Evaluating the Possibility of Replacing Natural Fine Aggregates in Concrete with Recycled Aggregates

Duy Duan Nguyen
Faculty of Construction
Vinh University
Vinh, Vietnam
duan468@gmail.com

Dieu Thuy Nguyen
Faculty of Construction
Vinh University
Vinh, Vietnam
dieuthuy03@gmail.com

Thi Hao Cao
Faculty of Construction
Vinh University
Vinh, Vietnam
haoxd13@gmail.com

Van Tien Phan
Faculty of Construction
Vinh University
Vinh, Vietnam
vantienkxd@vinhuni.edu.vn

Abstract-This paper presents an investigation on the possibility of replacing natural fine aggregates with recycled aggregates in concrete. The studied recycled aggregates were acquired from crushed waste concrete from demolishing works. The rate of replacement of natural fine aggregates was 10%, 20%, and 30% by weight. Compressive and flexural tensile strength of concrete incorporating recycled aggregates was investigated at 28 days of curing. The results show that the compressive and flexural strength of concrete is strongly affected by the percentage of recycled aggregates. It has been found that the strength decreases linearly with increasing recycled aggregate content. So, in order to apply recycled waste to concrete as fine aggregates, it is necessary to perform supplement research with appropriate additives to compensate for the loss of compressive and flexural strength.

Keywords-compressive strength; flexural tensile strength; recycled concrete; fine aggregates

I. INTRODUCTION

The use of recycled materials instead of natural sources in concrete has been concerned by various researchers [1-6]. The influence of using recycled waste aggregates instead of natural fine aggregates to the modulus of elasticity, pulse velocity and long-term properties such as drying shrinkage and creep has been investigated in [1]. It has been found that the detrimental effects of using crushed concrete fines in concrete can be mitigated by a partial replacement of crushed concrete fines with pulverized fuel ash [1]. It was found that the rate of replacement of fine aggregates by recycled sources can be up to 10% for producing C30 concrete [2]. By using recycled fine concrete aggregates, the environmental impact and the consumption of natural resources can be significantly reduced. The results in [5] indicate that recycled concrete has a suitable behavior according to the limits indicated by different international codes for structural concrete. The durability of concrete with recycled fine aggregates has also been investigated in [4], in which the recycled fine aggregates proved to be sustainable materials for construction works. The optimum replacement percentage of river sand by recycled fine aggregates was found to be 30%. Authors in [5] studied the use of recycled fine aggregates in concrete with durability requirements. Different percentages of recycled fine aggregates (0%, 20%, and 30%) were considered and evaluated. It has been found that the compressive strengths of recycled and conventional concrete are similar and the durable behavior of recycled concrete is as good as that of the conventional concrete.

Many studies on the use of recycled coarse aggregates instead of natural coarse aggregates in concrete have been carried out [2, 6-11]. The effect of the amount of recycled coarse aggregates on the properties of recycled aggregate concrete has been investigated in [11], in which 4 different recycled aggregate concrete types were produced with the same design compressive strength in replacement ratios up to 100%. The influence of the type of recycled aggregates, namely unbound stone, crushed concrete, and crushed brick, to the properties of concrete has been studied in [12]. The results showed that the performance of concrete containing each type of recycled aggregates was largely influenced by the aggregate nature and quality, in addition to the attached mortar content.

Studies on the use of recycled aggregates in concrete instead of natural coarse aggregates have been carried out by various authors. However, there are only a few published papers on the use of recycled aggregates instead of fine aggregate in concrete. In this paper, the possibility of replacing natural fine aggregates by recycled aggregates in concrete will be evaluated in terms of compressive and flexural strength of concrete. The results will give documented recommendations for further studies.

Corresponding author: Van Tien Phan

II. COMPOSITION OF RECYCLED CONCRETE

Waste concrete obtained from demolishing works was crushed and then sieved through standard sized sieves to obtain fine recycled aggregates with diameter ranging between 0.14mm and 5mm. The crushed aggregates were soaked in water until saturation, and then they were allowed to dry at room temperature. For evaluating the possibilities of replacing natural fine aggregates with recycled aggregates in concrete, a reference mixture was selected. Natural sand was then replaced by recycled aggregates at various rates, namely 10%, 20%, and 30% by weight. After casting into molds, the samples were stored under normal conditions and the experiments were carried out at 28 days of curing.

In the compressive strength experiment, normal force was applied on both surfaces of cylindrical concrete specimens with the loading speed set to 0.5kN/s. The maximum compression force was then recorded (Figure 1). Cylindrical samples sizes D150×H300 were cast and cured in normal conditions before being compressed to determine their compressive strength. The compressive strength of concrete was determined based on the Vietnamese standard TCVN 10303:2014.

In the flexural bending test, 3 beam specimens with a size of 150×150×600mm were sampled following the standard TCVN 3105:1993, and were left to be cured for 28 days. The flexural strength of concrete beams was determined based on the TCVN 3119:1993 standard. The four-point bending test set-up is shown in Figure 2. The bending load was continuously increasing at a constant rate equal to 0.6±0.4daN/cm^2 for 1s until failure occurred.

The replacement rates of recycled aggregates were 0%, 10%, 20% and 30%. Mix components for 1m^3 of concrete are presented in Table I.

(a)

(b)

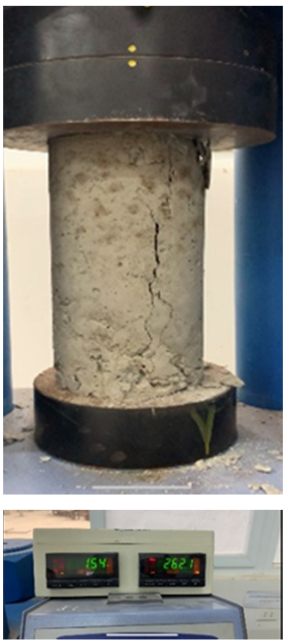

Fig. 1. (a) An in-process experiment (CP20) and (b) the recorded destructive force.

(a)

(b)

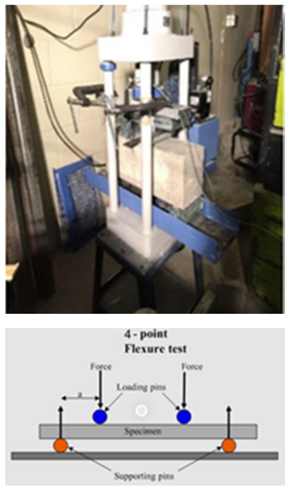

Fig. 2. Flexural experimental set-up.

TABLE I. MIX CONTENTS FOR 1 m^3 OF CONCRETE

Cement (kg)	Sand (kg)	Coarse aggregates (kg)	Water (kg)
292.5	648.3	1216.3	195.0

III. RESULTS AND DISCUSSION

The peak normal load obtained in the compression experiment is shown in Table II. From the value of the destructive force P (kN) of each sample, the compressive strength (MPa) is calculated as follows:

The bearing area S is calculated by (1) where R is the sample radius, which is half the sample diameter D = 15cm, so:

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

The compressive strength is then calculated by (2):

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

where P is the destructive load of the sample, S is the compressive area, α is the coefficient of converting the experimental results when compressing samples with different size from the standard samples (150×150×150mm). With cylinder sample D150×H300, α = 1.2.

TABLE II. COMPRESSIVE STRENGTH EXPERIMENT RESULTS

No.	Replacement rate	Sample destructive force (kN)	Compressive strength (MPa)	Average value (MPa)
1	0 %	295.2	20.04	19.98
2		293.5	19.93	
3		294.1	19.97	
4	10 %	288.1	19.56	19.36
5		286.2	19.43	
6		281.3	19.10	
7	20 %	262.1	17.79	17.82
8		259.4	17.61	
9		265.8	18.04	
10	30 %	251.2	17.05	17.07
11		252.4	17.13	
12		250.8	17.03	

The value of compressive strength of the experimental samples in shown in Table II. It can be observed that the replacement of recycled fine aggregates affects significantly the compressive strength of concrete. The decrease is recorded as 3% at the replacement rate of 10%, 10% at the replacement rate of 20%, and 14% at the replacement rate of 30%. The compressive strength of concrete at various replacement rates of recycled fine aggregate is shown in Figure 3.

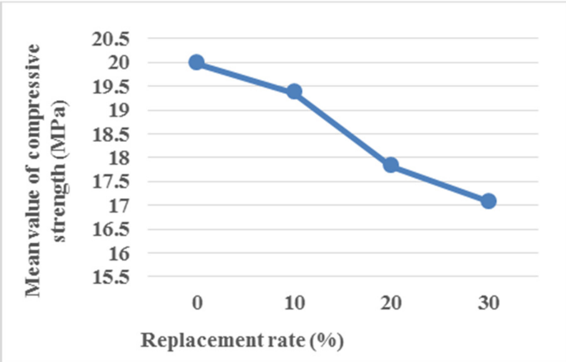

Fig. 3. Compressive strength of concrete at various replacement rates of natural fine aggregates with recycled fine aggregates.

The maximum force achieved in the bending test is the bending load that breaks the specimen. Table III shows the maximum bending force obtained in the flexural bending test. The flexural strength of beam specimens was calculated according to TCVN 3119:1993 by using (3):

$$R_{fs}=\gamma.P.l/(a.b^{2)}\ (daN/cm^2) \quad (3)$$

where P is the recorded maximum force, l is the span length, a and b are the dimensions of the specimen and ɣ is the coefficient of converting the experimental results when compressing samples of different size from the standard samples. In the present flexural experiment, the beam specimen was cast in standard dimensions, therefore ɣ = 1.

It can be seen from Figure 4 that the flexural strength of the specimens decreased linearly with increasing recycled aggregates percentage of replacement.

TABLE III. FLEXURAL BENDING EXPERIMENT RESULTS

No.	Replacement rate	Maximum force (kN)	Flexural strength (MPa)	Average value (MPa)
1	0 %	52.03	8.48	8.56
2		53.12	8.66	
3		52.37	8.53	
4	10 %	52.28	8.52	8.47
5		52.09	8.49	
6		51.50	8.39	
7	20 %	50.26	8.19	8.27
8		50.96	8.30	
9		51.02	8.31	
10	30 %	50.12	8.17	8.05
11		49.05	7.99	
12		48.98	7.98	

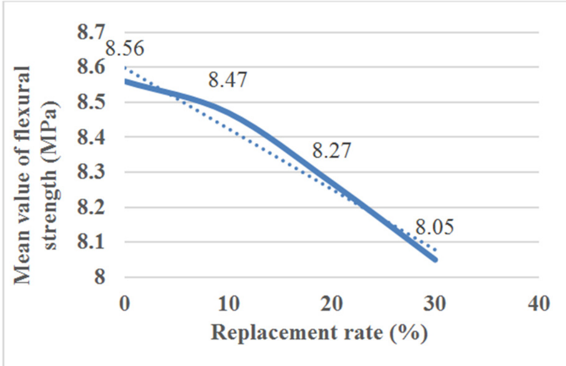

Fig. 4. Flexural strength of concrete at various replacement rates of natural fine aggregates with recycled fine aggregates.

The diminution of strength of recycled concrete with partially replacement of recycled aggregates has been reported by numerous authors [2, 3, 7 10, 12]. The present investigation on the influence of recycled fine aggregates on the compressive and flexural strength of concrete indicates that the compressive strength and flexural strength decrease linearly with the increasing content of recycled aggregates. Therefore, in order to apply recycled waste to concrete as fine aggregates, it is necessary to perform supplement research with appropriate additives to compensate for the shown above loss of strength. It is also possible to consider reinforcing concrete with fibers at appropriate concentrations.

IV. Conclusion

The current paper presented the results of a research on the compressive and flexural strength of concrete utilizing recycled fine aggregates from demolition works. The rates of replacement of natural aggregate with recycled aggregates were 0%, 10%, 20%, and 30%. The experiments were performed at 28 days of curing. The results show that the compressive strength and flexural strength of concrete are strongly affected by the percentage of recycled aggregates. It has been found that the strength decreases linearly with the increasing percentage of recycled aggregates. Additional studies are needed to evaluate more thoroughly the effectiveness of the use of recycled aggregates in concrete.

References

[1] R. Sri Ravindrarajah and C. T. Tam, "Recycling concrete as fine aggregate in concrete," *International Journal of Cement Composites and Lightweight Concrete*, vol. 9, no. 4, pp. 235–241, Nov. 1987, https://doi.org/10.1016/0262-5075(87)90007-8.

[2] V. T. Phan and T. H. Nguyen, "The Influence of Fly Ash on the Compressive Strength of Recycled Concrete Utilizing Coarse Aggregates from Demolition Works," *Engineering, Technology & Applied Science Research*, vol. 11, no. 3, pp. 7107–7110, Jun. 2021, https://doi.org/10.48084/etasr.4145.

[3] H. Yaprak, H. Aruntaş, I. Demir, O. Simsek, and G. Durmuş, "Effects of the fine recycled concrete aggregates on the concrete properties," *International Journal of Physical Sciences*, vol. 6, no. 10, pp. 2455–2461, May 2011.

[4] S. K. Kirthika and S. K. Singh, "Durability studies on recycled fine aggregate concrete," *Construction and Building Materials*, vol. 250, Jul. 2020, Art. no. 118850, https://doi.org/10.1016/j.conbuildmat.2020.118850.

[5] C. J. Zega and Á. A. Di Maio, "Use of recycled fine aggregate in concretes with durable requirements," *Waste Management*, vol. 31, no. 11, pp. 2336–2340, Nov. 2011, https://doi.org/10.1016/j.wasman.2011.06.011.

[6] D. V. M. Reddy and M. M. S. Swaroop, "Effect of Recycled Aggregates on Strength and performance of Recylced Aggregate Concrete," *E3S Web of Conferences*, vol. 184, 2020, Art. no. 01085, https://doi.org/10.1051/e3sconf/202018401085.

[7] X. H. Vu, T. C. Vo, and V. T. Phan, "Study of the Compressive Strength of Concrete with Partial Replacement of Recycled Coarse Aggregates," *Engineering, Technology & Applied Science Research*, vol. 11, no. 3, pp. 7191–7194, Jun. 2021, https://doi.org/10.48084/etasr.4162.

[8] M. Oad, A. H. Buller, B. A. Memon, and N. A. Memon, "Impact of Long-Term Loading on Reinforced Concrete Beams Made with Partial Replacement of Coarse Aggregates with Recycled Aggregates from Old Concrete," *Engineering, Technology & Applied Science Research*, vol. 9, no. 1, pp. 3818–3821, Feb. 2019, https://doi.org/10.48084/etasr.2498.

[9] M. F. Koondhar, B. A. Memon, M. Oad, F. A. Chandio, and S. A. Chandio, "Water Penetration of Concrete made with Coarse Aggregates from Demolishing Waste," *Engineering, Technology & Applied Science Research*, vol. 10, no. 6, pp. 6445–6449, Dec. 2020, https://doi.org/10.48084/etasr.3891.

[10] L. Butler, J. S. West, and S. L. Tighe, "Effect of recycled concrete coarse aggregate from multiple sources on the hardened properties of concrete with equivalent compressive strength," *Construction and Building Materials*, vol. 47, pp. 1292–1301, Oct. 2013, https://doi.org/10.1016/j.conbuildmat.2013.05.074.

[11] M. Etxeberria, E. Vázquez, A. Marí, and M. Barra, "Influence of amount of recycled coarse aggregates and production process on properties of recycled aggregate concrete," *Cement and Concrete Research*, vol. 37, no. 5, pp. 735–742, May 2007, https://doi.org/10.1016/j.cemconres.2007.02.002.

[12] N. A. Abdulla, "Effect of Recycled Coarse Aggregate Type on Concrete," *Journal of Materials in Civil Engineering*, vol. 27, no. 10, Oct. 2015, Art. no. 04014273, https://doi.org/10.1061/(ASCE)MT.1943-5533.0001247.