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Influence of Recycled Fine Aggregates on Strength Properties of Reactive Powder Mortar

Doaa H. Nayyef [a*], Shatha S. Hasan [b]

[a] Civil Engineering Department, University of Technology, Baghdad, Iraq. **ahmeddoaa.279@gmail.com**

[b] Civil Engineering Department, University of Technology, Baghdad , Iraq.

*Corresponding author.

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K E Y W O R D S

Recycled Reactive Powder Concrete, sustainable construction, compressive strength, flexural strength, direct tensile strength, local waste.

A B S T R A C T

Although many researchers have done many studies on recycled aggregate concrete, information is very little about the influence of utilizing recycled aggregate in the production of reactive powder concrete. Experimental work was executed to investigate the influence of utilizing recycled concrete as fine aggregate in reactive powder concrete. Five different mixes were prepared, the first mix, or control mix, was prepared with natural sand, four additional mixes were prepared with different percentage of substitution of fine aggregates(20%,40%,60%, and 80%). The investigation was carried out using compressive strength test, direct tensile strength test and flexural strength test, and two methods of curing were used standard curing at 20 °C and steam curing at 90°C. the results indicated that the strength decreases with increased the percentage of recycled fine aggregate, and the best percentage was 40% replacement where the percentages of decrease at this percentage at 28-day steam curing were 2.46, 6.66, and 2.14 for compressive strength, flexural strength, and direct tensile strength respectively.

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1. Introduction

Characteristics of reactive powder concrete (RPC) are super-high strength, superior toughness and ultimate durability [1]. It is a kind of concrete that contains a high amount of fine-grained cement and a minimum water-cement ratio, the Chinese standard GB/T 31387 defines RPC that concrete with a compressive strength greater than(100 MPa) [2]. One of the economic sectors that are more responsible for consuming natural resources and generating waste is the construction industry. Construction and demolition processes related to the use of concrete plays an essential role in the accumulation of waste. Globally, thousands of tons of concrete are produced every year [3]. There is a need for equivalent amounts of materials in the traditional process, which is a natural resource that is not renewable and limited, such as gravel, sand, and another aggregate to guarantee these levels of concrete consumption. On the other hand, the demolition of structures also causes a considerable environmental impact.

Masood et al. [4] estimated that concrete demolition waste in the United States of America and the European Union has reached 100 million tons per year. These huge amounts of waste are currently one of the biggest difficulties and concerns in the construction sector given the high costs of transportation and dumping and the scarcity of appropriate sites for receiving these materials. A conceivable answer to these problems is the recycling of concrete waste by crushing and grinding it to get grading approximately similar to the normal sand and manufacture an alternate aggregate for RPC in this method. RPC made with this recycled concrete aggregate is recognized recycled reactive powder concrete (RRPC).

2. Significance of the Research

1. This study was carried out to avoid the disposal problem of demolition waste of old concrete in order to preserve the environment.
2. This work was performed to determine strength properties (compressive strength, direct tensile strength, and flexural strength), and knowledge of the effect of using recycled fine aggregate on these properties of reactive powder mortar.

3. Materials

Ordinary Portland cement type I, fine aggregate of maximum size 600 µm and specific gravity of 2.6, recycled fine aggregate from demolition waste of old buildings of maximum size 600 µm and specific gravity of 2.2, high range water reducing admixture type Structure 520 from SIK ® company in Iraq, Micro silica Mega Add MS (D) from SIKA® company in Iraq, straight steel fiber with diameter of 0.2 mm and length 13mm and ordinary tap water were used in this study.

4. Mix Proportions

Five mixes of reference RPC and RPC with waste materials had been done to gain maximum compressive strength by using mechanical mixing. The mixing proportions of the reference mix were selected based on previous research. Ordinary RPC was once used as a reference. Then, four additional mixes were organized with different percentages of recycled fine aggregate as a partial replacement of normal sand (20, 40, 60, and 80)%, which represented by (mix1, mix2, mix3, and mix4) respectively to know the effect of recycled fine aggregate on the strength properties of RPC. The mixing was done by adjusting water to cement ratio to keep flow 75±5. Table 1 shows the mix proportion for all mixes.

Table 1: All mixes used in the present research

Material	Ref.	Mix 1	Mix 2	Mix 3	Mix 4
Cement (kg/m^3)	940	940	940	940	940
Silica fume (kg/m^3)	210	210	210	210	210
Normal Sand (kg/m^3)	990	792	614	396	198
Recycled Fine Aggregate (kg/m^3)	-	198	367	594	792
Super plasticizer liter\100 kg of cementitious material	2.5%	2.5%	2.5%	2.5%	2.5%
Steel Fiber% by volume	2%	2%	2%	2%	2%
Water (kg/m^3)	198	203	207	212	219
W/C (%)	0.210	0.215	0.220	0.225	0.230
Flow(mm)	78	78	77	76	75

5. Test Results and Discussion

I. Compressive Strength

The compressive strength test of reference and recycled RPC was executed in accordance with ASTM C109/C109M-05 [5]. 5cm cube specimens were used to determine compressive strength using a standard testing machine with a capacity of 2000 kN. The average of three specimens was recorded for each testing age (14, 28 and 90 days). At the beginning in the mix1, when 20% was replaced, a slight decrease was observed in the compressive strength. Then, it increased slightly in the mix2 when the replacement ratio was 40%. Then, it decreased again significantly in the mix3 and mix4 with the increase in the proportion of replacing natural sand with recycled fine aggregate compared with reference RPC made with natural sand as illustrated in Table 2. The reason for the decrease in compressive strength with the increased replacement ratio is the fact that fine recycled concrete aggregate is absorbent, more pores, and more microcracks in old adhered mortar as a recycled aggregate. These causes are weekend in the new interfacial transition zone (ITZ) compared to natural sand [6,7]. Steam curing at 90ºC gave a better performance of reference and recycled RPC with natural and recycled aggregate in terms of higher strength than the curing at room temperature (20ºC) as illustrated in Figures 1 and 2 for standard and steam curing respectively. This enhancement in the performance is due to that the microstructure of cement matrix is denser when compared to standard curing [8].

Table 2: The compressive strength in (MPa) of RPC and RRPC at two different curing

Curing Temp.	Age (day)	Ref.	Mix 1	Mix 2	Mix 3	Mix 4
20°C	14	82.2	77.56	79.88	75.24	68.28
	28	118.4	113.76	117.08	111.44	104.48
	90	124.5	118.86	122.2	116.4	109.68
90°C	14	109.2	103.56	106.88	101.74	96.38
	28	134.5	127.81	131.18	123.04	116.17
	90	137.6	129.21	134.1	127.2	120.41

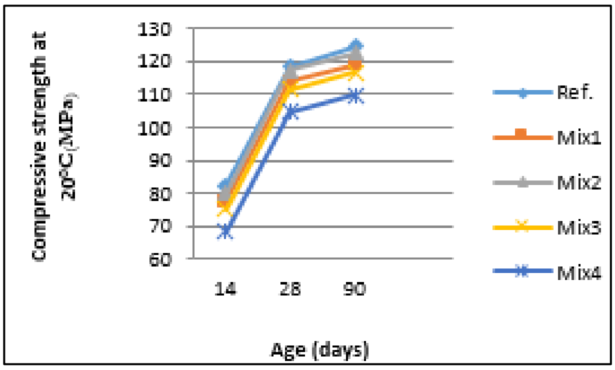

Figure 1: The compressive strength of RPC and RRPC at 20ºC

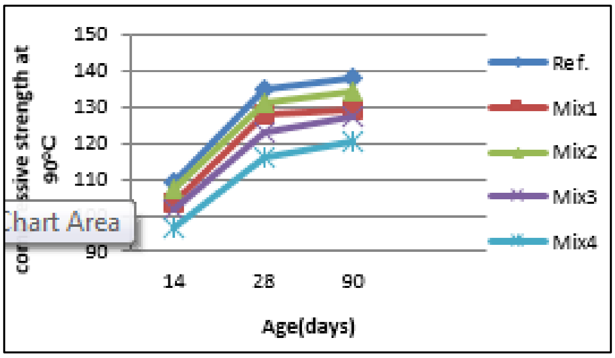

Figure 2: The compressive strength of RPC and RRPC at 90ºC

II. Flexural Strength

This test was carried out according to ASTM C 348-18specification [9]. Prisms of 40x40x160mm were utilized and tests were completed using a standard testing machine with a capacity of 10 kN. The test results of flexural strength are plotted in Figures 3 and 4 which present the flexural strength behaviour of RPC and RRPC mixes at 14,28 and 90 days with standard and steam curing respectively. The results indicate that there is very little decrease in flexural strength in the mix2 and mix3 when 20% and 40% were replaced compared to the reference mix, but then when the replacement ratio increased the decrease in flexural strength has increased. The slight reduction in behaviour in flexural strength is because of the physical and mechanical properties of recycled fine aggregate. Many factors influence the strength or weakness of the interfacial transition zone (ITZ) between cement paste and aggregate. One of the most important factors is w/c ratio. When added to the concrete mixtures, water will form around aggregate particles a water film. In this area, w/c ratio will be larger than double the rate in cement paste. The growth in this amount of water will lead to growth in the pores and thus (ITZ) will be weakened and its tendency to cracking will increase [6].The steam curing has a better performance than standard curing on the flexural strength. This enhancement in the performance is due to that the microstructure of the cement matrix is denser when compared to standard curing [8]. Maximum improvement was seen in mix3 when 40% of recycled fine aggregate was used as a replacement of natural sand as shown in Table 3.

III. Direct tensile strength

This test was executed on dogbone-shaped (76mm length, 25mm thickness, and 645mm^2 cross section at mid-length) in accordance with B.S 6319-7:1985 [10].The test results at the age of 14, 28 and 90 days are also used for two different curing. The general trend is the same as for the flexural strength and for the same reason as shown in Table 4. Figures 5 and 6 representing the variation in the direct tensile strength with different percentages of recycled fine aggregate in 14,28 and 28 days for standard and steam curing respectively.

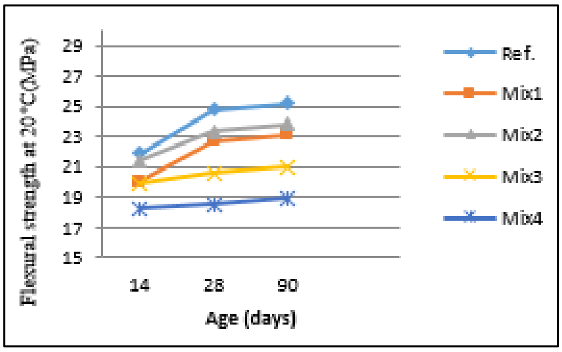

Figure 3: The Flexural strength of RPC and RRPC at 20ºC

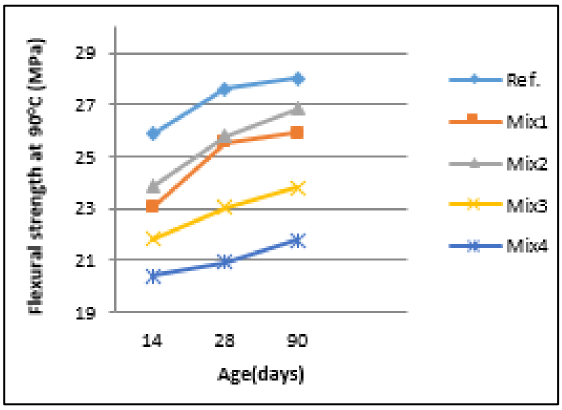

Figure 4: The Flexural strength of RPC and RRPC at 90ºC

Table 3: The Flexural strength in (MPa) of RPC and RRPC at two different curing

Curing Temp.	Age(day)	Ref.	Mix 1	Mix 2	Mix 3	Mix 4
20°C	14	21.9	20.01	21.39	19.88	18.21
	28	24.7	22.69	23.34	20.59	18.49
	90	9	23.13	23.81	21.02	18.92
		25.2				
90°C	14	25.8	23.03	23.82	21.82	20.4
	28	8	25.56	25.78	23.03	20.92
	90	27.6	25.93	26.85	23.81	21.75
		2				
		28.0				
		3				

Table 4: The direct tensile strength in (MPa) of RPC and RRPC at two different curing

Curing Temp.	Age (day)	Ref.	Mix 1	Mix 2	Mix 3	Mix 4
20°C	14	7.27	6.88	7.01	6.13	5.37
	28	10.05	9.41	9.75	8.45	8.15
	90	10.64	10.22	10.36	9.02	8.75
90°C	14	10.07	9.64	9.81	8.58	8.01
	28	11.68	11.37	11.43	10.26	9.12
	90	11.87	11.01	11.22	9.92	9.41

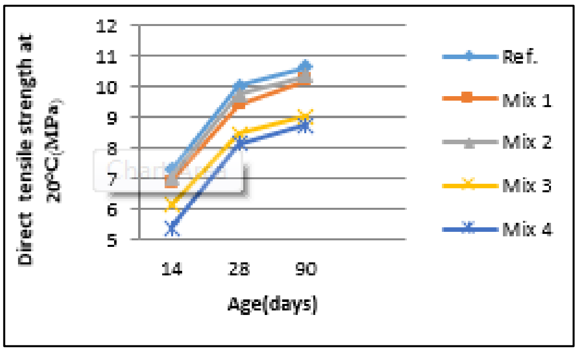

Figure 5: Direct tensile strength of RPC and RRPC at 20ºC

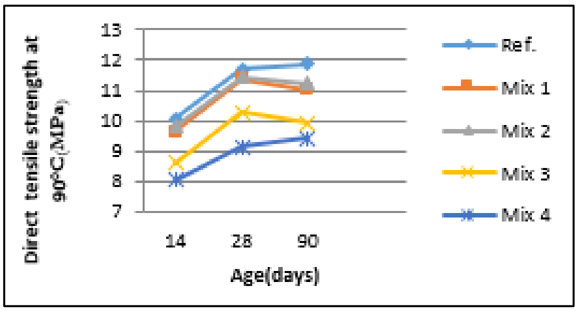

Figure 6: Direct tensile strength of RPC and RRPC at 90º

6. Conclusions

After the execution of the experiments and comparing ordinary reactive powder concrete with reactive powder concrete containing recycled fine aggregate in different percentages conclusion can be made as follows:

1. It is possible to produce reactive powder concrete containing recycled fine aggregate as a partial replacement of normal fine sand.
2. The best replacement ratio was 40%.
3. The percentages of decrease at 40% replacement of recycled fine aggregate by natural fine aggregate at 28-day steam curing were 2.46, 6.66, and 2.14 for compressive strength, flexural strength, and direct tensile strength respectively. But, then the decrease was greater in all strengths with the increased replacement ratio
4. Steam curing results at 90ºC performed better than standard curing at 20ºC.
5. Use of waste concrete not only cuts down the cost of construction but also contributes to the safe disposal of waste materials

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