

Experimental Study on Mechanical Properties of Pervious Concrete Containing Recycled Aggregate

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Abstract This investigational study aims to examine the influence of using recycled coarse aggregate (RCA) instead of natural coarse aggregate (NCA) on the fresh properties (workability) and mechanical properties of pervious concrete (PC). The mechanical properties include compressive strength, splitting tensile strength and flexural strength and the impact resistance of PC was also assessed using drop weight test. In total, four mixes were prepared (including control mix with 100% NCA) in which various ratios of RCA (30%, 70% and 100%) replaced the NCA in the preparation of PC mixes without using any fine aggregate and fixing the water-cement ratio (w/c) to 0.4. The outcomes of the study reveal that the content of the RCA has significant adverse effects on the workability and mechanical performance of the investigated mixtures. This adverse effects increase with the increase of the content of RCA. The strength reduction, compared to the mix with NCA, reached to 59% for compressive, 28% of the splitting tensile, 38% for flexural strength and 50% for the impact resistance when 100% RCA is used.

Keywords Pervious Concrete, Recycled Aggregate, Waste Construction Materials, Compressive Strength, Tensile Strength, Flexural Strength, Impact Resistance, Slump test, Drop Weight Test

1. Introduction

The amassing of massive quantities of waste materials in particular waste of construction and demolition activities, especially in urban areas, is one of the world's largest sustainability issues and environmental concerns. If such a large amount of waste is disposed of, the planet will face major environmental issues, such as the depletion of landfill space. Another question of sustainability is the depletion of natural resources for aggregates used in concrete manufacturing [1-3].

Following rapid industrial growth, the area of buildings and roads has grown, reducing the permeable area of surface runoff during heavy rains. As a result, rainwater that previously evaporated or drained into the groundwater is either flowing into the stream through the drainage system or accumulating on the road's surface. As a result, city flooding is increasing, groundwater levels are dropping due to reduced rainwater surface penetration, and environmental issues such as the heat island phenomenon in urban areas are emerging [4].

Pervious concrete (PC) is a form of concrete with a special structure characterized with a large content of voids (high porosity), usually between 15 and 35 percent by volume and interconnected pore structure [5].

Owing to the highly interconnected void structures, PC allows water to freely pass through its pores. This helps in decreasing flooding risk, recharging ground water, reducing storm water runoff, as well as diminishing noise

due to vehicle tires contact with road's surface. Furthermore, PC is developed at a low cost, making it one of the most promising sustainable systems for urban drainage. However, it needs regular maintenance to avoid sediment and vegetation which hinder the movement of water and affecting its high permeability. It may also have durability issues due to abrasion and freeze/thaw cycles. PC contains little to no fine aggregate, despite the fact that its constituent materials are identical to those of regular concrete that is why it is also called no-fines concrete. Low-traffic pavements including parking lots and sidewalks, as well as around homes, highway shoulders, and medians are the main applications of PC [6].

In an experimental study the results showed that the use of recycled coarse aggregate (RCA) decreases the workability (slump) of concrete because of recycled aggregate's high water absorption and rough surface. Similarly, the strengths values of normal concrete including compressive, splitting tensile and flexural decreased by 24.3%, 10.7% and 3.2% respectively, when RCA was used. This decrease can be attributed to the weakness of the recycled aggregate [1, 7].

On one hand, it has been found that PC shows lower strength than traditional concrete and the reduction depends on the strength grade of the concrete, as reported by [8]. In this study it was reported that the compressive strength reduced by 18.2% for M15, 14.5% for M20 and 12.6% for M25. Same study showed tensile strength reduction of 40.2%, 38.4% and 36.2% for M15, M20 and M25 grades respectively, and reductions of 29.9%, 27.6% and 24.6% for the flexural strength when compared to the normal concrete [8].

On the other hand, it was observed that replacing natural aggregate with recycled aggregate resulted in a significant increase in permeability coefficient while adversely affecting the mechanical properties of PC to some extent. It has also been reported that partially replacing cement with cementitious materials such as fly ash, silica fume, rice husk ash, cement kiln dust, and furnace slag will improve pervious concrete's compressive

strength and permeability. It is also concluded that incorporating waste materials into pervious concrete would significantly reduce the impact of concrete on the environmental and enhances the sustainability of concrete [9].

Furthermore, it has been experimentally found, using drop weight test, that adding steel fibers to the concrete mixes with 1.25% by volume of concrete improves the impact resistance of concrete compared to that of plain concrete [10].

In Iraq, there are very few studies on the efficiency of PC with recycled aggregate in terms of mechanical properties and behavior under impact loads.

As a result, the effect of replacing NCA with various ratios of RCA on the workability, mechanical properties, and impact resistance of PC is investigated in this paper. The experimental work, findings, and conclusions are presented in the following sections.

2. Experimental Program

2.1. Materials

The current study used Portland cement type CEM I, which satisfies BS EN 197 requirements. Table 1 shows the cement's chemical analysis (as given by the supplier).

Fine aggregate was completely left out in the mixes to create large open textured porous concrete. The coarse aggregate employed in this study were natural and recycled and are shown in (Figure 1).

The first one was natural rounded river aggregate. The second was recycled aggregate, which came from old concrete remnants left over from the demolition of old concrete structures. The natural and recycled coarse aggregates had the same maximum size of 12.5 mm in which 70% of this size was used, while the remaining 30% of the coarse aggregate was from those passing sieve 9.5 mm and remaining on sieve 4.5 mm. Table 2 lists the properties of coarse aggregates used in this study.

Table 1. Chemical composition of the Portland cement (CEM I)

SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	SO ₃	Na ₂ O	K ₂ O	Na ₂ O
20.94	4.96	2.92	65.9	0.78	2.8	0.25	0.42	0.52

Table 2. Physical properties of Coarse Aggregates (CA)

Property	Type of Aggregate	
	NCA	RCA
Shape	Rounded	Angular
Surface texture	Smooth	Rough
Specific gravity of the Saturated Surface Dry (SSD) condition	2.62	2.47

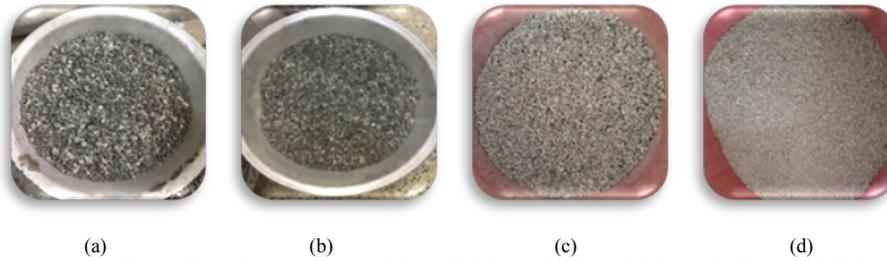


Figure 1. Coarse aggregate according to sieve size (passing): (a) Natural 12.5mm, (b) Natural 9.5mm, (c) Recycled 12.5mm, (d) Recycled 9.5mm

Table 3. Mix proportions (kg/m^3) and code of mixes of current study

Mix No.	Mix code	Air content %	Cement	Water	Fine Agg. (FA)	Coarse Agg. (NCA)	Coarse Agg. (RCA)
M1	PCN100	17	400	160	0	1423	0
M2	PCR30	17	400	160	0	996	402
M3	PCR70	17	400	160	0	427	939
M4	PCR100	17	400	160	0	0	1342

Table 4. Details PC samples prepared for each mix in this study

Sample Type	Sample Size (mm)	Number of Samples	Associated Test
Cubes	100	3	Compressive strength
Cylinders	100×200	3	Splitting Tensile strength
Prisms	100×100×400	3	Flexural strength
Cylindrical discs	152.4 dia., 63.5 hgt.	3	Impact resistance

2.2. Experimental Work



Figure 2. Some PC samples prepared in this study

In total, four mixes were prepared and tested in the study. Table 3 lists the study variables, code of mixes and mix proportions. The aggregate used was in a saturated surface dry (SSD) condition, and same water/cement (w/c) ratio of (0.4) was used for all mixes. To prepare the concrete mixtures, a 0.08 m^3 capacity pan mixer was employed to mix the constituents of the concrete. The type, size and number of the PC samples prepared for each mix are shown in Table 4. When designing the concrete mixes, the physical properties of NCA and RCA were taken into account especially the difference in specific gravity at saturated surface dry condition. The blended coarse aggregates' values were estimated by assuming that the properties of NCA and RCA influence the blended coarse aggregate proportionally. After casting, the concrete

specimens were protected using plastic sheets and then left to cure for 24 hours before demoulding. Afterward, the samples were moved to water tanks for the curing process for 28 days. Figure 2 shows some of the various PC samples prepared in this study.

2.3. Experiments

2.3.1. Workability “Slump Test”

Slump tests were used to evaluate the fresh concrete properties (workability) of all mixes according to the standard BS EN 12350-2 [11] as shown in (Figure 3).



Figure 3. Slump test

2.3.2. Compressive Strength Test

The 100 mm cubes specimens were examined for

compression after 28 days of curing using the BS EN 12390-3 [12] standard procedure. The compressive strength test machine is shown in (Figure 4).



Figure 4. Compressive strength test machine

2.3.3. Splitting Tensile Strength Test

This test was conducted using the BS EN 12390-6 [13] standard procedure and 100×200 mm cylinders specimens. The splitting tensile strength test machine is shown in (Figure 5).



Figure 5. Machine for splitting tensile strength test

2.3.4. Flexural Strength Test

The concrete specimens were assessed for its flexural strength after 28 days of curing according to the standard procedure of BS EN 12390-6 [14]. The (100×100×400) mm prisms were tested in two-point loading over a length of 300 mm using the flexural strength test machine as shown in (Figure 6).



Figure 6. Flexural strength test machine during testing

2.3.5. Impact Resistance Test

As per the ACI 544.2R-89 [15] standard test, the concrete discs were assessed for impact resistance at the age of 28 days. The impact load was applied repeatedly in the form of blows using a 10 lb (4.54 kg) compaction hammer that was dropped from an 18-in. (457-mm) height on a steel ball with a diameter of 63.5 mm that was mounted in the middle of the top surface of the concrete disc. The number of blows (N1) and (N2) that resulted in the first visible crack and specimen failure were reported. Figure 7 describes how the impact load was applied in this study to assess concrete's impact resistance.



Figure 7. Concrete impact resistance testing

Impact resistance energy was calculated for all specimens using (1), [16, 17]

$$\text{Impact energy (IE)} = N \times g \times m \times h \quad (1)$$

Where:

IE = Impact energy (resistance) (N.m),

N = Number of blows,

g: Acceleration of Gravity = 9.81 m/s²

m: Mass of hammer kg = 4.57 kg, and

h: Height of drop hammer = 0.457 m.

2.4. Results and Discussion

2.4.1. Workability of concrete “Slump Test”

The slump test method was used to evaluate the workability of all mixture. Table 5 and Figure 8 display the slump test results in millimeters for all mixes. The table also highlights the differences in slump between M1 and other mixes.

Table 5. Results of slump test values (+ increase or - decrease) compared to M1

Mix	Workability “Slump Test”	
	Slump mm	Slump Change (%)
M1	130	-
M2	95	-26.9
M3	45	-65.4
M4	25	-80.8

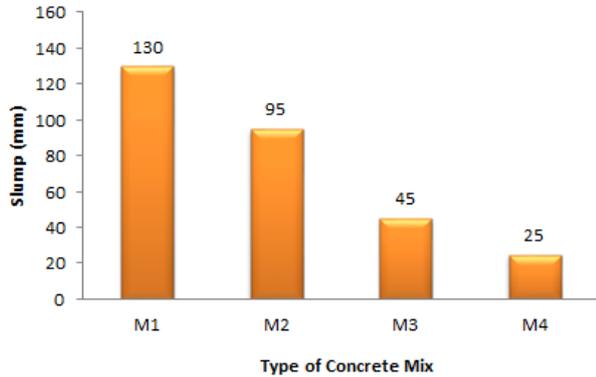


Figure 8. The effect of using RCA instead of NCA on the slump value of PC

The results in (Figure 8) show that replacing NCA with RCA in PC mixes decreases slump values. Increased NCA replacement with RCA resulted in a direct reduction in workability. As 30 percent, 70 percent, and 100 percent of NCA is replaced with RCA in PC mixes, the workability of the concrete is reduced by around 27%, 65%, and 81%, respectively, as compared to M1. This may be attributed to the rough surface texture of RCA and its higher water absorption than NCA [1, 18-20].

2.4.2. Compressive Strength

Table 6 and Figure 9 demonstrate the 28-day compressive strength values of all mixes. Those values represent the average of 3 specimens. The table also highlights the differences in strength between M1 and other mixes.

Table 6. Compressive strength test values (+ increase or - decrease) compared to M1

Mix	Compressive strength	
	Strength MPa	Strength Change (%)
M1	24.6	-
M2	15.0	-38.9
M3	11.4	-53.8
M4	10.1	-59.0

The results indicate that replacing NCA with RCA in PC mixes decreases concrete compressive strength, and that the reduction increases as the amount of NCA replaced with RCA increases. When 30%, 70%, or 100% of NCA is replaced with RCA in PC mixes, the compressive strength of concrete is reduced by about 39%, 54%, and 59%, respectively, when compared to M1. This reduction is predicted since the quality of RCA is low

compared to that of NCA. This can be attributed to the mortar attached to the RCA's surface, which has a low density and high porosity, resulting in a weaker concrete [1, 18, 20].

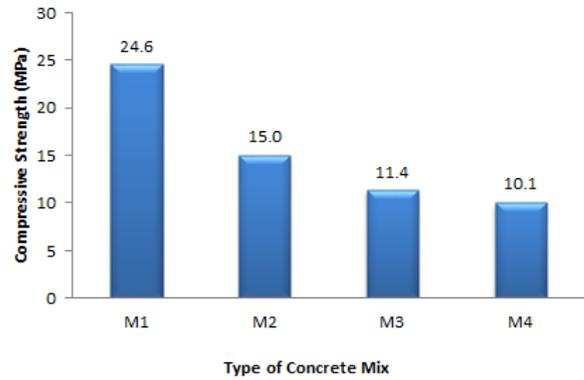


Figure 9. The effect of replacing NCA with RCA in the compressive strength value of PC

2.4.3. Splitting Tensile Strength

Table 7 and Figure 10 demonstrate the 28-day splitting tensile strength values of all mixes. Those values represent the average of 3 specimens. The table also highlights the differences in strength between M1 and other mixes.

Table 7. Splitting tensile strength test values (+ increase or - decrease) compared to M1

Mix	Splitting tensile strength	
	Strength MPa	Strength Change (%)
M1	2.39	-
M2	1.82	-23.9
M3	1.81	-24.3
M4	1.73	-27.6

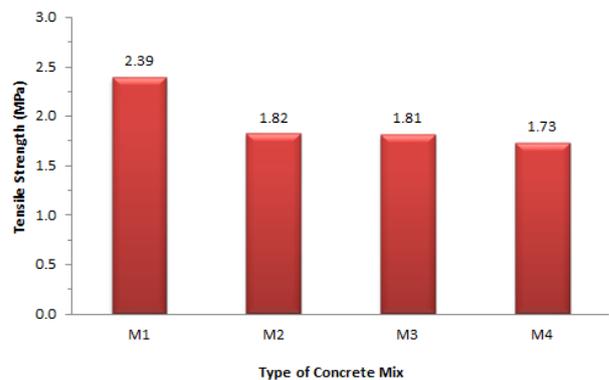


Figure 10. The effect of replacing NCA with RCA in the splitting tensile strength value of PC

The values for splitting tensile strength follow a pattern close to that of compressive strength. When 30%, 70%, and 100% of NCA is substituted with RCA, the strength of the PC mixes drops by about 23%, 24%, and 28%, respectively, when compared to M1. The increase in concrete porosity and the decrease in the bond between

the aggregate and the matrix are responsible for the drop in the splitting tensile strength values of PC with RCA [20, 21].

2.4.4. Flexural Strength

Table 8 and Figure 11 demonstrate the 28-day flexural strength values of all mixes. Those values represent the average of 3 specimens. The table also highlights the differences in strength between M1 and other mixes.

Table 8. Flexural strength test values (+ increase or - decrease) compared to M1

Mix	Flexural strength	
	Strength MPa	Strength Change (%)
M1	2.63	-
M2	1.99	-24.3
M3	1.69	-35.7
M4	1.63	-38.0

The values for flexural strength follow a pattern close to that of compressive strength and splitting tensile strength. The flexural strength of M1 is 2.63 MPa. In M2 where only 30% of natural aggregate replaced with recycled aggregate, the results showed lower strength than that of M1 by 24%. Furthermore, in M3 and M4 where 70% and 100% of natural aggregate replaced with recycled aggregate, the results showed lower strength than that of the M1 by 36% and 38%, respectively. The mortar

adhered to the recycled aggregate surface causes the flexural strength of PC with RCA to decrease, resulting in a low-density, low-strength concrete [1, 20, 22].

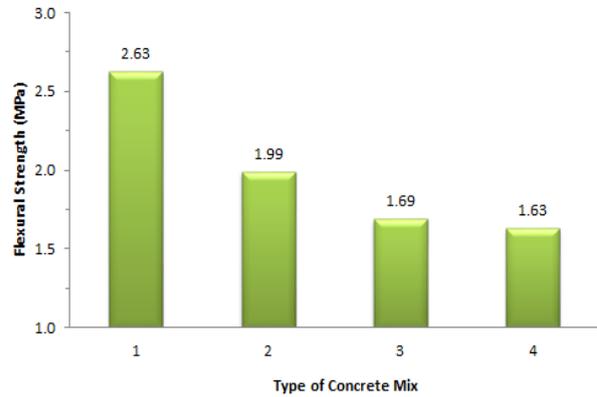


Figure 11. The effect of replacing NCA with RCA in the flexural strength value of PC

2.4.5. Impact Resistance

Table 9 shows the number of blows (average of 3 disc samples) that caused initial and failure cracks of the 28 days impact resistance test of PC discs for all mixes, it also shows the percentage of reduction in the impact resistance of PC compared M1 where natural aggregate is replaced with recycled aggregate in various ratios for mixes (M2, M3 & M4), while Table 10 presents statistical analysis for the results.

Table 9. Results of impact resistance of the PC

Mix	No. of blows that cause:			Impact Resistance			
	first crack N1	failure N2	Difference (blows)	First Crack IE1 (N.m)	Decrease (%)	Ultimate Failure IE2 (N.m)	Decrease (%)
M1	44	48	4	901	-	983	-
M2	30	35	5	615	32	717	27
M3	27	33	6	553	39	676	31
M4	18	24	6	369	59	492	50

Table 10. Statistical analysis of test results of the PC mixes.

Item	N1/N2			
	M1	M2	M3	M4
Average	44/48	30/35	27/33	18/24
Standard Deviation	4.58/4	2.65/1.73	1.73/3	1.73/2.65
Coefficient of Variance	10.41/8.33	8.82/4.95	6.42/9.09	9.62/11.02

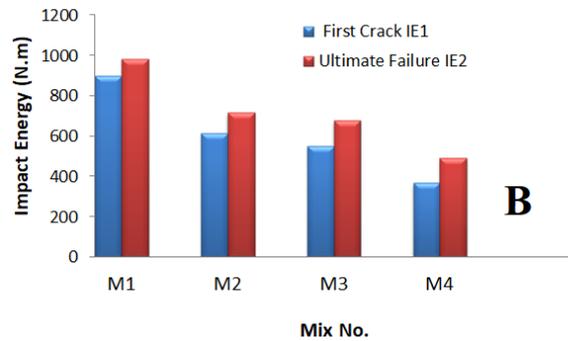
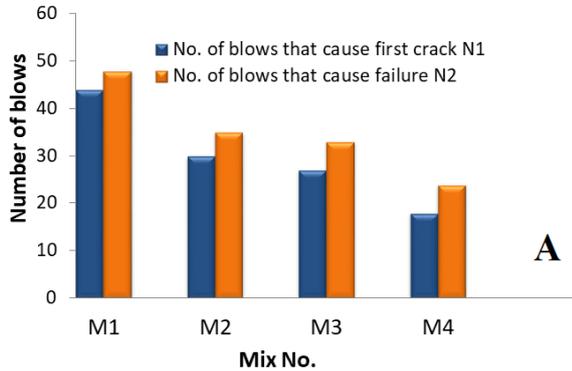


Figure 12. Impact test results of PC: (A) Number of blows, (B) Impact energy.

Figure 12 (A) and (B) show a comparison between number of blows and impact energy that cause first crack and failure in PC discs for all mixes. The general trend of the impact load resistance of the mixes with recycled aggregate shows a substantial decrease reaches more than 50% when 100% of NCA substituted with RCA as illustrated in Figure 12 (A). The reference mix M1 had an impact resistance of 901 N.m, and replacing 30% of NCA with RCA in M2, 70% in M3, and 100% in M4 resulted in a reduction in the number of blows required to cause the initial crack and those cause failure; hence, decreasing the impact resistance of the concrete as it is directly related to the number of blows. The percentages of the decrease in the impact resistance (at failure) due to the use of RCA for mixes M2, M3 and M4 are found to be 27%, 31% and 50%, respectively, as shown in Table 9. This decline in impact resistance may be attributed to a general decrease in PC strength as aggregate size increases and how it fits together in the hardened concrete mix, as well as the fact that the overall strength of the concrete is inversely proportional to the amount of voids. Also, from another point of view, it is predicted that the adhered mortar layer of the RCA is weaker than NCA and it causes a weak link in PC mass and results in crack's propagation [17, 23, 24].

2.4.6. Failure Pattern

Figure 13 shows the failure patterns of PC discs with different percentages of NCA replaced with RCA in mixes

M2, M3, and M4 at 28 days' age. Since no other material, such as waste rubber tires, is applied to concrete to improve its brittleness properties, brittleness failure is obvious on those mixes [17].

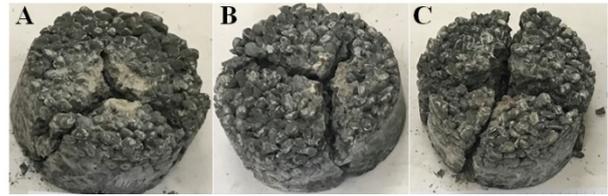


Figure 13. Failure patterns of the PC results from impact load with (A) 30%, (B) 70% and (C) 100% NCA replaced with RCA

3. Conclusions

The following can be deduced from the experimental tests findings:

- The workability (slump values) of the mixes with RCA decreased by 27%, 65% and 81%, respectively, for the mixes M2, M3 and M4 compared to the reference M1.
- Replacing NCA by RCA in the pervious concrete mixes caused a significant drop in the compressive strength of concrete by about 39%, 54% and 59%, respectively, for the mixes M2, M3 and M4 compared to the reference M1.
- Replacing NCA by RCA in the pervious concrete mixes caused a significant drop in the splitting tensile strength of concrete by about 23%, 24% and 28%, respectively, for the mixes M2, M3 and M4 compared to the reference M1.
- Replacing NCA by RCA in the pervious concrete mixes caused a significant drop in the flexural strength of concrete by about 24%, 36% and 38%, respectively, for the mixes M2, M3 and M4 compared to the reference M1.
- Replacing NCA by RCA in the pervious concrete mixes inversely affects the impact resistance by about 27%, 31% and 50%, respectively, for the mixes M2, M3 and M4 compared to the reference M1.
- This major reduction in pervious concrete overall strength arises from replacing NCA by RCA may highlight a significant point about the possibility of using such concrete in several applications and this may be enhanced by the addition of several materials to balance this reduction and keeping low cost of construction and ensure concrete sustainability.

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