Pergamon

Cement and Concrete Research 33 (2003) 125–132

CEMENT AND CONCRETE RESEARCH

Use of building rubbles as recycled aggregates

How-Ji Chen*, Tsong Yen, Kuan-Hung Chen

Department of Civil Engineering, National Chung-Hsing University, 250, Kuo-Kuang Road, Taichung 40227, Taiwan, ROC

Received 9 May 2002; accepted 15 July 2002

Abstract

The application of building rubble collected from damaged and demolished structures is an important issue in every country. After crushing and screening, this material could serve as recycled aggregate in concrete. A series of experiments using recycled aggregate of various compositions from building rubble was conducted. The test results show that the building rubble could be transformed into useful recycled aggregate through proper processing. Using unwashed recycled aggregate in concrete will affect its strength. The effect will be more obvious at lower water/cement ratios. When the recycled aggregate was washed, these negative effects were greatly improved. This is especially true for the flexural strength of the recycled concrete. The recycled coarse aggregate is the weakest phase at a low water/cement ratio. This effect will dominate the strength of recycled concrete. This mechanism does not occur in recycled mortar. The quantity of recycled fine aggregate will govern the mortar strength.

Keywords: Building rubbles; Recycled aggregates; Mechanical properties

1. Introduction

The possible effects of recycled aggregate upon concrete properties such as workability, strength and durability have been discussed in several papers [1–3]. In most of the literature, the main concerns were the variations in recycled aggregate properties caused by the native waste paste and their effects upon the concrete properties [4–6]. Most buildings in Asia were constructed of reinforced concrete accompanied with brick and tile materials. Thus, building rubble collected from damaged structures includes bricks and tile as well as waste concrete. The effects of brick and tile particles on the properties of recycled concrete are less well known in the literature.

This research investigated recycled aggregates made from building rubble, containing waste concrete, bricks and tiles. A series of tests was carried out to investigate the effects of recycled aggregates containing various compositions on the mechanical properties of the recycled concrete. The effect of recycled fine aggregate upon the mechanical properties of recycled concrete is also discussed.

2. Experimental program

Building rubble collected from damaged structures contains waste concrete, tiles, bricks, steel, wood, plastic, paper and other substances. Among these substances, wood, plastic and paper impurities seriously affect the strength of recycled concrete. Fortunately, the impurities present in building rubble have far less effect after recycling treatment, as shown in Fig. 1. After proper treatment, only waste concrete, bricks, tiles and a few impurities are left in the building rubble. In this research, two groups of recycled aggregate from different regions in Taiwan were selected for testing.

2.1. Aggregate property

The basic properties of recycled and natural aggregates were tested first. The tested properties included gradation, fineness modulus and aggregate particle shape. The procedures and test methods were in accordance with ASTM specifications.

* Corresponding author. Tel.: +886-4-22859390; fax: +886-4-22855610.

E-mail address: hjchen@mail.ce.nchu.edu.tw (H.-J. Chen).

0008-8846/03/$ – see front matter
PII: S0008-8846(02)00938-9

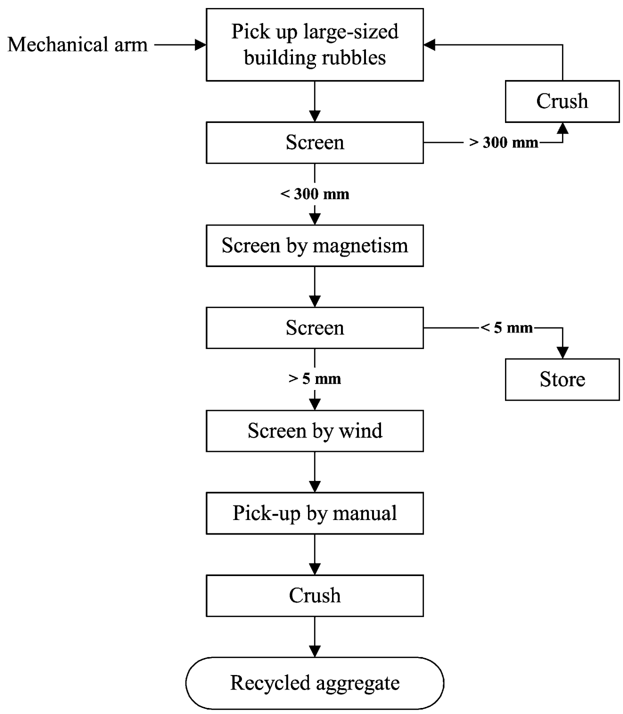


Fig. 1. The production of recycled aggregate.

2.2. Recycled concrete

The compressive strength, flexural strength and modulus of elasticity of recycled concrete and normal concrete were tested for comparison. The test methods followed ASTM specifications. Specimens were cured in a curing room and then taken out to air dry 1 day before the tests. Specimens used in the tests for compressive strength were $\phi100 \times 200$ mm. Specimens for the flexural tests were $100 \times 100 \times 360$ mm.

2.2.1. The brick and tile content effect

To evaluate the properties of concrete made with various recycled aggregate compositions, five groups of recycled concrete made with washed recycled aggregate (without any recycled sand, wood, plastic, paper or other impurities), with the same water/cement ratio of 0.5, were adapted for testing. In these five groups, the bricks and tiles content in the recycled aggregate were the only variables. The weight proportions of brick and tile particles in the recycled aggregates were 0%, 17%, 33%, 50% and 67%. They were numbered R0, R17, R33, R50 and R67, respectively. Additionally, concrete made of natural aggregate with the same water/cement ratio (numbered as N-0.5) served as the control batch. The test results from R0, R17, R33, R50 and R67 were compared with the results from N-0.5.

2.2.2. Recycled aggregate property effect

Natural aggregate, washed recycled aggregate and unwashed recycled aggregate (with recycled sand and other impurities) were used for casting concrete specimens. These mixtures had different water/cement ratios of 0.38, 0.46, 0.56, 0.67 and 0.80. Accordingly, they were labeled N-0.38, AR-0.38, AS-0.38 and BS-0.38, where A and B indicate the source of the recycled aggregate, N is natural aggregate, R is washed recycled aggregate, S is unwashed raw recycled aggregate and 0.38 represents the water/cement ratio. As raw recycled aggregate contains less fine aggregate, the fine aggregate insufficiency was made up using an equal volume of natural sand. The mixture proportions are shown in Tables 1 and 2.

Table 1
Concrete mixture proportions

Normal concrete (kg/m^3)

Mixture	Water	Cement	Natural fine aggregate	Natural coarse aggregate
N-0.5	190	380	637	1123

Recycled concrete (kg/m^3)

Mixture	Water	Cement	Natural fine aggregate	Recycled aggregate	
				Waste concrete	Bricks and tiles
R0	190	380	637	969	0
R17				808	161
R33				646	323
R50				485	485
R67				323	646

2.3. Recycled mortar

To evaluate the effect of recycled fine aggregate on the properties of the recycled mortar, freshly mixed recycled

Table 2
Recycled concrete mixture proportions (kg/m^3)

Mixture	Water/cement ratio	Water	Cement	Natural fine aggregate	Natural coarse aggregate	Recycled aggregate
N-0.38	0.38	198	520	579	1042	0
N-0.46	0.46		430	654		
N-0.58	0.50		339	729		
N-0.67	0.67		294	767		
N-0.80	0.80		249	805		
AR-0.38	0.38	198	520	579	0	906
AR-0.46	0.46		430	654		(Group A)
AR-0.58	0.50		339	729		
AR-0.67	0.67		294	767		
AR-0.80	0.80		249	804		
AS-0.38	0.38	198	520	388	0	1066 (160)[a]
AS-0.46	0.46		430	463		(Group A)
AS-0.58	0.50		339	538		
AS-0.67	0.67		294	576		
AS-0.80	0.80		249	614		
BS-0.38	0.38	198	520	145	0	1281 (374)[a]
BS-0.46	0.46		430	220		(Group B)
BS-0.58	0.50		339	295		
BS-0.67	0.67		294	333		
BS-0.80	0.80		249	371		

[a] The number inside the parentheses is the quantity of recycled fine aggregate.

concrete was sieved using a #4 mesh and the separated mortar was cast in 50 × 50 × 50 mm molds. The specimens were labeled MN (mortar was sieved from N series concrete), MA (recycled mortar was sieved from AS series concrete) and MB (recycled mortar was sieved from BS series concrete). The compression test method used followed ASTM specifications.

3. Results and discussions

3.1. Properties of recycled aggregate

The sieve analysis results for recycled aggregate groups A and B are shown in Fig. 2. The volume fractions of fine aggregate in the two groups were about 30% and 15%, respectively. The grading curves for these two aggregate groups are basically similar. This implies that using the same crusher with the same maximum aggregate size will produce

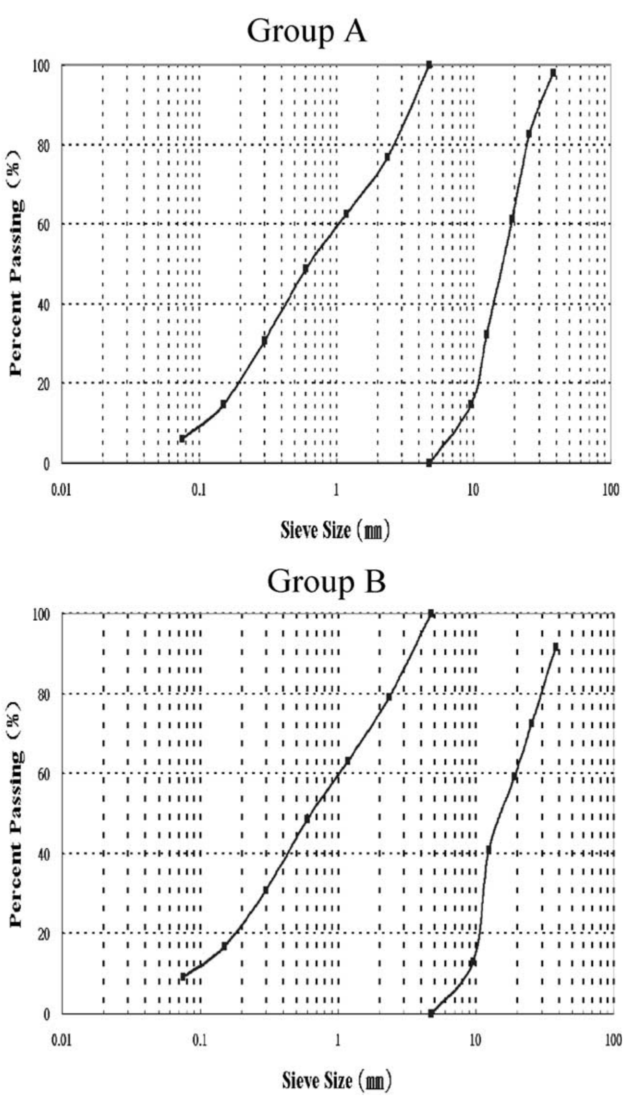


Fig. 2. Gradating curves for recycled aggregate.

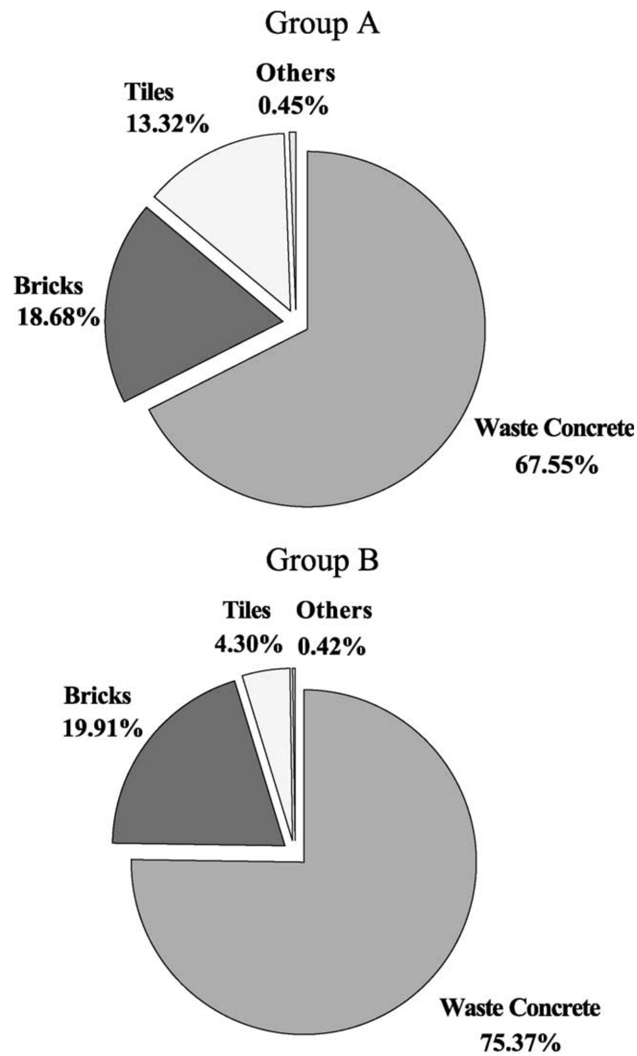


Fig. 3. Compositions of recycled aggregate.

similar recycled aggregate gradation. The recycled aggregate grades also satisfied the aggregate requirements used for concrete.

Fig. 3 shows the analyzed results for the Groups A and B compositions. In Group A, waste concrete was the main component with a weight fraction of about 68%. Bricks comprised about 19%, with tiles comprising about 13%. The other impurities, such as gypsum and clay, totaled about 0.45%. Waste concrete was also the main component in Group B and comprised about 75%. Bricks comprised about 20%, with tiles making up about 4%. Other impurities comprised about 0.42%. Although the impurity quantity was small, a weak zone could be produced in the recycled concrete and affect its mechanical properties. From these test results, it is apparent that recycled aggregate collected from building rubble in Taiwan is composed primarily of waste concrete, bricks and tiles.

The basic property test results for recycled aggregate and natural aggregate are summarized in Tables 3 and 4. It can be found in the tables that the SSD specific gravity of recycled

Table 3
Natural aggregate properties

Properties	Coarse aggregate	Fine aggregate
SSD specific gravity	2.63	2.62
SSD absorption capacity (%)	1.17	1.04
Dry-rodded unit weight (kg/m^3)	1533	–
FM	–	2.95

coarse aggregate is about 2.28, which is 13% less than that of natural coarse aggregate. The dry-rodded unit weight (from 1241 to 1252 kg/m^3) is also lighter than that of natural coarse aggregate. The absorption ranges from 5.04% to 7.54%, which is much higher than that for natural aggregate. This is due to the greater porosity of recycled aggregate, which is composed of tiles, bricks and waste concrete with some mortar. Similar to recycled coarse aggregate, recycled fine aggregate also has smaller SSD specific gravity of 2.19–2.26, about 15% less than that of natural fine aggregate, with a larger absorption of 7.22–10.37%. The fineness modulus of recycled fine aggregate ranges from 2.61 to 2.68, similar to that for natural fine aggregate.

The particle shape analysis of recycled aggregate is shown in Table 5. It is obvious that the recycled aggregate has similar particle shape as the crushed rock used in normal concrete. Both the recycled coarse aggregate and the recycled fine aggregate meet the standard requirements for aggregate used in concrete.

3.2. Effect of brick and tile content on recycle concrete

The mechanical properties of the five groups of recycled concrete made with various recycled coarse aggregate compositions (without any recycled sands) are shown in Figs. 4–6. The test results show that the compressive strength of concrete made with recycled coarse aggregate containing brick and tile particles is about 75–85% that of normal concrete. The greater the brick and tile content, the lower the compressive strength of the recycled concrete (Fig. 4). However, within a 10% variation of the compressive strength (75–85%), it means that recycled aggregate may contains brick and tile particles up to a certain amount (up to 67%).

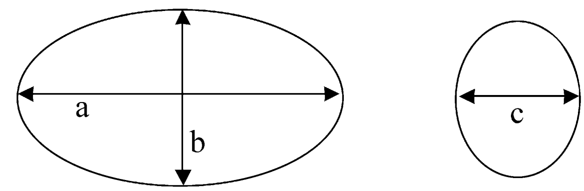
Table 4
Recycled aggregate properties

	Coarse aggregate	Fine aggregate
Group A		
SSD specific gravity	2.28	2.19
SSD absorption capacity (%)	7.54	10.37
Dry-rodded unit weight (kg/m^3)	1241.4	–
FM	–	2.61
Group B		
SSD specific gravity	2.29	2.26
SSD absorption capacity (%)	5.04	7.22
Dry-rodded unit weight (kg/m^3)	1252.3	–
FM	–	2.68

Table 5
Particle shape analysis for recycled aggregate

Aggregate type		a/c	ab/c	a/b
Waste concrete	Group A	2.26	36.0	1.41
	Group B	2.25	34.5	1.40
Brick	Group A	2.32	43.2	1.42
	Group B	2.29	42.3	1.38
Tile	Group A	2.87	54.1	1.50
	Group B	2.45	53.4	1.51
Gravel	–	2.28	45.9	1.47
Crushed rock	–	2.80	56.0	1.57

Note:



a: the long axis of aggregate; b: the midterm axis of aggregate; c: the short axis of aggregate.

Because these materials possess basic strength, their impact upon the compressive strength of recycled concrete is relatively limited.

It can be seen from Fig. 5 that the flexural strength of recycled concrete is about 78–91% that of normal concrete. There is no major difference among the flexural strength of recycled concrete mixes containing various amounts of brick and tile. Similar to the previous compressive and flexural strength results, the modulus of elasticity for recycled concrete, as shown in Fig. 6, was about 70–80% that of normal concrete. This indicates that the brick and tile content in recycled aggregate does not significantly affect the *E* values of recycled concrete.

From the results, it can be concluded that brick and tile particles will have some impact upon the mechanical properties of recycled concrete. Using brick and tile par-

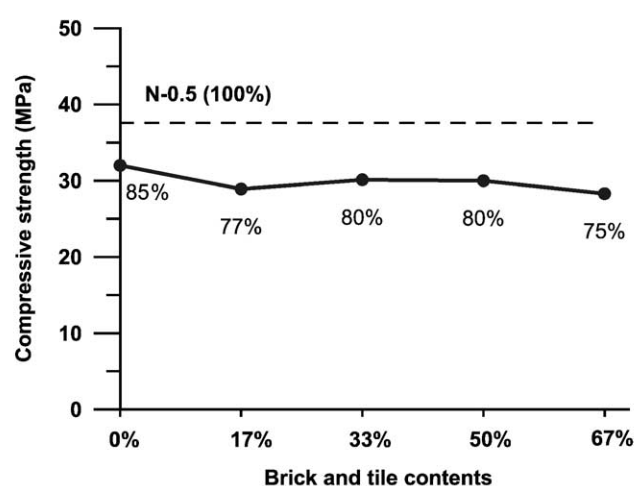


Fig. 4. Compressive strength of concrete.

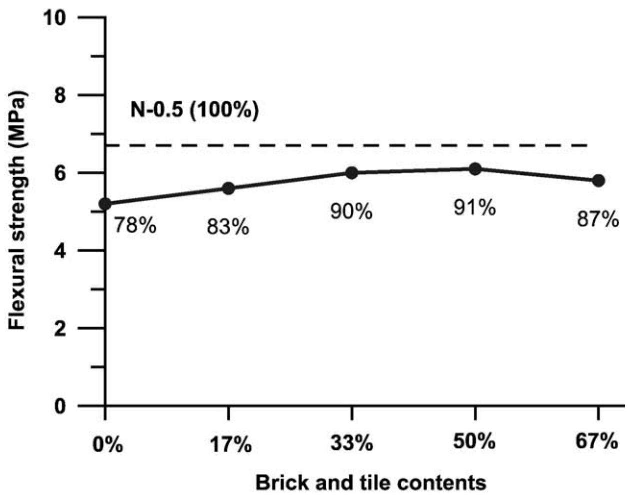


Fig. 5. Flexural strength of concrete.

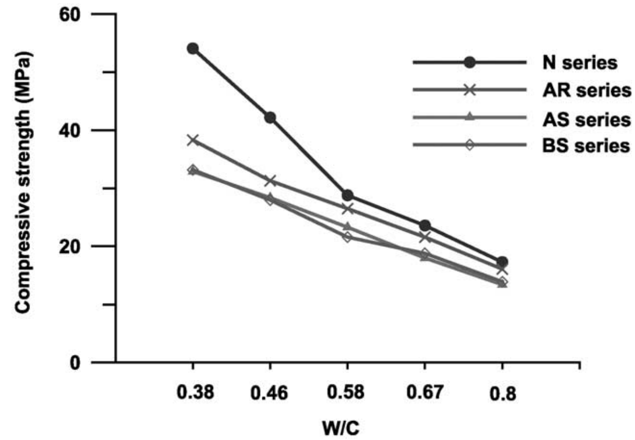


Fig. 7. Compressive strength of recycled concrete.

ticles in recycled aggregate is acceptable in recycled concrete production when the brick and tile content in recycled aggregate is lower than 67%.

3.3. Mechanical properties of recycled concrete

The mechanical properties of recycled concrete and normal concrete with different water/cement ratios are shown in Figs. 7 and 8. At lower water/cement ratios, the compressive strength of AR series recycled concrete can reach more than 70% that of normal concrete. The other series AS and BS recycled concrete can reach only about 60%. For higher water/cement ratios, the compressive strength of AR, AS and BS series can reach about 90%, 75% and 75% that of normal concrete, respectively. The AR series has higher strength than the AS and BS series. This is due to the effects of washed recycled aggregate. The impurities, powder and harmful materials on the aggregate surfaces are washed away, resulting in a better bond effect. Fig. 8 shows that the compressive strength ratio of recycled concrete to normal concrete decreases at low water/cement ratios. The main reason is that the strength of the paste greatly increases at low water/cement ratios. According to the composite material theory, the recycled aggregate becomes a weak material and its bearing capacity is smaller, thus leading to a decrease in concrete strength. This behavior is similar to that of lightweight aggregate concrete [7].

The concrete flexural strength test results, as indicated in Figs. 9 and 10, show that the flexural strengths of the AR series were higher than that for the AS and BS series regardless of the water/cement ratio. Under the same water/cement ratio, the flexural strength for the entire AR series reached about 90% that for normal concrete. The flexural strength of the AR series could be even higher than that for normal concrete (for water/cement ratio>0.67). This

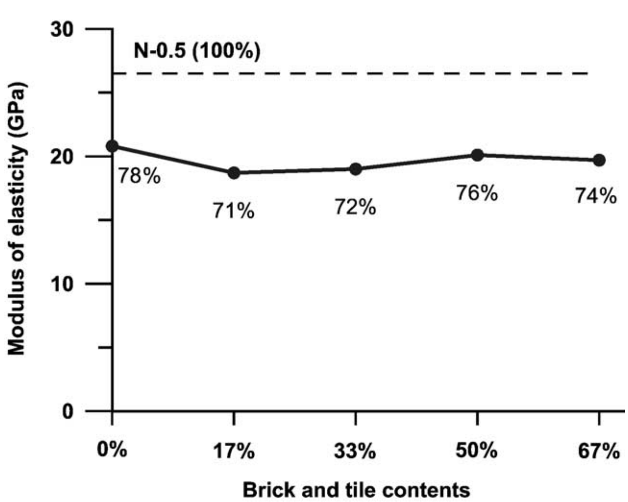


Fig. 6. Concrete modulus of elasticity.

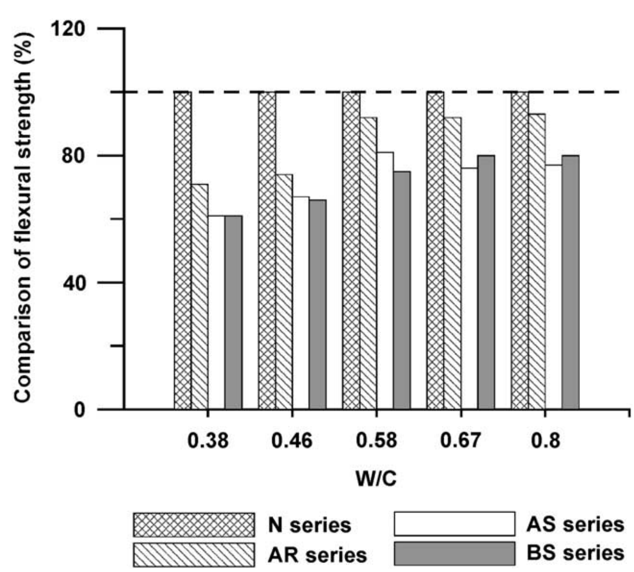


Fig. 8. Concrete compressive strength comparison.

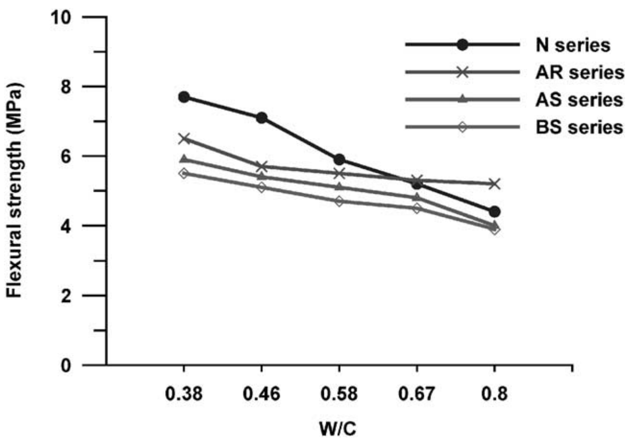


Fig. 9. Flexural strength of recycled concrete.

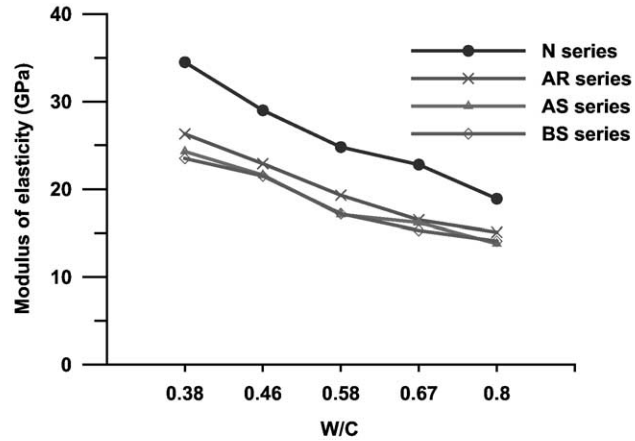


Fig. 11. Modulus of elasticity of recycled concrete.

phenomenon is possible because under high water/cement ratio conditions the interface between the aggregate and the paste becomes a weak interface. The wash process cleans the recycled aggregate surface, thus leading to enhancement of the bond between the aggregate and the paste.

The flexural strengths of the AS and BS series were much lower. This tendency was more obvious at lower water/cement ratios. For water/cement ratios under 0.5, the flexural strengths of the AS and BS series reached only 75% of that for normal concrete. With a higher water/cement ratio (>0.67), the flexural strengths of both the AS and the BS series can reached up to about 90% of that for normal concrete.

Fig. 11 shows the concrete modulus of elasticity test results. The results reveal that the E value for recycled concrete can reach about 70% that for normal concrete at various water/cement ratios. The differences in the E value for recycled concrete mixes using various recycled aggregates were also not obvious.

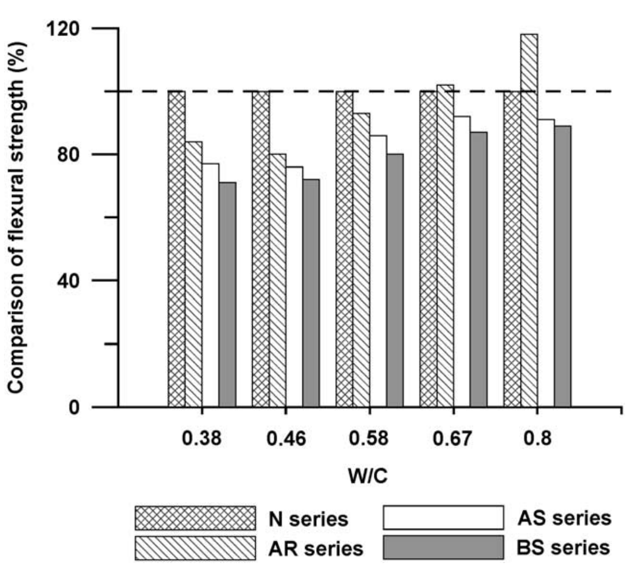


Fig. 10. Comparison of flexural strength of concrete.

3.4. Strength behavior of recycle mortar

Figs. 12 and 13 show the series MN (mortar with 100% normal sand), MA (recycled sand volume fraction is about 30%) and MB (recycled sand volume fraction is about 65%) recycled mortar test results. These results (Fig. 12) show that the compressive strength–water/cement ratio relationships in the three series exhibit a similar tendency. Under the same water/cement ratios, the strength of the MA and MB series was lower than that for the MN series. From Fig. 13, the strength of the MA and MB recycled mortar was about 80% and 65% that for MN series, respectively, when the water/cement ratio was changed from 0.38 to 0.8. This percentage reduction does not change with the water/cement ratio in the mortar. However, the quantity of recycled fine aggregate in the mix will govern the percentage reduction in the mortar strength. As the recycled fine aggregate content is increased,

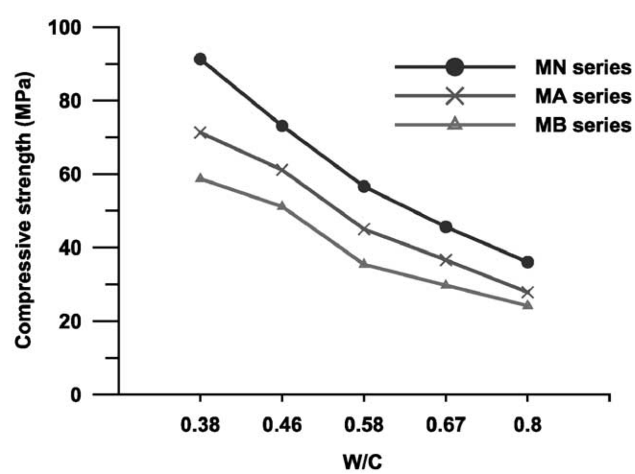


Fig. 12. Compressive strength of recycled mortar.

the percentage reduction in mortar strength increases. This result differs greatly from the recycled coarse aggregate effect on recycled concrete. Comparing the recycled coarse aggregate in concrete phenomenon with the recycled fine aggregate in mortar phenomenon, the recycled coarse aggregate is the weakest phase under a low water/cement ratio. This effect will dominate the strength of recycled concrete. This mechanism does not occur in recycled mortar because the recycled fine aggregate has only smaller particles. The quantity of recycled fine aggregate will in turn govern the percentage reduction in the mortar strength.

3.5. Strength comparison of recycle concrete and normal concrete

Compressive strength test results from the recycled and normal concrete made from same mortar and same water/cement ratio are illustrated in Fig. 14. Fig. 14 shows that the compressive strength of normal concrete is higher than that of recycled concrete, especially at lower water/cement ratios. At a water/cement ratio of 0.38, the mortar strength can reach to 92 MPa, while the compressive strength for normal and recycled concrete are only 54.1 and 38.3 MPa, respectively. This indicates that a lower water/cement ratio will produce a higher strength mortar. The strength for this mortar can be even higher than that for concrete. The recycled coarse aggregate is the weak phase in the concrete. The compressive strength of recycled concrete is relatively confined by the lower strength of the recycled coarse aggregate. Conversely, the compressive strength difference between recycled concrete and normal concrete at higher water/cement ratios is much less. Both compressive strengths are similar, while the mortar strengths are between 36.1 and 56.6 MPa. The mortar controls the failure mode for recycled concrete. The strength of the recycled coarse aggregate has little effect on the strength of recycled concrete. This implies that the strength of recycled concrete is dominated by the strength of the mortar. This means that high-strength recycled concrete might be achieved through using high-strength mortar (low water/cement ratio) with an increase in cement. However, this is not an economical mixture proportion.

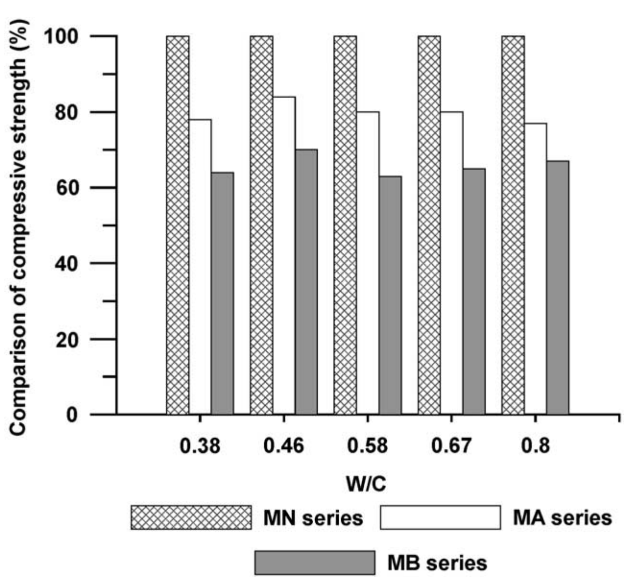


Fig. 13. Comparison of compressive strength of recycled mortar.

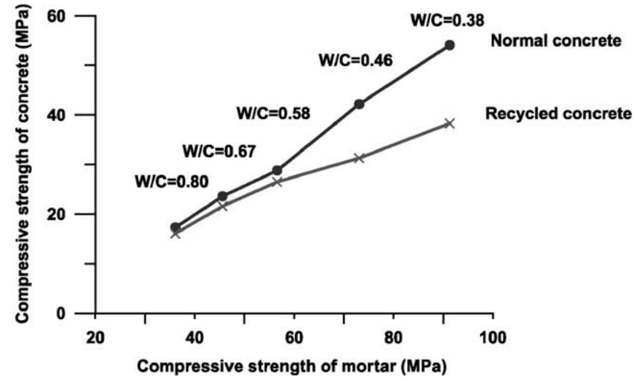


Fig. 14. Comparison of compressive strength of concrete and mortar.

4. Conclusions

From the test results and discussions, the following conclusions are drawn:

1. Building rubble could be transformed into useful recycled aggregate through proper processing. The mechanical properties of tested recycled concrete were generally worse than those of normal concrete. The effect of brick and tile contents (0–67%) on the mechanical properties of recycled concrete is relatively limited.

2. Using unwashed recycled aggregate in concrete will affect its strength. The effect will be more obvious at lower water/cement ratios. At a water/cement ratio of 0.38, the compressive strength of recycled concrete remains only 60% that of normal concrete. However, the strength ratio can be increased to more than 75% when the water/cement ratio is greater than 0.60.

3. The modulus of elasticity for recycled concrete was only about 70% that of normal concrete. Changing the water/cement ratio or brick and tile content in recycled aggregate does not have a significant effect on the modulus of elasticity values.

4. Under the same mixture proportions, the mechanical properties of recycled concrete were worse than that for normal concrete. When the recycled aggregate was washed, these negative effects were greatly improved. This is especially true for the flexural strength of the recycled concrete.

5. Adding recycled fine aggregate in the mortar will decrease the mortar strength. The quantity of recycled fine aggregate in the mortar is more effective than the water/cement ratio in governing the percentage reduction in strength for recycled mortar. This is totally different from

the behavior of recycled coarse aggregate in recycled concrete.

6. At higher water/cement ratios (lower strength of mortar), the compressive strength of recycled concrete is similar to that of normal concrete. At lower water/cement ratios (higher strength of mortar), the compressive strength of recycled concrete is much lower than that of normal concrete. High-strength recycled concrete might be achieved through using high-strength mortar with an increase in cement. However, this is not an economical mixture proportion.

Acknowledgements

The authors would like to thank Public Construction Commission Executive Yuan for the financial support and Chuen-Jr. Liau for his experimental assistance during this project.

References

[1] S. Mindess, J.F. Young, Concrete, Prentice-Hall, New Jersey, 1981.
[2] D. Back, Recycle concrete as a source of aggregate, ACI Mater. J. 74 (22) (1977) 212–219.
[3] ACPA, Concrete Paving Technology, Recycling Concrete Pavement, American Concrete Pavement Association, Skokie, IL, 1993.
[4] W.H. Chesner, R.J. Collons, M.H. MacKay, User Guidelines for Waste and Byproduct Materials in Pavement Construction, Publication No. FHWA-RD-97-148, Federal Highway Administration Office of Engineering R&D, McLean, VA, 1997, pp. 14-1–14-13.
[5] W.H. Chesner, Selected state engineering and environmental specifications, policies and regulations for the beneficial use of by-product materials in construction applications, Technical Conference on the Beneficial Use of By-Product Materials in Construction Applications, Albany, NY, 1999.
[6] T.C. Hansen, Recycling of demolished concrete and masonry, RILEM, Report of Technical Committee 37-DRC Demolition and Reuse of Concrete, 1992.
[7] H.J. Chen, T. Yen, T.P. Lai, Y.L. Huang, Determination of the dividing strength and its relation to the concrete strength in lightweight aggregate concrete, Cem. Concr. Compos. 21 (1) (1999) 29–37.