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Developing Porous Concrete Interlocking Pavement Blocks Utilizing Recycled Concrete Aggregate for Rainfall Harvesting Use

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ABSTRACT

Rainwater harvesting and flood prevention in cities are significant urban hydrological concerns. The use of porous pavement is one of the most effective solutions to handle this matter. Thus, this study aims to develop Porous Interlocking Concrete Pavement (PICP) using recycled aggregate from concrete waste. This porous pavement, then later, can be utilized in low traffic areas and parking lots to harvest water by infiltration and reduce surface runoff. First, the physical properties of the porous concrete blocks, such as density (unit weight), absorption, coefficient of permeability, and porosity, were studied. Also, the mechanical properties of concrete mixtures like compressive strength and flexural strength were tested. This study used two types of PICP, the first one with ordinary coarse aggregate (P1) and the second with recycled crushed concrete coarse aggregate (P2), and then compared their performance to the conventional concrete pavement blocks used the two types of coarse aggregate (R1 and R2). The results show that the unit weight (density) of porous types was reduced by 25% and 26%, and the total porosity increases by around 2.4 times and 18 times respectively, as compared to conventional concrete pavement types. However, the compressive strength and flexural strength of porous concrete types decreased by (55% and 71%), respectively, compared to conventional types. Overall, the infiltration test results showed that the infiltrated water through porous concrete increased by about 83% in comparison to conventional concrete. From the results, utilizing porous concrete pavement can be considered a promising material in terms of water harvesting and decreasing rainwater flooding. Additionally, using recycled concrete can bring economical and environmental benefits.

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تطوير التبليط بالكتل الخرسانية المسامية المتشابكة باستخدام الركام الخرساني المعاد تدويره

الخلاصة

يعتبر حصاد مياه الأمطار والوقاية من الفيضانات في المدن من الاهتمامات الهيدرولوجية الحضرية الهامة. يعد استخدام التبليط المسامي أحد أكثر الحلول فعالية للتعامل مع هذا الأمر. لذلك، تهدف هذه الدراسة إلى تطوير التبليط بالكتل الخرسانية المسامية المتشابكة باستخدام الركام المعاد تدويره من نفايات الخرسانة. يمكن استخدام هذا التبليط المسامي، بعد ذلك، في مناطق حركة المرور المنخفضة ومواقف السيارات لحصاد المياه عن طريق الارتشاح وتقليل الجريان السطحي. تمت دراسة الخواص الفيزيائية للكتل الخرسانية المسامية مثل الكثافة (الكثافة الوزنية) والامتصاص ومعامل النفاذية والمسامية. كما تم اختبار الخواص الميكانيكية للخلطات الخرسانية مثل مقاومة الانضغاط وقوة الانثناء. استخدمت هذه الدراسة نوعين من الكتل الخرسانية المسامية المتشابكة، الأول باستخدام الركام الخشن العادي (P1) والثاني باستخدام الركام الخشن المكسر المعاد تدويره (P2)، ومن ثم مقارنة أدائهما مع الكتل الخرسانية التقليدية التي استخدم فيها نفس النوعين من الركام الخشن. بينت النتائج أن الكثافة الوزنية للأنواع المسامية انخفضت بنسبة 25٪ و 26٪، والمسامية الكلية زادت بحوالي 2.4 مرة و 18 مرة على التوالي، مقارنة بأنواع الكتل الخرسانية التقليدية. ومع ذلك، انخفضت مقاومة الانضغاط وقوة الانثناء لأنواع الخرسانة المسامية بنسبة (55٪ و 71٪) على التوالي مقارنة بالأنواع التقليدية. بشكل عام، أظهرت نتائج اختبار الارتشاح أن الماء المتسرب عبر الخرسانة المسامية زاد بنحو 83٪ مقارنة بالخرسانة التقليدية. من النتائج، يمكن اعتبار استخدام التبليط الخرساني المسامي مادة واعدة من حيث حصاد المياه وتقليل فيضان مياه الأمطار. بالإضافة إلى ذلك، فإن استخدام الخرسانة المعاد تدويرها يمكن أن يحقق فوائد اقتصادية وبيئية.

1. Introduction

Porous concrete is mainly chosen to transmission the quantities of water resulting from rainstorms and floods to the lower ground layers to improve groundwater storage later on through a series of interconnected gaps between them. These gaps are produced by bonding and balanced gradation of aggregates and when designing the concrete mixture for porous concrete, consideration must be given to there should be a sufficient amount of gaps to reduce the amount of water produced by rainstorms [1].

Huge amounts of water due to rain and floods cause trouble to traffic and the daily use of roads in cities. Therefore, the need to produce a special type of concrete, which is porous concrete, has an exceptional property that distinguishes it from other types of concrete, as water penetrates easily through it. Porous concrete is a type of concrete that does not comprise any amount of fine aggregate (no sand) or contains it in low proportions and has high permeability and filtration rate [2].

Concrete is a primary material used in buildings and structures. Depending on the use, the concrete's ability to resist load varies. The concrete composition consists primarily of water, cement, and aggregate, which depending on many factors such as strength and cost consideration, are mixed with different proportions. In the concrete mixture, sand or fine aggregate is also added as a component to fill the gap between larger aggregates. Compared to porous concrete, traditional concrete is different in terms of the content of the mixture and usage. By enabling the water to seep between the interconnecting void in it to prevent the water from pooling at the surface, the previous concrete works as a drainage cover or hardstand pavement [3].

Porous paving has benefits over standard pavement, such as reducing pavement quantity, cleaning surface runoff and groundwater, reducing flood risk and erosion, eliminating the heat island effect, and noise pollution [4]. Therefore, one of the solutions for the urban flooding problem is using porous interlocking concrete pavement (PICP), not only to carry traffic but also to manage runoff.

PICPs are designed with a large joint space between pavers to allow rainwater to enter. Instead of sand or other materials, joints in a PICP technique are filled with tiny aggregate, and pavers provide chances for a bedding sheet, base layer, and subbase layer to participate [5].

Many researchers have conducted studies on paving with permeable concrete blocks. Some of these studies focused on the study of the physical and mechanical properties of this type of concrete [6, 7], others focused on the use of recycled materials and additives to improve the properties of the porous concrete such as fly or polymer [8-12]. In addition, other studies deal with the use of permeable concrete pavement blocks in improving and purification of rainwater [13, 14].

In Iraq, it has been recognized that the amount of demolished buildings and construction waste is high and rising every year. The problem of accumulation and management of waste occurs in different countries. Any of the building waste is used or left as landfill material [16].

Waste concrete aggregate (WCA) is gradually more being used in concrete. We propose that taking advantage of the rubble of buildings destroyed by devastating earthquakes occurring in different locations would be advantageous because it could generate good-quality concrete, given the rubble is properly used as WCAs. To be used in concrete, environmental pollutants such as WCAs should be standardized, taking into account the usual aggregate [16].

This study aims to produce porous interlock pavement from recycled aggregate using waste concrete to be used in areas with low traffic volume of roadways and parking lots, to collect water by increasing infiltration and reducing surface runoff, and they are collected to benefit in the future. To that end, researchers will examine physical and mechanical properties of a porous concrete interlocking pavement made from recycled crushed concrete, as well as the properties of porous concrete blocks made from the use of ordinary coarse aggregate, and whether or not it is possible to make porous concrete from this type of recycled material.

2. Materials and Experimental Work

The materials characteristics used in this study are presented as follows:

Cement: Ordinary Portland Cement (type I) was used, and its properties were in conformity with the Iraqi standard specifications (IQS No.5/1984). Table (1) shows the chemical and physical properties of the cement type that used in preparing the study models.

Table 1.
Chemical and physical properties of cement Type I

Cement Composition[17]	Content %	Limit of Iraqi Specification No. 5/1984
CaO	57.65	-
Al_2O_3	4.40	-
SiO_2	18.05	-
Fe_2O_3	4.03	8% Max
MgO	3.81	5 % Max
SO_3	2.12	2.8 %Max
(L.O.I)،Loss on Ignition	1.26	4 %Max
Insoluble material	0.90	1.5 %Max
Lime Saturation Factor (L.S.F)	0.89	(0.66-1.02)
	Main Compounds	
C_3S	44.61	-
C_2S	24.1	-
C_3A	3.39	-
C_4AF	14.28	-
Limit of Iraqi specification No. 5/1984	Test Results	Physical Properties
(230 m²/kg) lower limit	259 m²/kg	Fineness of Cement (m²/kg) [18]
		Setting time (Vicat Needle)[19]
Not less than 45min	3hr:15min	Initial setting, (hrs. : min)
Not more than 10 hrs	8hr:35min	Final setting, (hrs. : min)
		Compressive strength (kg/cm²) [20]
Not less than 15 MPa	28.68 MPa	For 3-day
Not less than 23 MPa	39.44 MPa	For 7-day

***Fine Aggregate*:** The fine aggregate that is used in this study is river sand which was taken from Samarra region, the sand passing through a sieve No.4 (4.75mm) was used. Table (2) shows the gradation of this sand which confine to the Iraqi Standard IQS No. 45/1984 [21], within the second gradient zone, and the proportion of clay materials in it were within the limits of the standard. Table (3) shows the chemical and physical properties of sand.

Table 2.
Grading of the separated fine aggregate

Sieve size IQS No. 23	Retained %	Cumulative passing %	Limit of IQS No. 45/1984 for 2/2010, Zone No. (2)
10-mm	0	100	100
4.75-mm	0.24	99.76	90 – 100
2.36-mm	10.24	89.71	75 – 100
1.18-mm	20.33	79.67	55 – 90
600-μm	41.21	58.79	35 – 59
300-μm	70.60	29.40	8– 30
150-μm	93.938	6.068	0 – 10

Table 3.
Mechanical properties of fine aggregate

Properties	Specification	Test Results	Limits of specification
Specific gravity	ASTM C128-01[22]	2.46	-
Absorption %	ASTM C128-01[22]	1.22	-
Dry loose unit weight, kg/m³	ASTM C29-C29M[23]	1490	-
Sulfate content (as SO_3), %	(I.Q.S.) No. 45/1984	0.057	0.5 (max. value)
Material finer than sieve 0.075 mm	(I.Q.S.) No. 45/1984	3.8%	5 (max. value)

Coarse Aggregate: Two types of coarse aggregates were used, the first type was regular rounded gravel size (5-12.5) mm from Samarra region, and the maximum size of aggregate used was (12.5mm). The aggregates are sifted on two sieves of 12.5 mm and the second by the size of 5 mm, the used aggregates are selected that pass from a sieve No. 12.5 mm and the remainder on a sieve No. 5 mm (Figure 2-A). The sifted aggregates are washed with clean water several times to get rid of impurities and suspended materials and prepare for pouring. The second type is recycled concrete aggregates (RCA) obtained from rubble concrete from the debris of one of the old buildings to be reconstructed. The age of the building is estimated to be around 30 years. The debris was crushed into small pieces of aggregate using an iron hand hammer and sieved using iron sieves to obtain recycled crushed aggregate of concrete with size (5-12.5 mm), the coarse aggregate was washed for disposal of the clay materials debris (Figure 1-B). Tables (4) and (5) represent the gradation and chemical and physical properties of the normal coarse aggregate respectively. The gradation of coarse aggregate is confined to the Iraqi Standard IQS No.45/1984 [21]. Tables (6) and (7) represent the gradation and chemical and physical properties of the recycled crushed coarse aggregate respectively.

A: (NA) normal coarse aggregate

B: (RCA) recycle coarse aggregate

Figure (1): Normal coarse aggregate and recycled concrete aggregate (RCA).

Table 4.
Grading of the separated normal coarse aggregate

Sieve size	Cumulative Retained %	Cumulative passing %	Limit of IQS No. 45/1984
14-mm	0	100	90-100
10-mm	24.87	75.13	50-85
5-mm	99.82	0.18	0-10
pan	0	0	-

Table 5.
Chemical and physical properties normal coarse aggregates

Properties	Specification	Test Results	Limits of Specification
Specific gravity	ASTM C127-01	2.67	-
Absorption (%)	ASTM C127-01	0.80	-
‹Dry loose unit weight kg/m³	ASTM C29-C29M	1610	-
Sulfate content (as SO_3) (%)	(I.O.S.) No. 45-84	0.027	0.1 (max. value)

*Laboratory tests and sieve analysis were performed in the laboratories of the College of Engineering - Tikrit University

Table 6.
Grading recycle coarse aggregate (RCA)

Sieve Size	Cumulative Retained %	Passing %	Limit of Passing % for IQS No. 45/1984
14 mm	0	100	90-100
10 mm	35.11	64.89	50-85
5 mm	99.65	0.35	0-10
pan	0	0	-

*Laboratory tests and sieve analysis were performed in the laboratories of College of Engineering - Tikrit University

Table 7.
The chemical and physical properties of recycled coarse aggregate (RCA)

Properties	Specification	Test Results	Limits of Specification
Specific gravity	ASTM C127-01	2.37	-
Absorption (%)	ASTM C127-01	7.32	-
Dry loose unit weight, kg/m³	ASTM C29-C29M	1197	-
Sulfate content (as SO_3) (%)	(I.O.S.) No. 45-84	0.421	0.5 (max. value)

*Laboratory tests and sieve analysis were performed in the laboratories of College of Engineering - Tikrit University

Water: Natural drinking water supplied to the laboratory was used in preparing the concrete mixes for this study. pH test was performed on this water and it was found to be equal to 7.4 and in conformity with the Iraqi specifications (IQS No. 1703/1992) [24].

Testing device: A laboratory rain simulator, with dimensions (1000*1500*650) mm, was used to illustrate the runoff quantity and infiltration rates through the pavement structure, this device was locally manufactured and consists of three parts, as shown in Figure (2).

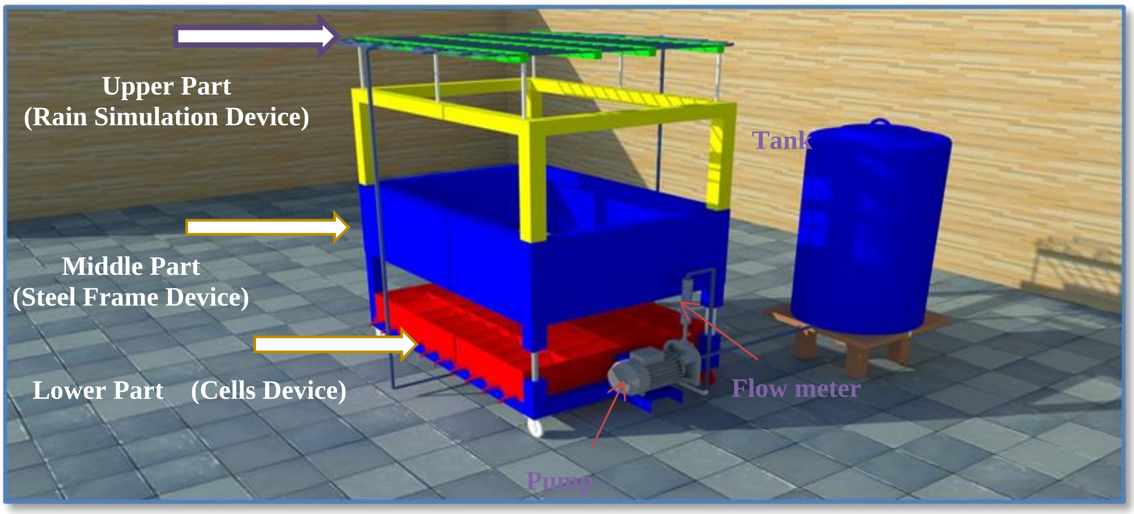

Figure 2: Rain simulator device

Upper Part (Rain Simulation Device)

The upper part consists of 16 PVC perforated tubes 12.5 mm diameter with a nozzle diameter of 2 mm and the distance between one tube and the other is 97.5mm, the distance between every two openings is 100 mm that drilled equally along each pipes. The distribution of the pipes for the simulated rainfall system is designed so that the water is supplied for the system from two directions and then divided into four sections to ensure the distribution of rain discharges down on the pavement equally and with the same intensity to be closer to the truth of rain. A wooden frame is used to ensure a uniform rain simulation and to cover the complete paved area that fixes the PVC tubes. The wooden frame is connected by iron cages and connected by 6 screws of 250 mm length which is used to ensure the rainfall simulator to be at horizontal level, and to be fixed to a steel frame that sits on the middle part as shown in Figure (3).

Figure 3: The rainfall simulator device

Middle Part (Steel Frame Device):

The porous interlocking concrete pavement (PICP) was paving on the intermediate portion, thus it was constructed with a steel frame. At the bottom of the box, a two-layer network of BRC is installed with small holes to attach the pavement layers and enable filtered water to flow from the pavement layers. Under the interlocking pavement, three layers were arranged: the bottom layer (base layer), the intermediate layer, and the upper layer. The thickness of the base layer is 270 mm, which contains (No.2) aggregate. While the thickness of the next layer is 100 mm and includes (No.57) aggregate. After kneading, the gravel is distributed, the upper layer that is located under the interlocking pavement, this layer is called (bedding layer) and it is 50 mm thick and contains rubble of size (No.8). The aggregate of all layers was washed several times with clean water to get rid of the mud and soil attached to it to avoid the penetration of soft materials into the layers and thus the blockage. It is necessary to press the materials to give the layers the required density by using a hand hammer to fix the layers and give them the design resistance of the pavement. The last layer is the PICP interlocking pavement layer with dimensions (200*100*50) mm, where the concrete blocks are paved at the top of the bedding layer. The joints between the porous blocks were filled with river sand. Finally, the paving is compressed by the available means as shown in Figure (4).

Figure (4): Porous interlocking pavement and layer (PICP) filter

Lower Part (Cells Device):

The lower part of the simulation device includes 40 boxes designed to collect water leaking from the upper paving layers and these boxes have dimensions of (220*150*250) mm and are designated as shown in Figure (5-A). Also, a large box, with dimensions (1000*150*200) mm, was made to collect the runoff water, it was connected with a pipe of diameter 1 inch which use to convey water to the pipes of the rainfall simulator system container. The rate of flow meter that used in the simulation device system ranged between (20-110) l/min as shown in Figure (5-B). Three different rainfall discharges (20, 40, 60) l/min were used in each group of runs.

(A) (B)

Figure 5: (A): Cells for infiltration & Runoff (B): Flowmeter

Rubber Molds: 75 rubber molds were used to produce a traditional and porous concrete pavement with dimensions (200*100*50) mm that were used in forming a pavement interlocking in the rainfall simulator.

Electronic balance: An electronic balance is used with a digital tablet screen is used to measure the weights of materials and the weight of models, also it was used to calculate the quantities and volumes of filtered rainfall water to the boxes and surface runoff water.

3. Mix Proportions and Trail Mixes

Three cubes of concrete with dimensions (100×100×100) mm were cast and cured for 28 days. The mixing ratio is (1:1.5:3) (cement:sand: gravel) and the design compressive strength of the concrete was selected within limits (f_{cu} =35 MPa) with multiple water-cement ratio (W/C) (0.4 and 0.38), depending on a previous study [2]. Compression strength class (Cyber-PLUS EVOLUTION), capacity 2025 kN, and rated load shedding rate 7 kN/sec.

A mix proportion (1:1.5:3: 0.4) (cement:sand:gravel: W/C) with compressive strength 44.84 MPa is chosen as the best mix as shown in Figure (6). Table (8) shows the mixing ratios of the adopted mixes.

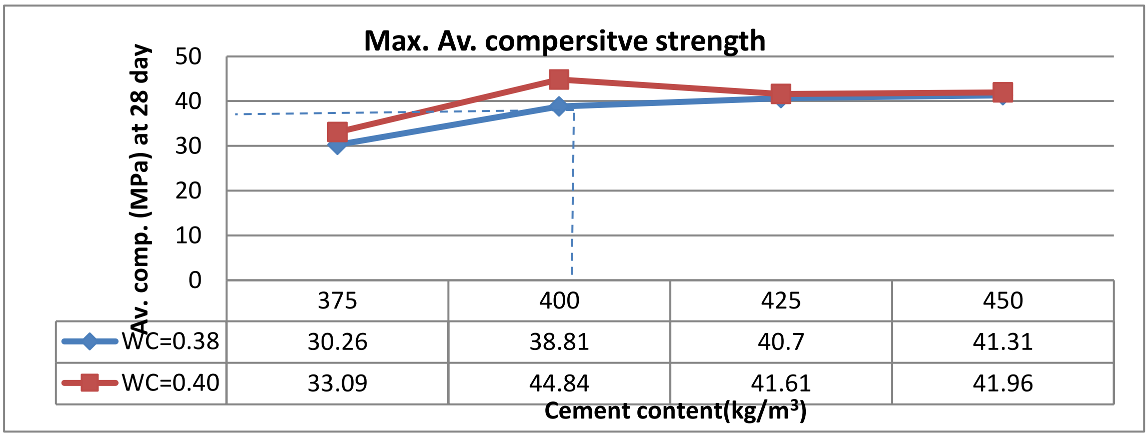

Figure 6: The relationship between average compressive strength and the cement content

Table 8.
Mixing ratio for all mixture types

Mixture type and symbol	Coarse aggregate type	Mixing ratio (cement: sand: gravel)	Water to cement ratio (W/C)
Reference Mixture (R1)	Normal Aggregate (rounded)(NA)	(1:1.5:3)	0.40
Reference Mixture (R2)	Waste Concrete Aggregate (RCA)	(1:1.5:3)	0.40
porous Mixture (P1)	Normal Aggregate (rounded)(NA)	(1:0:3)	0.40
porous Mixture (P2)	Waste Concrete Aggregate (RCA)	(1:0:3)	0.40

4. Specimens Preparation

After mixing, the fresh concrete was immediately poured into the cast iron molds (cubes, cylinders, and prisms). After casting, the molds were mounted on the vibrating table. Concrete is cast in layers, with each layer compacted for (15-30) sec on the vibrating table. The concrete was smoothed out on the top, and the surface was leveled off the molds' peak.

The specimens were then kept in the laboratory for around 24± 2 hours, covered with a polyethylene membrane. The samples were then de-molded and deposited at 23 C° in the curing tank until the age of testing.

5. Results and Discussion

The results of this study are divided into two sections. The first section includes the results of the physical and mechanical properties of porous concrete and its comparison to conventional concrete, while the second section covers porous concrete's infiltration results.

Physical and Mechanical Properties Results of Hardened and Porous Concrete

Dry Unit Weight

The unit weight for hardened and oven-dried porous concrete was measured according to American standards (ASTM C567-00) [25] for all types of mixes. For each kind of concrete mixture, three cylindrical models with dimensions of (150*300) mm and a 28-day age were tested. As shown in Figure (9), the average unit weight (density) of porous concrete (P1and P2) ranged from (1756.5 to 1645.83) kg/m3, whereas that of normal concrete (R1and R2) ranged from (2336.46 to 2234.96) kg/m3. These results indicating that the unit weight of porous concrete (P1and P2) was lower than the reference concrete specimens (R1and R2) with rates of were (24.886%, 26.36%) respectively. This is due to the low percentage of fine aggregates in porous mixes (P1 and P2) compared to normal mixtures (R1 and R2), as well as the vibration rate used in conventional mixtures (R1 and R2). Where, the mixtures (R1 and R2) had a fine aggregate percentage of 100% and the use of vibrators during casting as for porous concrete mixes, the weight ratios of fine aggregates were removed 100% without the use of vibrators to preserve the pores. Furthermore, the data reveal that specimen (P2) had a lower unit weight than specimen (P1) by (5.618%).

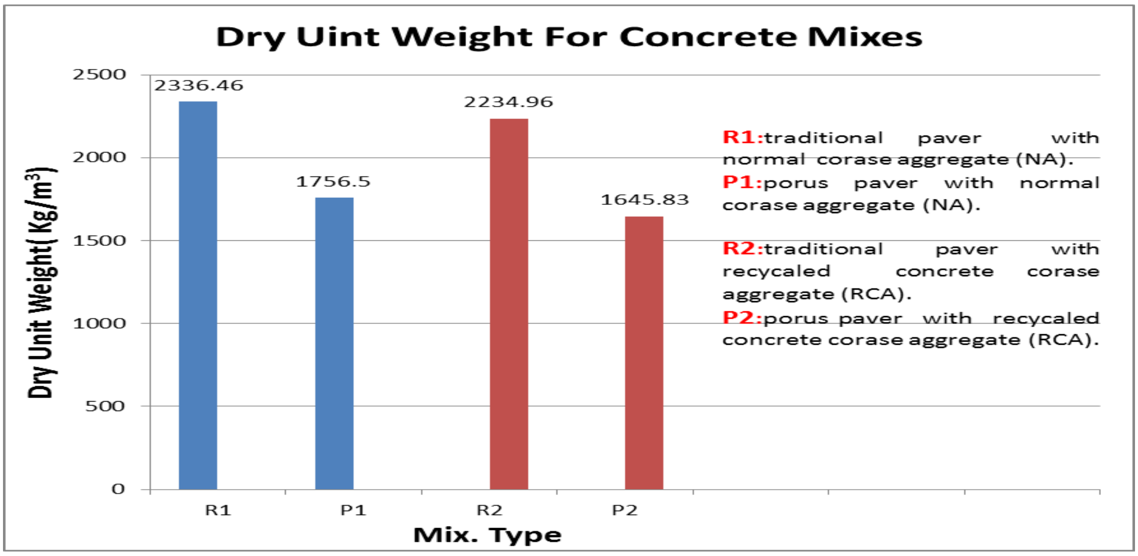

Figure 7: Density (unit weight) of porous and conventional concrete mixes.

Compressive Strength

The compressive strength of concrete, particularly porous concrete, is an essential property that indicates the quality and durability of the material. According to the British standard (BS1881 116: 1989), the compressive strength of cubes with dimensions of (100*100*100) mm and an age of 28 days was tested using three cubes for each kind of concrete mixture [26]. The results reveal that porous concrete has a lower compressive strength than conventional concrete, as the compressive strength of porous mixes (P1, P2) is (15.43, 12.36) MPa at 28 days, respectively, compared to conventional concrete (R1 and R2), as shown in Figure (8). This discrepancy is attributable to several causes, including the content and size of the gaps, because air voids and their distribution do not provide resistance and enable pressure to build upon them, weakening the internal structure of the concrete.

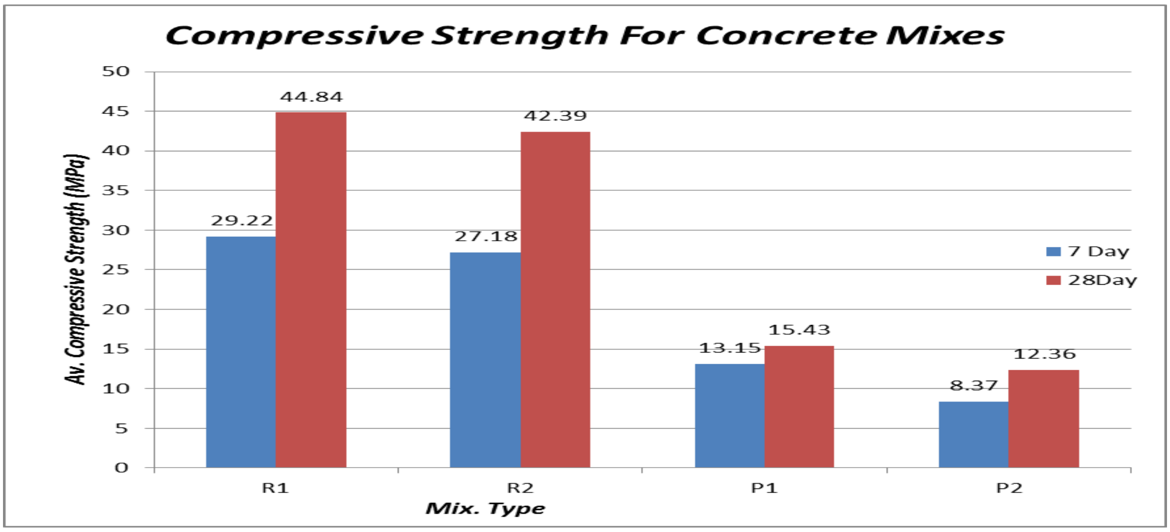

Figure 8: Compressive strength of porous and conventional concrete mixes.

Modulus of Rupture (Flexural Strength Test)

One of the most significant tests for concrete, particularly porous concrete, is the flexural strength test (fracture calibrators). This test was carried out according to the American standard specifications (ASTM C78-02) [27]. According to the test results shown in Figure (9), the porous concrete mixtures (P1 and P2) with zero fine particles the flexural strength is reduced by (37.82% and 34.01%) respectively compared by the flexural strength of the reference concrete (R1 and R2).

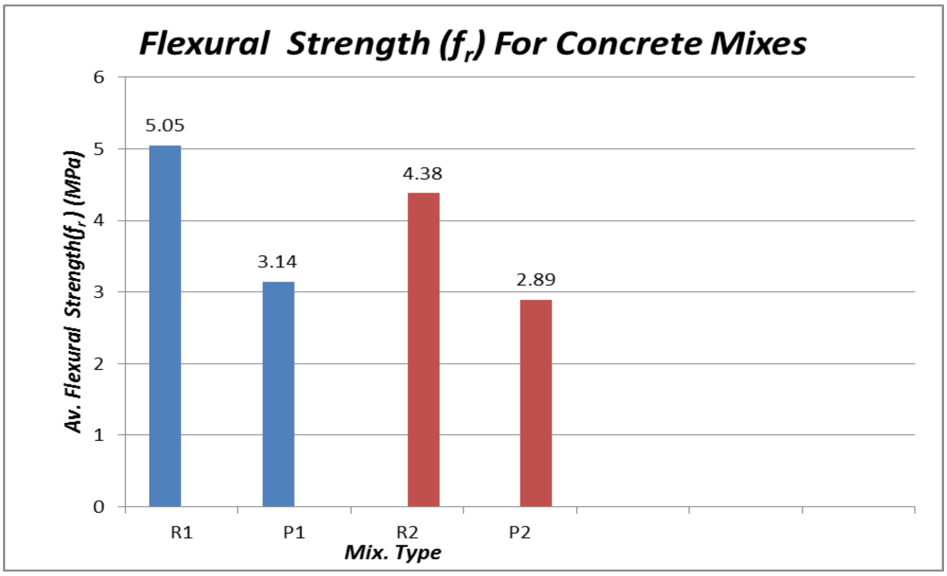

Figure 9: Flexural strength of porous and conventional concrete mixtures.

Absorption

The absorption of each kind of concrete mixture was tested using three cylindrical specimens with dimensions of (150*300) mm and an age of 28 days according to (ASTM C642-97) [28]. Figure (10) shows that the absorption value of porous concrete (P1 and P2) varies from 4.34% to 4.39% respectively, with a rising ratio of (147-138)% when compared to the absorption of conventional concrete (R1 and R2).

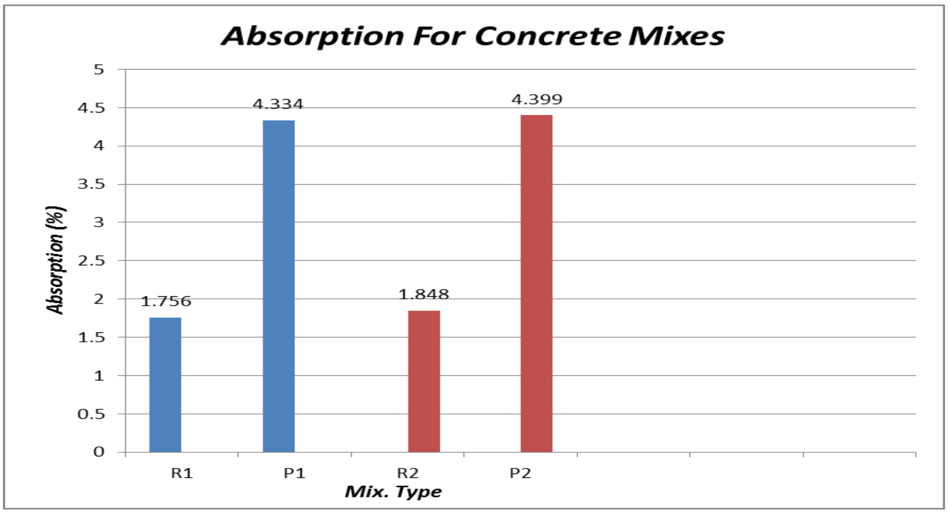

Figure 10: Absorption of porous and conventional concrete mixtures.

Total and Effective Porosity

The size of the total pores (total voids) and the size of the active pores (continuous voids) were measured for each kind of porous concrete mixture using three cylindrical specimens with dimensions of (150*300) mm and an age of 28 days, as indicated by (Tamai et al., 2004) [29]. Due to the absence of fine particles in the porous concrete mixes (P1 and P2), the total porosity of the porous concrete mixtures (P1 and P2) increased (18.31-17.65) times when compared to the total porosity of the reference mixtures (R1 and R2), as shown in Figure (11).

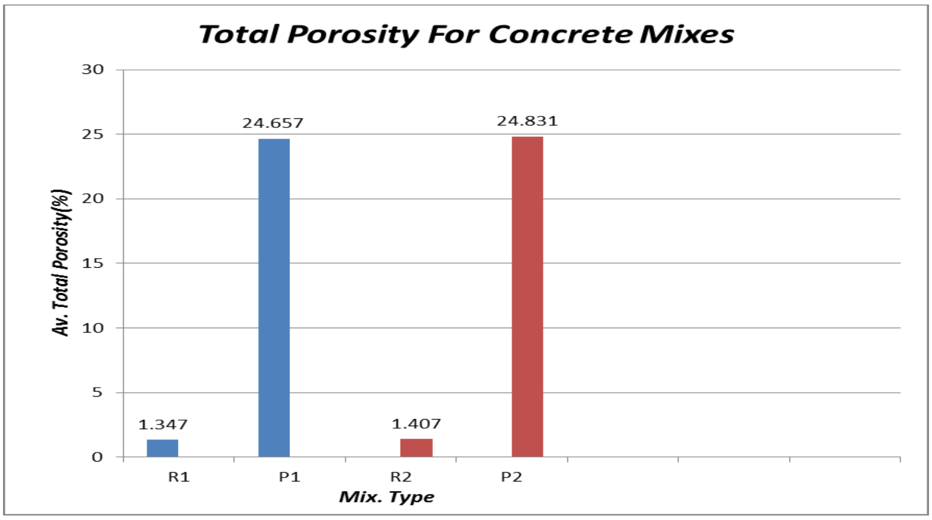

Figure 11: Total porosity of porous and reference concrete mixtures.

Permeability

The permeability coefficient, or water filtration velocity, is an essential physical property for the porous concrete sample, and it was measured using the (Falling Head) technique based on American standards using a locally produced apparatus, as shown in Figure (12).

Figure 12: Permeability measurement of porous concrete

The permeability coefficient (K) for porous concrete mixes increases with the decrease in the amount of fine aggregate. The permeability coefficients for concrete mixtures (P1and P2), with zero fine aggregate proportions, are (3.215, 3.225) m/sec as shown in Figure (13), whereas it is zero for non-porous pavement blocks, whether made of ordinary coarse aggregate (R1) or coarse aggregate recycled from concrete waste (R2).

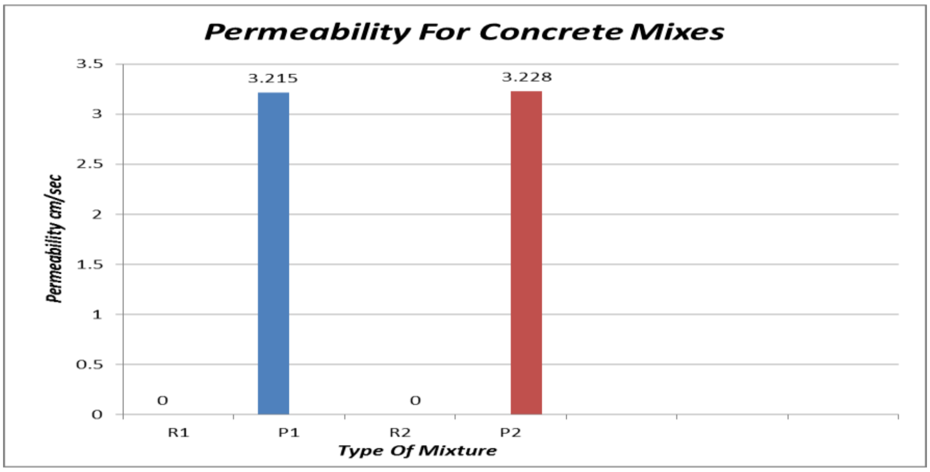

Figure 13: Permeability coefficient of porous and reference concrete mixtures.

Infiltration Results of Conventional and Porous Concrete

To test the porous concrete and see how it compares to conventional concrete in terms of water infiltration, the rainfall simulation device used in this study was tiled in a stretcher bond pattern with produced interlocking blocks of each of the models (P1, P2, R1, and R2). For each of these models, two distinct spaces (2 and 5) mm filled with river sand were employed. Three different discharge intensities of rain (20, 40, and 60) liters were utilized for each model for one minute. As a result, the volume of water penetrated to the lower part of the simulation device (cells of infiltration), as well as the surplus water (surface runoff water), were collected and measured. Table (9) shows the infiltration results for all types of interlocking blocks with a spacing of 2mm between them, whereas Table (10) shows the results with a space of 5mm between them.

Table 9.
Amount of infiltration through (porous and solid) paving with spacing 2mm during 1 min

Type	Discharge intensity (20) l/min		Discharge intensity (40) l/min		Discharge intensity (60) l/min	
	Infiltration (lit)	(%)	Infiltration (lit)	(%)	Infiltration (lit)	(%)
R1	3	15%	6.565	16.41%	10.959	18.26%
R2	3.89	19.45%	6.33	15.82%	12.37	20.61%
P1	20	100%	39.35	98.37%	59.25	98.75%
P2	20	100%	39.73	99.32%	58.76	97.93%

Table 10.
Amount of infiltration through (porous and solid) paving with spacing 5mm during 1 min

Type	Discharge intensity (20) l/min		Discharge intensity (40) l/min		Discharge intensity (60) l/min	
	Infiltration (lit)	(%)	Infiltration (lit)	(%)	Infiltration (lit)	(%)
R1	5.91	29.55%	8.23	20.57%	14.94	24.9%
R2	5.62	28.1%	9.17	22.92%	14.77	24.61%
P1	20	100%	39.84	99.6%	59.72	99.53%
P2	20	100%	39.92	99.8%	59.55	99.25%

The above results show that porous concrete enhances the infiltration rate by a significant amount for the two different spacing between the blocks. When the spacing was 2m and the rainfall intensity discharge was 20 l/min, the infiltration increased by about 85% when the porous concrete model (P1) was utilized instead of conventional concrete (R1) for the concrete mixes of these models that included normal aggregate. The increase in the infiltration was 80.55% when porous concrete with recycled coarse aggregate (P2) was used instead of normal concrete with the same coarse aggregate (R2). Furthermore, for the same rainfall intensity discharge (20 l/min) and 5mm spacing between the blocks, the infiltration increases by 70.55% when the model (P1) is used instead of (R1), and 71.9% when the model (P2) is used instead (R2). The effects of enhanced infiltration were nearly comparable for rainfall intensity discharges of 40 l/min and 60 l/min.

6. Conclusions

The current study is conducted to demonstrate the benefit of porous concrete in exploiting and harvesting rainwater that falls on urban areas, as many of the roads, parking lots, or playgrounds, as well as the corridors in residential complexes, are paved using interlocking paver blocks. Furthermore, this study demonstrated the feasibility of using concrete waste in the production of blocks that can be utilized for the aforementioned purposes. The results of the current study showed encouraging results for both sides, as follows:

1- The use of recycled concrete as a coarse aggregate instead of ordinary gravel in normal concrete mixtures had no significant effect on compression strength and flexural strength.
2- The compressive strength of porous concrete with ordinary coarse aggregate is 65.59% lower than that of conventional concrete with the same coarse aggregate, while crushed recycled concrete as coarse aggregate reduces compressive strength by 71.09% when compared to conventional concrete with the same coarse aggregate. The above ratios can be lowered by adding certain additives to porous concrete mixes.
3- The permeability of normal concrete (R1 and R2) increased from nearly zero to around 3.2 m/sec for both types of porous concrete (P1 and P2).
4- As the permeability of porous concrete increases, the infiltration test revealed that the amount of water permeated through this type of concrete increased. This suggests the possibilities of utilizing porous concrete in the process of water harvesting and decreasing rainwater flooding of streets, with the preference of using recycled concrete to save money and dispose of it, especially because it is abundant.

7. References

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