Study of the Compressive Strength of Concrete with Partial Replacement of Recycled Coarse Aggregates

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Abstract-This paper presents a study on the compressive strength of concrete using recycled aggregates. The concrete was designed to have a 25MPa compressive strength and an 8cm slump. The rates of replacing natural aggregates with recycled coarse were 0%, 10%, and 20%. The test samples were compressed to determine their compressive strength value after 7, 14, and 28 days of curing. The results showed that the concrete slump did not change effectively at a 10% replacement rate. When using 20% recycled aggregates, the concrete was too hard and the homogeneity of the concrete mixture could not be guaranteed. The compressive strength slightly decreased using 10% of recycled aggregates and decreased significantly using 20%. Therefore, 20% of recycled aggregate replacement is not suitable. The results showed that using recycled aggregates at a rate of 10% is optimal.

Keywords-compressive strength; recycled concrete; demolishing work

I. INTRODUCTION

In recent years, developed countries deal with the recycling and treatment of construction solid waste. Construction's solid waste treatment, solid waste minimization, pressure to change, and the approach to resolving these issues in the UK were studied in [1]. China faces a similar problem as the amount of solid construction waste was more than 1.5 billion tons per year in 2018, and it was predicted to reach 2.5 billion per year in 2020 [2]. The solid waste treatment in current construction sites, the life cycle of sustainable development, and the evaluation of the environmental impact of the construction materials consumed in China during 2000-2015 were studied in [3]. Many studies have been conducted on recycled aggregates, such as their use in green concrete [4, 5], coarse aggregates for concrete [6], and fine concrete [7, 8]. While the reuse of construction solid waste as aggregates for concrete has been widely used and achieved remarkable efficiency, many studies have been conducted recently on the mechanical properties of concrete with recycled aggregates. The influence of the recycled aggregates on the compressive strength of concrete was studied in [9], concluding that they did not have a significant influence on compressive, flexural, and tensile strength. The use of recycled aggregates from demolished works after crushing and grading, helps to save natural aggregate sources and protect the environment, was studied in [10]. The compressive strength of concrete made from recycled coarse aggregates was studied in [11], with consideration of the source of the recycled aggregates and the strength of the target concrete. The toughness and soundness test results on the recycled coarse aggregates showed a higher percentage loss than the natural, but it remained within the acceptable limits. The compressive and splitting tensile strengths of concrete with recycled coarse aggregate depend on the mix proportions. In general, the strength of the recycled concrete can be 10-25% lower than the conventional made with natural coarse aggregates.

This paper presents a study on the compressive strength of concrete having a partial replacement of natural with recycled coarse aggregates.

II. COMPOSITION OF RECYCLED CONCRETE

The concrete obtained after a project's demolition was crushed and the resulting coarse aggregates were washed, dried, and pre-screened to remove any dust particles. These raw aggregates were screened to classify the particles and then mixed again to be graded as standard for concrete according to [12]. To avoid strongly absorbing recycled aggregates affecting the setting of the concrete, the coarse aggregates were soaked in water and then dried under normal conditions. In this study, a natural concrete aggregate was selected as a reference. The coarse aggregate was replaced partially by solid waste from the crushed demolition site. After casting according to the standard, the samples were stored under normal conditions and tested for compressive strength after 7, 14, and 28 days.

Fig. 1. Recycled coarse aggregates

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A. Sand

The mechanical properties of the sand used in the experiment were:

- Density: 2.65g/cm^3
- Modulus of magnitude: 2.50
- Volumetric mass: 1660kg/m^3

B. Cement

A commercial Portland cement PCB40 was used, having the following mechanical properties:

- Actual strength: 40MPa
- Density: 3.1g/cm^3

C. Coarse Aggregates

Natural coarse aggregates were mixed with recycled materials. In this study, 20mm aggregates, the most common size of aggregates used in construction, was used having the following mechanical properties:

- Density: 2.61g/cm^3
- Volumetric mass: 1430kg/m^3

D. Concrete

The designed recycled concrete had the grade of B20, and the design slump was 8cm. The compressive strength of the concrete was tested according to the Vietnamese standard 3118:1993. Cylindrical samples with size $D150\times H300$ were cast and cured in water before being compressed to determine their compressive strength. The loading speed was set to 0.5kN/s. The replacement rates of coarse aggregates were 0%, 10%, and 20% of the standard reference sample, respectively. The mix components for 1m^3 of concrete are presented in Table I.

TABLE I. MIX COMPONENTS FOR 1M^3 OF CONCRETE

	Mix components for 1m^3 of concrete			
Aggregates by mass	**Cement (kg)**	**Sand (kg)**	**Aggregate (kg)**	**Water (kg)**
	292.5	648.3	1216.3	195.0
Aggregates by volume	**Cement (kg)**	**Sand (m^3)**	**Aggregate (m^3)**	**Water (l)**
	292.5	0.391	0.851	195.0

TABLE II. EXPERIMENTAL DETAILS OF CONCRETE SAMPLES

No.	Notation of samples	Description	Quantity
1	CP0	Reference sample: Mix according to Table I	3 samples for 7 days, 3 samples for 14 days, and 3 samples for 28 days.
2	CP10	Recycled aggregate replacement rate: 10%	
3	CP20	Recycled aggregate replacement rate: 20%	

III. RESULTS AND DISCUSSION

The results of measuring the slump of the concrete with recycled coarse materials are shown in Table III and Figure 2.

TABLE III. THE SLUMP OF THE RECYCLED CONCRETE

No.	Replacement rate	Slump (mm)
1	0%	73
2	10%	70
3	20%	12

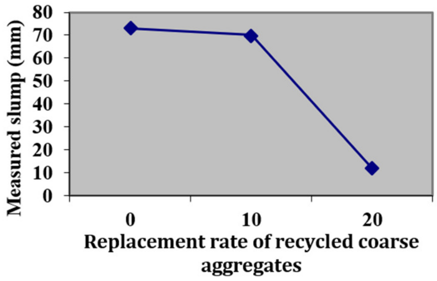

Fig. 2. The slump of recycled concrete at various recycled coarse aggregates replacement rates.

From Figure 2, it can be noted that the slump of concrete did not change significantly at 10% replacement rate. When using 20% recycled coarse aggregates, the drop was markedly obvious as it dropped from 73mm at 0% to 70mm at 10%, and finally to 12mm at 20%. Thus, when using 20% recycled aggregates, the concrete was too hard and its homogeneity could not be guaranteed.

Fig. 3. Samples after the compressive experiments.

Table IV shows the destructive force (kN) results obtained from the compression test. Compressive strength (MPa) was calculated from the destructive force P (kN) for each sample having a 15cm diameter, using:

$$S = \pi \times R^2 =$$
$$= \pi \times 7.5^2 = 176.71 cm^2 \quad (1)$$

Compressive strength was calculated, using (1), as:

$$R = \alpha \times P/S \quad (2)$$

where P is the destructive load of the sample, S is the compressive area, and α is the coefficient of converting the experimental results when compressing the samples with different sizes from the standard samples (150×150×150mm). For a cylinder sample having 150mm diameter and 300mm height, α was calculated to 1.2. Table V shows the compressive strengths of the experimental samples after 7, 14, and 28 days.

TABLE IV. DESTRUCTIVE FORCE RESULTS

No.	Replacement rate of recycled aggregates (%)	Sample destructive force (kN)		
		7 days	14 days	28 days
1	0	185.55	231.94	309.25
2	0	196.30	199.47	316.61
3	0	200.32	239.73	328.39
4	10	195.36	224.52	291.58
5	10	186.26	228.32	300.41
6	10	176.80	240.82	304.83
7	20	130.95	178.79	251.82
8	20	135.02	173.24	254.76
9	20	126.93	161.77	248.87

TABLE V. COMPRESSIVE STRENGTH RESULTS

No.	Replacement rate of recycled aggregates (%)	Compressive strength (MPa)		
		7 days	14 days	28 days
1	0	12.6	15.75	21
2	0	13.33	13.545	21.5
3	0	13.603	16.279	22.3
4	10	13.266	15.246	19.8
5	10	12.648	15.504	20.4
6	10	12.006	16.353	20.7
7	20	8.892	12.141	17.1
8	20	9.169	11.764	17.3
9	20	8.619	10.985	16.9

As it can be noted, the experimental concrete samples did not reach the design strength. The reference sample reached only 86.4% of the design strength. This rate was 81.2% when using 10% and 68.4% when using 20% recycled aggregates. Thus, using 10% recycled aggregates did not affect significantly the compressive strength of the concrete. When using 20% recycled aggregates, the compressive strength dropped significantly. For a clearer observation, the compressive strength results of concrete at various recycle aggregate replacement rates are shown in Figure 4 and Table VI.

TABLE VI. COMPRESSIVE STRENGTH MEAN VALUES FOR EACH EXPERIMENT

No.	Replacement rate of recycled aggregates (%)	Compressive strength (MPa)	Mean value	Achieved compared with design (25 MPa)
1	0%	21	21.6	86.4 %
		21.5		
		22.3		
2	10%	19.8	20.3	81.2 %
		20.4		
		20.7		
3	20%	17.1	17.1	68.4%
		17.3		
		16.9		

The decrease of compressive strength when using recycled aggregates was predicted, as noticed in previous studies [11, 13, 14]. The higher compressive strength of the concrete having a lower recycled aggregate replacement rate may be attributed to the greater bonding force and strength when using the same type of aggregate. Figure 5 shows the strength development of recycled concrete, which indicates that concrete strength reached 51-67% after 7 days and about 63-75% after 14 days of curing. Details are shown in Table VII.

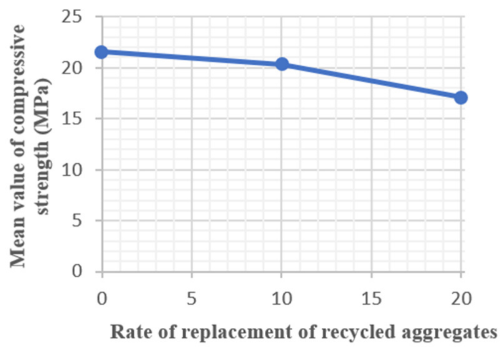

Fig. 4. Compressive strength of concrete at various recycled coarse aggregate replacement rates.

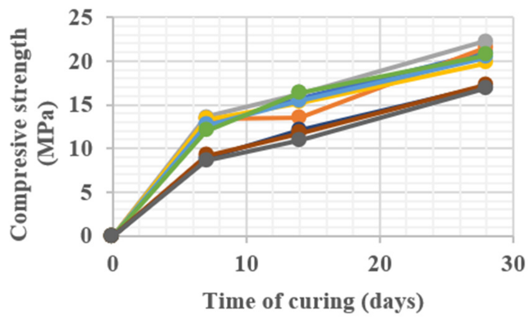

Fig. 5. The development of concrete's compressive strength.

TABLE VII. COMPARISON OF THE COMPRESSIVE STRENGTH OF CONCRETE WITH THE STRENGTH AFTER 28 DAYS OF CURING (R_{28})

No.	Compressive strength (MPa)				
	7 days	Ratio compared to R_{28}	14 days	Ratio compared to R_{28}	28 days
1	12.6	60%	15.75	75%	21
2	13.33	62%	13.545	63%	21.5
3	13.603	61%	16.279	73%	22.3
4	13.266	67%	15.246	77%	19.8
5	12.648	62%	15.504	76%	20.4
6	12.006	58%	16.353	79%	20.7
7	8.892	52%	12.141	71%	17.1
8	9.169	53%	11.764	68%	17.3
9	8.619	51%	10.985	65%	16.9

As it can be noted, the strength development of the concrete using recycled aggregates at a low rate (≤ 20%) is similar to ordinary concrete. However, a few notes can be pinpointed:

- Normal concrete grows up to 65% of its maximum design strength at the age of 7 days. The experimental samples did not reach this level. This growth rate was slowed down when using 20% recycled aggregates, with a ratio of 51-53% to R_{28}.

- At 14 days of curing, the experimental concrete achieved about 70-75% of the maximum design strength. However, most of the concrete samples using 20% recycled aggregate had slightly lower strength than normal.

IV. CONCLUSION

This paper presents the results of a study on the compressive strength of concrete using recycled aggregate from demolition works. The concrete was designed to have 25MPa compressive strength and 8cm slump. The rates of replacing natural aggregates with recycled coarse were 0%, 10%, and 20%. The test samples were compressed to determine their compressive strength values at 7, 14, and 28 days of curing. The results showed that the concrete slump did not change significantly at samples having 10% recycled aggregates. When using 20% recycled coarse aggregates, the drop was markedly obvious. Thus, using 20% recycled aggregate resulted in too hard concrete, while the homogeneity of the concrete mixture could not be guaranteed. The compressive strength decreased slightly when using 10% recycled aggregates and significantly when using 20%. Therefore, it can be concluded that the 20% replacement rate is not appropriate. The results showed that using recycled aggregates at a rate of 10% is an optimal solution.

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