COMPRESSIVE STRENGTH OF RECYCLED AGGREGATE CONCRETE WITH VARIOUS PERCENTAGE OF RECYCLED AGGREGATE

Suraya Hani Adnan, Lee Yee Loon, Ismail Abdul Rahman,
Hamidah Mohd Saman, Mia Wimala Soejoso
Fakulti Kejuruteraan Awam dan Alam Sekitar
Universiti Tun Hussein Onn Malaysia (UTHM)
E-mail: suraya@uthm.edu.my

ABSTRACT: Compressive strength is the basic mechanical properties and one of the indicators to determine the performance of a concrete. In this paper, the effects of various percentages (0%, 25%, 50%, 75%, 100%) of Recycled Aggregate (RA) on compressive strength of Recycled Aggregate Concrete (RAC) were investigated. RA is used to replace natural aggregate (NA) as coarse aggregate in concrete mixes. This research also covered RAC mixtures at different water-cement ratio (0.4, 0.5, 0.6). It was found that RAC had lower compressive strength compared to Natural Aggregate Concrete (NAC). At the age of 28 days, RAC with water-cement ratio 0.4 had the highest strength.

Keywords: compressive strength, recycled aggregate, recycled aggregate concrete, natural aggregate, natural aggregate concrete, replacement, water cement ratio

1.0 INTRODUCTION

Recycled Aggregate Concrete (RAC) is concrete that using Recycled Aggregate (RA) as partially or fully replacement in coarse and fine aggregate. It is believed RA have been used from 1945 in concrete producing and started when World War II damaged a large quantity of concrete structures and the high demand of aggregate to rebuild the structures (Kheder and Al-Windawi, 2005). They recognised the factors like depletion of natural aggregates, tightly environmental law and waste disposal problems which influenced the application of RA.

RA had such a possible application in certain area and Masood et. al. (2002) have summarised it. They have conducted some experimental investigations and found that RA had a potential functioning as aggregate that can be applied in concrete roads, drainage work, shallow storage tanks, culverts and sewage or treatment plants.

Recently Malaysia is not yet practising RA in its construction industry. No depletion of natural aggregate sources are the main factor why RA is not been using. But according to Masood et. al. (2002), Asia country should think seriously about the application of RA due to the increasing of discharge concrete for each year. Hong Kong, Japan and China have become pioneer counties in Asia which are actively conducted study on RA application in construction industry. They can be seen in some research by Poon and Chan, (2006), Eguchi et. al., (2006) and Huang et. al.,(2002). Poon and Chan, (2006) has reported the application of 14,300 m^3 RA for Hong Kong Wetland Park construction. Meanwhile in Taiwan, the Construction and Demolition (C & D) waste is handling properly since 1999 (Huang et. al, 2002) and Japan have committed in application of RA by publishing 'Standard for Usage of Concrete with Recycled Aggregate' in 1996 (Eguchi et. al., 2006).

United Kingdom is one good example of western countries which practising RA in its construction industry. In DOE 1996, the '1995 UK Government White Paper Making Waste Work' had targets to increase the using of waste and recycled materials as aggregates to 30 million tonnes per year by 2006. In UK, Construction and Demolition (C&D) waste has been identified were had value in engineering materials for construction industry (Lawson et. al., 2001). Lawson et. al. (2001) also reported that 51.1% or 27.4 million tonnes of (C& D) waste were disposed directly to landfill,

39.6 % or 21.2 million tonnes were excepting from licensed disposal and were primarily used for land modelling during the construction projects and 9.2 % or 5 million tonnes were either crushed to produce a graded product or directly recovered. Recycling and reuse (C&D) waste and produced as RA is expected to improve on supplying of construction material and also can solve the disposal of waste construction material (Masood et. al., 2001).

RAC has attracted many researchers to study its performance. Previous researchers have conducted study on application of RA and found that RAC have lower compressive strength compared to Natural Aggregate Concrete (NAC), (Ismail, Suraya and Mia, 2007). Table 1.0 shows the results of previous studies which were using RA as replacement coarse aggregate in concrete mixes at different water-cement ratio.

Table 1.0 Summarisation Result of Compressive Strength from Previous Studies

No.	Name of Researcher	Source of Aggregates	w/c ratio	Percentage Replacement of RA	Compressive Strength (Mpa)
1	Rahal K.	Natural Aggregate from	0.65	0%	22.7
		Gabbro crushed rock	0.5	0%	32.3
		imported from United	0.48	0%	36
		Arab Emirates	0.43	0%	46
			0.4	0%	53.5
		Recycled Aggregate from	0.65	100%	20.3
		two buildings under demolition	0.5	100%	29.2
		in the Hawally area in Kuwait	0.48	100%	32.2
			0.43	100%	39.4
			0.4	100%	46.5
2	Topcu and Sengel	Natural Aggregate is Gravel	0.639	0%	18.8
			0.639	30%	15.2
			0.635	50%	15
			0.638	70%	14.2
			0.637	100%	13.8
		Recycled Aggregate is crushing	0.571	0%	20
		natural concrete (28-day	0.57	30%	18.2
		cylindrical compresiive strength	0.569	50%	17.8
		of 14 MPa)	0.571	70%	16.6
			0.57	100%	14
3	T.Y. Tu, Y.Y. Chen	Recycled Aggregate from	0.32	100%	32
	and C.L Hwang	demolished-construction wastes	0.36	100%	27

		generated during 921 Chi-Chi earthquake	0.4	100%	28
4	H.J. Chen, T.Y. and K.H. Chen	Natural Aggregate is from crushed rock	0.38	0%	55
			0.46	0%	42
			0.58	0%	29
			0.67	0%	25
			0.8	0%	20
		Recycled Aggregate is from building rubble collected from damaged structures that containing waste concrete, tiles, bricks and other impurities such as gypsum and clay.	0.38	100%	38
			0.46	100%	32
			0.58	100%	27
			0.67	100%	22
			0.8	100%	19
5	Kou, Poon and Chan	Natural aggregate is crushed Granite	0.45	0%	66.8
				20%	62.4
				50%	55.8
				100%	42
		Recycled Aggregate is from Recycling facility in Hong Kong	0.55	0%	48.6
				20%	45.3
				50%	42.5
				100%	38.1

From Table 1.0., can be seen in Topcu and Sengel (2004) and Kou, Poon and Chan (2007) study, that compressive strength of RAC is lowered when replacement of RA as coarse aggregate in concrete mix is increased. According to Olorunsogo (1999), the factors like RA had smoother surface and rounder compared to NA which lead to this matter. Otherwise, Otsuki et. al. (2003) and Tam et. al. (2005) had proposed modified mixing procedure to enhance compressive strength of RAC.

Different sources of RA also played an important role in determining compressive strength of RAC. Although those concrete had same w/c ratio, but it's compressive strength seemed quite different to each other. For example, in Rahal K. (2007) and T.Y T.Y. Tu, Y.Y.Chen and C.L.Hwang (2005) study, although their w/c ratio for concrete mixture is 0.4 and used RA at 100% replacement, but they obtained a different result in compressive strength which is 46.5 and 28 MPa. Cements content in the mixture also be a factor which lead to this different result.

In T.Y. Tu, Y.Y.Chen and C.L.Hwang (2005) study also, it found that water content in concrete mixes must be sufficient when RA is used in concrete mixes. This can be viewed in their study which RAC with same w/c ratio but had a different water content that 150, 160 and 170 kg/m^3. Supposedly, lower water content will lead to greater compressive strength, but in this study, RAC with water content 160 kg/m^3 obtained higher compressive strength than that of 150 and 170 kg/m^3. Although they found a different result from expected, they have concluded that RA need sufficient water to fulfil the absorption capacity needs. Strength will decrease when water content is insufficient and poor hydration process occurred. But excessive amount of paste also leading to weak interface-zone and low density concrete will deal to poor compressive strength.

In H.J. Chen, T.Y. and K.H. Chen (2003) study, washed RA is used as coarse aggregate. They found that washed RA comprised higher strength than that of unwashed RA. Greater bond effects were produced when impurities, powder and harmful materials on aggregate surface in RA are washed away. They also identified that at low w/c ratio, the compressive strength ratio of recycled concretes to normal concretes are decreased. Main factor which lead to this result is strength of the paste is increase at low w/c ratio. Based on composite material theory, they revealed that RA will become a weak material and its bearing capacity become smaller which influenced to decrease in strength.

General conclusion is made based from this table that compressive strength of RAC is lower than that of NAC. It is also showed that when w/c ratio of concrete mix is lower, compressive strength for RAC and NAC is higher. Accordingly, this paper will study the effect of various replacement of RA on its compressive strength for different water-cement ratio.

2.0 EXPERIMENTAL WORK

2.1 Materials

The materials used in this experiment were:
1. Ordinary Portland Cement (OPC)
2. Sand
3. Natural gravel with maximum size 20 mm (NA)
4. Superplasticizer
5. Recycled Aggregate (RA) - used as coarse aggregate

The recycled coarse aggregates were produced by crushing the waste concrete cubes at outer UTHM Material Laboratory that had compressive strength between 20 to 25 MPa. These waste cubes were broken into smaller pieces and crushed using a jaw crusher. Then the RA produced is sieved with max size 20 mm. Table 2.1 showed the physical properties of NA and RA.

Table 2.1 Physical Properties of Aggregate

Type of Properties		Normal Aggregate	Recycled Aggregate
Specific Gravity	SSD	2.48	2.39
	Oven Dried	2.46	2.31
	Apparent	2.51	2.5
Aggregate Impact Value		17.6	36.3

(%)		
Aggregate Crushing Value (%)	17.25	35.86
Absorption (%)	0.83	3.34

2.2 Concrete mixes

Two groups of concrete mixes, NAC and RAC were produced using natural sand as fine aggregate. NAC mixes were used fully Natural Aggregate as coarse aggregate in concrete mix. Meanwhile RAC mixes were used Recycled Aggregate as partially or fully replacement of Natural Aggregate as coarse aggregate. These mixes were designed according to DOE mix design. The concrete mixtures were prepared with a water-cement (w/c) ratio 0.4, 0.5 and 0.6. The slump target is between 60 mm to 180 mm for NAC and RAC mixes. Skim Quick Set (SQS) is used as superplasticizer. The combination in concrete mixes after this will be called as RA 00, RA25, RA50, RA75 and RA100. Table 2.2 showed the details of concrete mixes.

Table 2.2 Series of mix proportion

Series	Natural Aggregate (%)	Recycled Aggregate (%)
RA00	100	0
RA25	75	25
RA50	50	50
RA75	25	75
RA100	0	100

2.3 Testing of Concrete

Slump and compressive test is conducted to determine concrete's workability and compression strength. Slump test is conducted following ASTM C 143-90a. Meanwhile, compressive test is conducted by following BS 1881: Part 108:1983 and three cubes of 100mm x 100mm x 100mm were tested at 7, 14 and 28 days.

3.0 RESULTS AND DISCUSSION

3.1 Slump Test Result

The slump results are presented in Table 3.1. It can be observed in Figure 3.1 that concrete mixes at 0.4 had a lower slump compared to 0.5 and 0.6 concrete mixes. On the other hand, when replacement of RA is increased in concrete mixes, the slump of concrete mixes is decreased. It was expected because recycled aggregate is high in water absorption. Poon C.S. et. al. (2006) revealed that mortar over RA is lead to low slump of RAC.

Table 3.1 Slump for Different w/c Ratio Concrete Mixes

SERIES	W/C RATIO	SLUMP (mm)
RA00	0.4	135
	0.5	173
	0.6	179
RA25	0.4	128
	0.5	165
	0.6	170
RA50	0.4	90
	0.5	165
	0.6	165
RA75	0.4	60
	0.5	160
	0.6	159
RA100	0.4	50
	0.5	153
	0.6	156

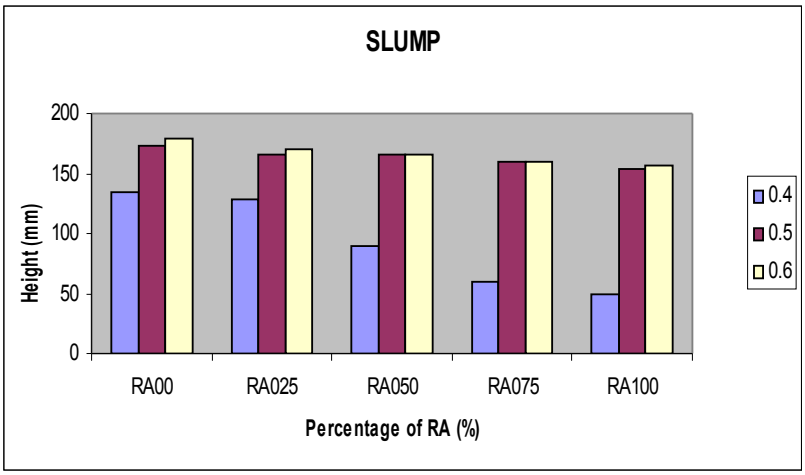

Fig. 3.1 Slump for Concrete Mixes

3.2 Compressive Test

The compressive strength results are presented in Table 3.2. Each presented value is the average of three measurements. It is shown in Fig. 3.2.1 that compressive strength of RAC is lowered compared to Natural Aggregate Concrete (NAC). For w/c ratio 0.4 and 0.5, the concrete mixtures prepared with 25, 50, 75 and 100 % replacement of RA had a decrease of 21.9, 23.7, 43.3, 32.7 % and 13.2, 7.7, 19.1,13.2 % in the compressive strength at 28-day compared to NAC. Then, the concrete mixtures with w/c ratio 0.6 that prepared with 25, 50, 75 and 100% replacement of RA had a decrease of 11.85, 17.1, 31.3, 22.3 % in compressive strength than that of NAC. In these figure, it also found that RA100 obtained higher compressive strength than that of RA075. Normally as RA replacement increased, compressive strength will decrease (Topcu and Sengel (2004) and Kou, Poon and Chan (2007)). The higher compressive strength may be attributed to the greater bonding force and strength when same type of aggregates was used. Otherwise, RAC still obtained lower compressive strength compared to NAC.

Table 3.2 Result of Compressive Strength for Different W/C Ratio

SERIES	W/C RATIO	7-day	14-day	28-day
RA00	0.4	**34.4**	**38.6**	**56.6**
	0.5	**20.3**	**22.0**	**30.2**
	0.6	**15.9**	**18.4**	**21.1**
RA025	0.4	**29.9**	**37.5**	**44.2**
	0.5	**19.2**	**21.7**	**26.2**
	0.6	**13.4**	**16.4**	**18.6**

RA050	0.4	**27.1**	**36.3**	**43.2**
	0.5	**15.5**	**21.9**	**25.1**
	0.6	**12.3**	**15.8**	**17.5**
RA075	0.4	**23.2**	**31.3**	**32.1**
	0.5	**16.1**	**18.6**	**22.0**
	0.6	**11.4**	**12.9**	**14.5**
RA100	0.4	**21.8**	**30.2**	**38.1**
	0.5	**16.5**	**18.9**	**23.6**
	0.6	**10.3**	**11.9**	**16.4**

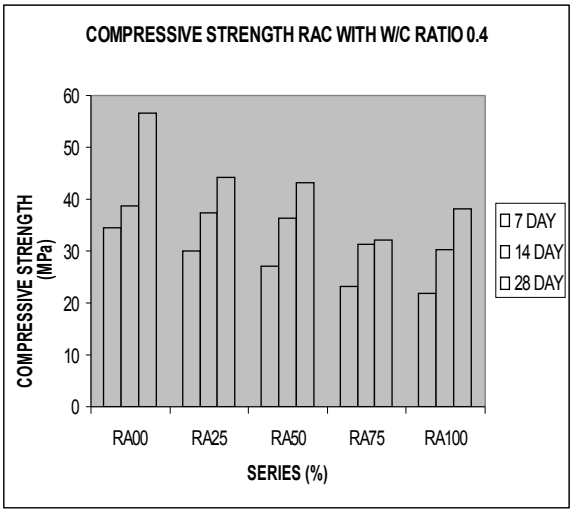

Fig. 3.2.1 Compressive Strength for w/c ratio 0.4

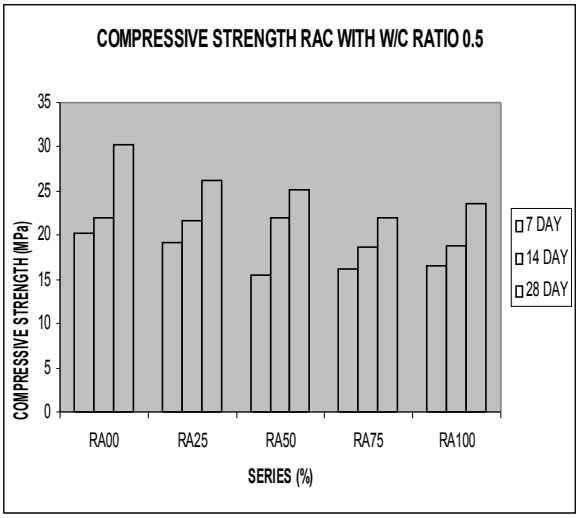

Fig. 3.2.2 Compressive Strength for w/c ratio 0.5

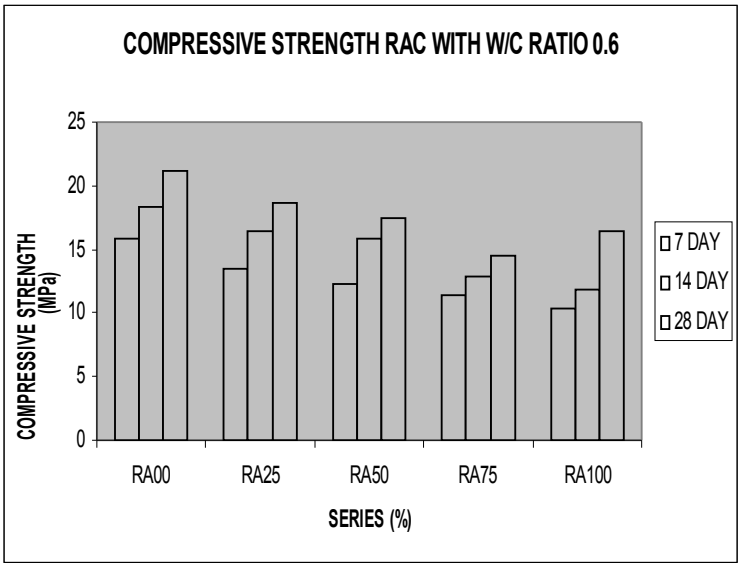

Fig. 3.2.3 Compressive Strength for w/c ratio 0.6

5.0 CONCLUSION

The following conclusions have been made based on the results of this study:

1. With the same w/c ratio, the slump value decreases if percentage of RA is increased.
2. The compressive strength of Recycled Aggregate Concrete was lower than that of Natural Aggregate Concrete.
3. Lower water-cement ratio of Recycled Aggregate Concrete lead to higher in compressive strength. RAC could increase its compressive strength by reducing the water-cement ratio of concrete.
4. The relationship of w/c ratio and compressive strength of RAC is inversely proportional.

6.0 REFERENCE

Chen, H.J., Yen, T. and Chen, K.H., "*Use of Building Rubbles as Recycled Aggregates*," Cement and Concrete Research 33, (2003), pp. 125-132.

Eguchi, K., Teranishi, K., Nakagome, A., Kishimoto, H., Shinozaki, K. and Narikawa, M., "*Application of Recycled Coarse Aggregate by Mixture to Concrete Construction*,", Construction and Building Materials, 2006.

Huang, W.L., Lin, D.H., Chang, N.B., Lin,K.S., "*Recycling of Construction and Demolition Waste via A Mechanical Sorting Process*". Resources Conservation & Recycling, Vol. 37, Issue 1, Dec 2002.

Ismail, A.R., Suraya, H.A., Mia, W.M.S., "*Possibility of Using Recycled Aggregate as an Alternative to Natural Aggregate in Malaysia*," Proceedings of AWAM 2007 held at Universiti Sains Malaysia, 2007.

Kheder, G.F., Al-Windawi, S.A., "*Variation in Mechanical Properties of Natural and Recycled Aggregate Concrete as Related to the Strength of Their Binding Mortar*," Materials and Structures 38 (August-September 2005), pp. 701-709.

Kou, S.C., Poon, C.S. and Chan, D., "*Influence of Fly Ash as Cement Replacement on the Properties of Recycled Aggregate Concrete*." Journal of Materials in Civil Engineering, September 2007.

Lawson, N., Douglas, I., Garvin, S., McGrath, C., Manning, D. and Vetterlein, J., " *Recycling Construction and Demolition Wastes- A UK Perspective*, ", Environmental Management and Health, Vol. 12, No. 2, (2001).

Masood, A., Ahmad, T., Arif, M. and Mahdi, F., "*Waste Management Strategies for Concrete*,", Environ Eng Policy (2002).

Olorunsogo, F.T., "*Early Age Properties of Recycled Aggregate Concrete".* Proceedings of the International Seminar on Exploiting Wastes in Concrete held at the University of Dundee, Scotland,UK on 7 September 1999,pp. 163-170.

Otsuki,N., Miyazato,S.,Yodsudjai,W., "*Influence of Recycled Aggregate on Interfacial Transition Zone, Strength, Chloride Penetration and Carbonation of Concrete*". Journal of Materials in Civil Engineering, Sept/Oct 2003, pp.443-451.

Poon, C.S. and Chan, D., "*The Use of Recycled Aggregate in Concrete in Hong Kong*,", Resources Conservation & Recycling, 2006.

Poon, C.S., Kou, S.C., Lam, L., " *Influence of Recycled Aggregate on Slump and Bleeding of Fresh Concrete,* " Materials and Structure, 2006.

Rahal, K., "*Mechanical Properties of Concrete with Recycled Coarse Aggregate*," Building and Environment 42, (2007), pp. 407-415.

Tam,V.W.Y., Gao, X.F.,Tam, C.M., "*Carbonation around near aggregate regions of old hardened concrete cement paste".* Cement and Concrete Research, Vol 35, Issue 6, June 2005, pp. 1180-1186.

Topcu, I. B., Sengel, S., "*Properties of Concretes Produced with Waste Concrete Aggregate,*" Cement and Concrete Research 34, (2004), pp. 1307-1312.

Tu, T.Y., Chen, Y.Y. and Hwang, C.L., "*Properties of HPC with Recycled Aggregates*," Cement and Concrete Research 36, (2006), pp. 943-950.