Interdependence between Structural Engineering and Construction Management
Edited by Ozevin, D., Ataei, H., Modares, M., Gurgun, A., Yazdani, S., and Singh, A.

ISBN: 978-0-9960437-6-2

SOME PROPERTIES OF REACTIVE POWDER CONCRETE MADE WITH RECYCLED AGGREGATE

SHATHA HASAN

Dept of Civil Engineering, University of Technology, Baghdad, Iraq

An experimental study was carried out to investigate, the strength properties, of recycled aggregates for use in reactive powder concrete (RPC), to better understand the properties of reactive powder concrete with recycled aggregates used as a substitution material for normal sand in reactive powder concrete. The effects of variable parameters on these properties were carefully studied which are the percent of recycled fine aggregate (0%, 25%, 50%, and 75%) as a partial replacement by weight of normal sand, recycled fine aggregate (50%) as a partial replacement by weight of glass sand, and two different curing (20, 90 ^{o}C). The inclusion of using reactive silica sand powder leads to a considerable increment in both compressive and tensile strength for recycled reactive powder concrete (RRPC) and the heat treatment improves the properties of the RPC and RRPC considerably. Finally, the results indicated that it is possible to produce reactive powder concrete from recycled aggregate depending on the strength, the results show to suggest only a gradual lowering in compressive and splitting tensile strength.

Keywords: Strength, Silica sand, Silica fume.

1 INTRODUCTION

Reactive powder concrete (RPC) is a relatively new family of Portland cement – based material with high strength, high elastic modulus, very low porosity, ductility with ultimate elongation, and high impact strength (Richard and Cheyrezy 1995, Hassan 2006, and Abdelalim *et al*. 2008). RPC is obtained by an optimization of its grain size distribution by scaling down the maximum size of aggregate to 600 microns and by applying some very simple heat treatment. The properties of RPC are achieved by combining Portland cement, silica fume, fine silica sand, high range water reducing admixture, water, and steel fiber (Richard and Cheyrezy 1995, Perry and Zakariasen 2004).

Concrete is one of the most widely used structural materials in the world, and continues to evolve. The main purpose behind its popularity is its characteristics such as high strength and durability. For this reason, it is important to use crushed concrete from demolition waste as concrete aggregate instead of natural aggregate to preserve natural resources of materials in order to reduce the amount of demolition waste (Weimann *et al.* 2003, Puri *et al.* 2013). During the last few years, many studies and projects have been carried on the utilization of Recycled Aggregate Concrete (RAC) in ordinary concrete. These researches have explained that RA from building demolition can be utilized instead of normal aggregates. Prior investigations on the replacement of natural sand by recycled sand from building demolition in several types of concrete are studied. In this study, it was, therefore, examined the possibility of replacing normal sand with recycled concrete sand in RPC to produce recycled reactive powder concrete, RRPC.

Demiss *et al*. (2018) carried out an experimental study on the mechanical and microstructural properties of RRPC containing waste glass powder and fly ash at standard curing. The experimental results indicated that replacing the silica fume fully by finely dispersed local waste glass powder and fly ash is a promising approach for local structural construction applications. In this study, some properties of the RPC incorporating local powders as a pozzolanic material and replacing natural aggregate by recycled concrete aggregate were investigated.

2 EXPERIMENTAL PROGRAM

2.1 Materials

2.1.1 *Cement*

Ordinary Portland cement, manufactured in Iraq, was used throughout this study. Its chemical and physical properties conform to Iraqi specification No.5.

2.1.2 *Fine aggregate*

Two types of normal fine aggregate are used in this study. The first one is Al-Ekhaider sand (NS) and the second type is silica sand (SS) known as glass sand. Glass sand used throughout this study was crushed silica rock brought from Al- Ramadi Glass factory. The two types of fine aggregate with maximum size 600 μm were tested and the physical and chemical properties were within the requirements of the Iraqi specification No. 45.

2.1.3 *Recycled aggregate*

The fine recycled concrete aggregate was gained from buildings destruction. Large parts of demolition were brought to the Laboratory and broken up by a laborer into small parts and the parts passing through a 4.75mm sieve were utilized as a fine recycled concrete aggregate (RCS). The particle size distribution of fine recycled aggregate was thus similar to the particle size distribution of normal fine aggregate.

2.1.4 *High range water reducing admixture*

High range water reducing admixture (SP) used in this study is modified polycarboxylic ether, which has been primarily developed for applications where the highest strength, durability, and performance is required. It is free from chlorides and complies with ASTM C494.

2.1.5 *Mineral admixtures*

Condensed Silica fume (CSF) is a highly reactive pozzolanic material and is an extremely fine powder, with particles about 100 times smaller than an average cement grain. The chemical composition and physical requirements show that the silica fume conforms to the chemical and physical requirements of ASTM C1240 specifications.

2.1.6 *Steel fibers*

Hooked steel fibers (S_f) used in this work and each steel fiber has a diameter of 0.4mm and length of approximately 20mm with aspect ratio = 50, density= 7800 kg/m^3 and ultimate tensile strength of 1600 MPa.

2.1.7 *Reactive silica sand powder*

Reactive silica sand powder (RSSP), which is used in this work, brought from Al- Ramadi Glass factory and conformed to the physical and chemical requirements of ASTM C618 class N Pozzolan.

2.2 Mix Proportions

Many mix proportions according to pervious researches (Hassan 2006, Gao *et al.* 2005) were tried in this study to have maximum compressive strength and flow of (75+5%) of RPC and recycled RPC. Nine mixes were prepared in the laboratory. Ordinary RPC (mix1) was used as a reference mix, then eight additional mixes were prepared to investigate the effects of replacing the normal fine aggregate with fine recycled aggregate on the properties of RPC. Table 1 shows the mix proportions for all mixes. Fine silica sand known as glass sand is used in mixes eight and nine to compare them with mixes made with natural fine sand in other mixes.

Table 1. Normal and RRPC mixes used in the present research.

		Series 1		Series 2		Series 3		Series 4	
Mix No.	**Mix 1**	**Mix 2**	**Mix 3**	**Mix 4**	**Mix 5**	**Mix 6**	**Mix7**	**Mix 8**	**Mix 9**
C	970	970	970	970	970	970	970	970	970
NS	1060	795	795	530	530	265	265		
SS								1060	530
CSF	175	175	135	175	135	175	135	175	135
RSSP			40		40		40		40
RCS		265	265	530	530	795	795		530
W/C	0.187	0.19	0.191	0.192	0.194	0.199	0.204	0.192	0.194
Flow Table %	78	77	77	76	74	74	73	74	73
SP	All mixes the *SP* 8.5 % by weight of cement								
S_f	All mixes the steel fibers 2% by volume								

2.3 Mixing, Casting and Curing Procedure

All normal and recycled RPC mixes were performed in a rotary mixer of $0.1m^3$. The compaction was affected by means of a vibrating table for a period of twenty seconds/ layer for (5 cm cubes) and (10cm × 20 cm cylinder). After twenty-four hours from casting, the specimens were molded. Then concrete specimens were moist cured in two different conditions:

A. 20 ^{o} C (Room temperature).
B. Steam curing at 90 ^{o}C after preliminary curing at room temperature for twenty-four hours.

3 TEST RESULTS AND DISCUSSION

3.1 Compressive Strength

The compressive strength tests of normal and recycled RPC were carried out in accordance with B.S: 1881: part 116. Five cm cube specimens were used to define compressive strength using a standard testing machine with a capacity of 2000 kN. The loading was used at a rate of fifteen Mpa per minute. Cubes were removed from curing solution at age of (14, 28, and 90) days. The average of three specimens was recorded for each testing age. Generally, test results demonstrate a considerable decrease in compressive strength of all recycled reactive powder mixes made by replacing normal fine sand by fine recycled concrete aggregate compared to the mixes of ordinary RPC made with normal sand as shown in Table 2.

Figures 1 and 2 exhibits the growth of compressive strength for all RPC when tested at different ages. The test results of normal and recycled RPC showed that replacing normal fine aggregate with recycled demolished concrete aggregate at the levels of 25%, 50%, and

75% had only a slight effect on the compressive strength. In general, the decrease of compressive strength may have been due to the goodness of recycled fine aggregate, as the fine recycled aggregate was gained from the demolition of unknown quality building concrete. Similar results have been reported by other researchers (Bo-Tsun *et al.* 2010, Vaishali and Rao 2012).

Results given in this Table 2 show that RPC with glass sand (Mix 8) can also reach the high compressive strength. On the other hand, the compressive strength of the mix 9 in series 4, which replaced the silica sand with recycled fine aggregate, were greater than mix 5 in series 2, which replaced the natural fine aggregate with recycled fine aggregate, which may be due to the better properties of silica sand and powerful bonding between old mortar.

Steam curing at 90^{o}C gave a better performance of RPC and RRPC with silica fume and RSSP in terms of higher strength than the curing at room temperature (20^{o}C) as shown in Figures 1 and 2.

Table 2. The compressive strength of RPC and RRPC at two different curing.

Series		**1**	**2**		**3**		**4**		**5**	
Curing	**Days**	**Mix 1**	**Mix 2**	**Mix 3**	**Mix 4**	**Mix 5**	**Mix 6**	**Mix7**	**Mix 8**	**Mix 9**
20^{o} C	**14**	78.5	73.8	72.6	68.1	66.8	58.3	57.1	80.1	76.3
	28	120.4	114.2	110.9	111.5	110.3	95.7	90.3	123.3	126
	90	128.2	123.9	121.7	118.7	119.2	102.6	98.4	130.9	130.2
90^{o} C	**14**	85.2	82.1	81.5	74.6	72.5	66.3	62.2	82.3	79.6
	28	129.9	123.8	123.1	125.6	123.1	104.5	99.8	132.8	131.9
	90	140.5	136.8	133.5	126.6	126.1	119.4	115.7	139.8	138.2

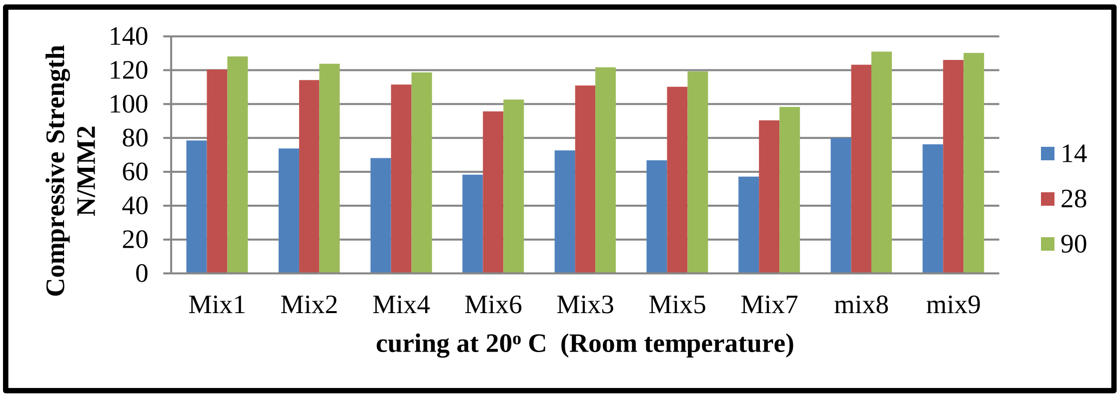


Figure 1. The compressive strength of RPC and RRPC at 20 ^{O}C.

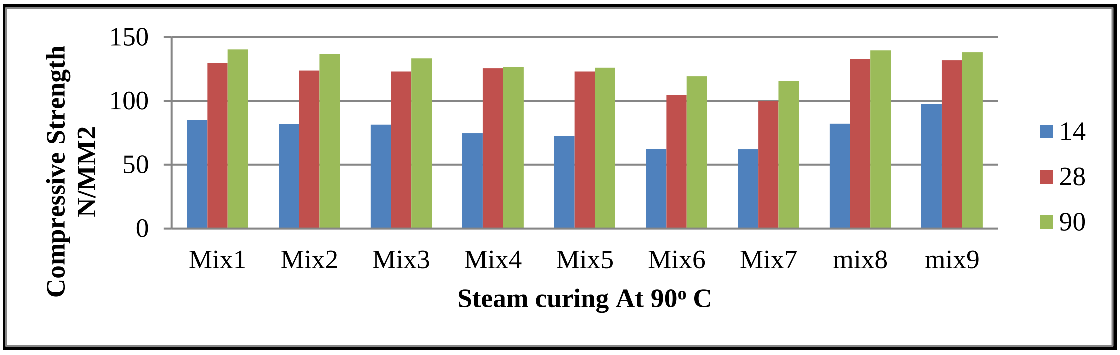
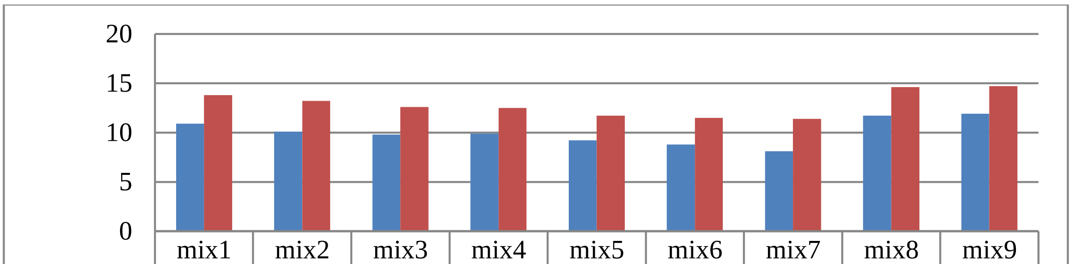


Figure 2. The compressive strength of RPC and RRPC at 90°C.

3.2 Splitting Tensile Strength

This test was done according to ASTM C496-86 specification. Cylinders of ten cm diameter and twenty cm height were utilized and tests were completed using a standard testing machine with a capacity of 2000 kN. The load was gradually raised up to a point of failure. The loading was applied at a rate of 1.5 MPa per minute. The test results of the splitting tensile strength are plotted in Figure 3 which presents the splitting tensile strength behavior of RPC and RRPC mixes at 28 days with different curing condition. The heat treatment has a considerable influence on the splitting tensile strength, for instance, the splitting tensile strength of mixes 5 and 9 rises from (9.2 to 11.7) MPa and from (11.9 to 14.7) MPa respectively. The results also indicate that the splitting tensile strength increase due to the heat treatment is less than the increase in compressive strength of the same mixtures. Since the heat treatment affects the w/cm ratio, it can be concluded that the compressive strength is significantly affected more than the splitting tensile strength. The test results of normal and recycled RPC showed that replacing fine aggregate with recycled demolished concrete aggregate had only a slight effect on the splitting tensile strength.



	mix1	mix2	mix3	mix4	mix5	mix6	mix7	mix8	mix9
2o o C	10.9	10.1	9.8	9.9	9.2	8.8	8.1	11.7	11.9
9o o C	13.8	13.2	12.6	12.5	11.7	11.5	11.4	14.6	14.7

Figure 3. Splitting tensile strength of RPC and RRPC at 28 days.

4 CONCLUSIONS

Depending on the results of this study on RPC and RRPC the following conclusions can be drawn:

1. It is possible to produce recycled reactive powder concrete from recycled fine concrete aggregate as a partial replacement of normal fine sand or glass sand.
   The heat treatment improves the properties of the RPC and RRPC considerably.
2. It is possible to produce RPC and RRPC from glass sand as a fine aggregate.
3. The effect of the use of recycled fine aggregate on the strength of RRPC depends on

the percentage of recycled fine aggregate utilized

4. Concrete mixes designed with a group of recycled fine aggregate as a partial replacement for glass sand offered higher compressive and splitting tensile strengths than concrete mixes designed with a group of recycled concrete aggregate used as partial replacement normal sand.

5. The inclusion of reactive silica sand powder as a partial replacement of mineral admixture leads to a considerable increase in strength.

References

Abdelalim, A., Ramadan, M., Bahaa, T., and Halawa, W., Performance of Reactive Powder Concrete Produced Using Local Materials, *HBRC Journal*, 4 (3), December 2008.

Bo-Tsun, C., Ta-Peng, C., Tzong-Ruey, Y., Ya-Chu, C., and Tien-Chin, H., Statistical Study on Properties of High-Performance Recycled Aggregate Concrete, *Korea Concrete Institute*, ISBN978-89-5708-182(2), 2010.

Demiss, B., Oyawa, W., and Shitote, S., Mechanical and Microstructural Properties of Recycled Reactive Powder Concrete Containing Waste Glass Powder and Fly Ash at Standard Curing, *Cogent Engineering*, 5, 1464877, 2018.

Gao, R., Stroeven, P., and Hendriks, C., Mechanical Properties of Reactive Powder Concrete Beams, *ACI Special Publication*, 228(79), 1237-1252, 2005.

Hassan, S., *Static and Impact Properties of Reactive Powder Concrete*, Ph.D. Thesis, University of Technology, Baghdad, 2006.

Perry, H., and Zakariasen, D., First Use of Ultra-High-Performance Concrete for an Innovative Train Station Canopy, *Concrete Technology Today*, 25(2), August 2004.

Puri, N., Kumar, B., and Tyagi, H., Utilization of Recycled Wastes as Ingredients in Concrete Mix, *International Journal of Innovative Technology and Exploring Engineering (IJITEE)*, 2(2), January 2013.

Richard, P. and Cheyrezy, M., Composition of Reactive Powder Concretes, *Cement and Concrete Research*, 25(7), 1501-1511, 1995.

Vaishali, G., and Rao, H., Strength and Permeability Characteristics of Fiber Reinforced High-Performance Concrete with Recycled Aggregates, *Asian Journal of Civil Engineering (Building And Housing)*, 13(1), 55-77, 2012.

Weimann, K., Giese, L., Mellmann, G., and Simon, R., Building Materials from Waste, *Materials Transactions*, 44(7), 1255-1258, 2003.