

It can be seen from Figure 1 that lnf_{ts} and lnf_{cu} are approximately linear, as shown in formula (2). The judgment coefficient (goodness of fit) R^2 = 0.712 > 0.650, which shows that the correlation between the prediction results and the test results is good [10]. By simplifying formula (2), the conversion formula between the RAC splitting tensile strength f_{ts} and the cube compressive strength f_{cu} can be obtained, such as formula (3).

$$\ln f_{ts} = 0.633 \ln f_{cu} - 1.191 \tag{2}$$

$$f_{ts} = 0.304 f_{cu}^{0.633} \tag{3}$$

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3.2. Conversion Formula between f_f and f_{cu}

The flexural strength f_f of concrete is generally calculated based on $f_{cu}^{0.5}$ [5]. The data in Table 1 are drawn into a scatter diagram and then fitted, with f_f as the Y-axis and $f_{cu}^{0.5}$ as the X-axis. The results are shown in Figure 2.

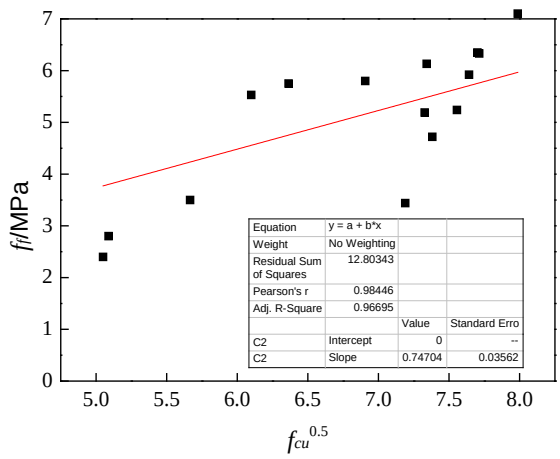

Figure 2: The relationship between f_f and f_{cu}

It can be seen from Figure 2 that f_f and $f_{cu}^{0.5}$ are approximately in a positive proportion. The conversion formula between RAC flexural strength f_f and cube compressive strength f_{cu} is shown in formula (4), and its goodness of fit R^2 = 0.967. The correlation between the predicted results and the test results is good.

$$f_f = 0.747 f_{cu}^{0.5} \tag{4}$$

4. Verification of Conversion Formula

In order to verify the applicability of the conversion formula, reliability analysis is carried out for formula (3, 4). According to the compressive strength test value in Table 1, the splitting tensile strength calculation value and bending strength calculation value are calculated by formula (3, 4), and compared with the splitting tensile strength and bending strength test value in literature [6-9], the results are shown in Table 2.

Table 2: Reliability analysis of conversion formula

	Test value / calculated value	
	Splitting tensile strength	Flexural strength
Average value	1.007	0.978
Standard deviation	0.117	0.193
Coefficient of variation	0.116	0.197

From Table 2, it can be seen that the average value of the ratio of the splitting tensile strength test value to the calculated value is 1.007, the average error of 20 groups of data is only 0.7%, the standard deviation and the coefficient of variation are 0.117 and 0.116 respectively, and the data dispersion degree is relatively low. This result shows that the test value is in good agreement with the calculated value, and equation (3) can be used to convert the splitting tensile strength and cube compressive strength of RAC. The average value of the ratio of the flexural strength test value to the calculated value is 0.978, the average error of 15 groups of data is 2.2%, the standard deviation and coefficient of variation are small, and the data

dispersion degree is low. Equation (4) can be used to convert the flexural strength and cube compressive strength of RAC.

5. Conclusion

According to the test data, the conversion formulas between the splitting tensile strength f_{ts}, the flexural strength f_f and the cube compressive strength f_{cu} are fitted, and the applicability of the conversion formulas is analyzed. The following conclusions are obtained:

The logarithm of splitting tensile strength $\ln f_{ts}$ and logarithm of cube compressive strength $\ln f_{cu}$ are approximately linear, and the goodness of fit is 0.712. The average value, standard deviation and coefficient of variation of the ratio of splitting tensile strength test value to formula calculation value are 1.007, 0.117 and 0.116, respectively, the data error and dispersion degree are relatively low, and the conversion formula between f_{ts} and f_{cu} obtained in this paper has good applicability.

The relationship between the flexural strength f_f and the 0.5 power of the cube compressive strength $f_{cu}^{0.5}$ is approximately positive proportion, and the goodness of fit is 0.967. The average value, standard deviation and coefficient of variation of the ratio of the flexural strength test value to the calculated value of the formula are 0.978, 0.193 and 0.197, respectively, and the formula in this paper can be used for the conversion between f_f and f_{cu}.

Due to the lack of experimental data in this study, the conversion formulas between RAC splitting tensile strength f_{ts}, flexural strength f_f and cube compressive strength f_{cu} need to be further studied.

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