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Some Properties of Sustainable Pervious Concrete Reinforced with Carbon Fibers

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ABSTRACT

As a result of the rising amount of ceramic waste generated by demolition operations and the breaking down of ceramic products during transmission and production processes, the need to get rid of this waste increased. In addition to the importance of preserving natural resources, the trend has begun to utilize these wastes as a partial alternative to aggregates. In this research, it was studied to replace (30%) of the volume of coarse aggregate with crushed ceramic, replacing 10% by weight of cement with local metakaolin and Carbon fibers were added with (1%) by weight of the cementitious material in order to produce pervious concrete in terms of sustainability. Compressive strength, splitting, and density tests were performed. The results showed that the density of the mixture containing (30%) crushed ceramic decreased by (19.4 %) compared to the reference mixture. As for the results of the mixture containing (30%) crushed ceramic, (10%) metakaolin, and (1%) carbon fiber, it decreased compressive strength by (4.14%) and increased in splitting by (29.95 %) compared with the reference mixture at 28 days.

Keywords: Pervious concrete, Carbon fibers, Metakaolin, Ceramic waste, Density.

1. INTRODUCTION

Lightweight concrete (LWC) has been effectively employed in the construction of buildings on account of its physical characteristics, including its low weight, high thermal insulation capacity, and long durability **(Ali and Awad, 2023)**. The term "pervious concrete" refers to a type of concrete in which the fine aggregate portion has been removed. This type is gaining popularity due to some of the advantages it has over traditional concrete. When natural coarse aggregate is used to make no-fines concrete, the density may range from 1600 to 1900 kg/m^{3}, but when lightweight aggregate is utilized, the density may reach nearly 360 kg/m^{3} **(Gambhir, 2013)**. Also, it may refer to a particular concrete with high water permeability that allows water to flow via its linked prominent pore structure (**Sriravindrarajah et al., 2012)**.

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The main drawbacks of no-fine concrete are its increased permeability and decreased flexural, compressive, and bond strength **(Alwaan, 2018)**. Reducing the water-cement ratio does not increase previous concrete strength; however lowering the average aggregate size and increasing paste content accomplishes it **(Chaubey, 2020)**. In addition, the percentage of void content might vary from 15% to 35%. Usually, the compressive strengths fall between 2.8 to 28 MPa **(ACI 522R, 2010)**. Large pore sizes prevent water from flowing through the concrete matrix by capillary properties (**Salih and Fidel, 2016)**. Unlike conventional concrete, which does not allow water to drain freely. Therefore, its uses are when it's necessary to drain water from precipitation or other sources and enhance groundwater levels. A growing focus on sustainable construction is a significant factor in reviving interest in previous concrete. Due to its advantages in reducing storm-water runoff and preventing pollution **(Sabnis, 2015)**. Some applications of this type are Beach structures and seawalls, Swimming pool decks, county roads, driveways, and airports **(Li et al., 2022)**. Rural roads can be paved with no-fine concrete if it is appropriately constructed. Additionally, this particular variety of concrete can be used as a sub-base material in flexible and rigid pavements**(Fawzi and Awad, 2023)**. However, a result heading towards the production of sustainable concrete can be achieved by partially replacing cement with pozzolanic material in addition to saving money and reducing pollution by recycling waste products, which is a significant study **(Abbas et al., 2017)**. So, the majority of the most recent research that has been conducted in Iraq about construction has focused on identifying whether or not local basic materials can be utilized as alternatives for imported materials that are needed for specific practical purposes, notably those that include heat and sound insulation **(Ali and Fawzi, 2021).** Most contemporary concrete varieties must use supplemental cementitious materials to substitute cement partially. Some of these materials are derived from geological resources such as natural pozzolans and metakaolin (MK) **(Ahmed, 2021)**. In making concrete, employing metakaolin (MK) is popular due to its ease of supply and low manufacturing cost **(Kumar et al., 2023).**

(Arunchaitanya et al., 2023) investigated the mechanical properties of previous concrete by substituting metakaolin; the rate of replacement varies by 5% ranging from 0% to 20%with for a cure duration of 7 and 28 days. The mixture with aggregate size 10 mm showed the addition of 5% metakaolin resulting in a peak compressive strength of 25.87N/mm^2 with an increase in percentage over the reference mixture of 8.3 % after 28 days. 10% metakaolin content results in a maximal split tensile strength of 2.03 N/mm^2 which Increased over the reference mixture by 35.3% at 28 days.

One of the most significant challenges contemporary construction workers suffer is the accumulation of waste from construction and demolition projects **(Abdullah et al., 2022).** Solid waste recycling has become more significant due to the rapid urbanization that is reducing the availability of natural aggregate resources **(Xie et al., 2023)**. Significant quantities of construction debris cause serious environmental problems around the world. On the other hand, Approximately 20 billion tons of aggregates are used annually in the concrete industry **(Salih and Fidel, 2016)**. So, these wastes might be employed to preserve natural resources used in construction and lessen the environmental impact of this problem. Using recycled aggregate has become more popular in recent years to conserve natural resources and generate lightweight concrete **(Abbas and Abbas, 2023; Aljubori and Al-Hubboubi, 2019).**

One of these recycled materials is crushed ceramic, Products made of ceramics are among the basic building materials found in most structures. Wall and floor tiles, sanitary products, home ceramics, and technical ceramics are several types of manufactured ceramics that are frequently used **(Sofi and Bhatt, 2019)**. However, the brittle nature of ceramic materials causes a significant amount of waste to occur during processing, transportation, and fixing **(Daniyal and Ahmad, 2015)**. As a partial substitution of the coarse aggregates, the waste ceramic proportions are (10, 20, 30, 40, and 50%) for mixtures studied by **(Marshdi et al., 2021)**. The results of compressive strength showed a decrease of (22.56, 6.72, 61.22, 42.01, and 36.85 %) compared with the reference mixture, which was without waste at 28 days, respectively, with the replacement ratio. The result for the density test showed a decrease of (2.8%, 6.09%, 9.75%, 7.31%, and 10.16%) respectively, with the ratio of replacement at 28 days. studying the properties of this type, with carbon fibers was made. Carbon fibers have a density lower than 4 times that of steel, but it has a significantly high strength. Carbon fibers composites provide lightweight material with excellent structural characteristics **(Huang, 2009)**. The addition of three percentages of carbon (0.5, 1, and 1.5%) by volume of concrete mixture was studied by **(Rangelov et al., 2016)**. compressive strength results at 28 days showed an increase of (8.7, 10.76, and 5.64 %) compared with the control mixture, respectively, with volume fraction. For splitting strength the increase was by (11.11, 0, 44.44 %) at 7 days. **(Rehman, 2012)** studied examines the mechanical properties of no-fine-aggregate concrete reinforced with polypropylene and carbon fibers, with different proportions of fibers. The test results showed that adding fibers to previous concrete mixtures had no significant effect on compressive strength. With a volume fraction of (1%, 3%, and 5%), Tensile strength increased by (93%, 101%, and 129%) for polypropylene mixes and by (170%, 177%, and 220%) for carbon mixes, respectively, with volume fraction. Therefore, in this research, permeable concrete was studied as environmentally friendly concrete by reducing the consumption of natural sources such as aggregates, reducing the impact on the environment resulting from the cement industry. Some of the characteristics of this type were studied with different mixtures, especially the mixture that contains three variables together: carbon fibers, ceramic waste, and local metakaolin.

2. EXPERIMENTAL WORK

2.1 Materials

2.1.1 Cement

The OPC (CEM I- 42.5R) is tested. It was compatible with the requirements of the Iraqi specification **(IQS No.5, 2019)**

2.1.2 Coarse Aggregate

Two types of coarse aggregate Natural coarse aggregate and crushed ceramic waste from demolished houses which used after washing and crushing using a hammer to a small size and grading using sieves. These types were confirmed to Iraqi Standard Specifications **(IQS No.45, 1984)**

2.1.3 Water

The Water used for mixing and curing in this investigation met Iraqi standards **(IQS No. 1703, 2018)**

Table 1. Some properties of used aggregate

Properties	Natural aggregate	Ceramic waste	Specification
Grading	Passing 20 mm sieve and retained on 10 mm sieve	Passing 20 mm sieve and retained on 10 mm sieve	--
Dry-roded Density	1549	1002	**(ASTM C29/C29M, 2010)**
Water absorption%	0.6	1.35	**(ASTM C127-07, 2015)**

2.1.4 Metakaolin

The local Iraqi Metakaolin was used conformed to **(ASTM C 618-19, 2019)**

2.1.5 Carbon Fibers

The diameter of carbon fibers is 0.17 mm, length 15 mm and specific gravity 1.76.

2.1.6 Admixture (Superplasticizer)

A Superior Superplasticizer was used conformed to **(ASTM C494/C494M, 2019; En B.S.934-2, 2009)** as types F and G. The normal dosage range is between 0.2 to 2 liter/100 kg of cementitious material. The aim of using it is to increase compressive, and flexural strength. Also **(ACI-522R, 2010)** describes "previous concrete" typically as a near-zero-slump. So, the superplasticizer used to treat concrete by increased slump value

2.2 Preparing Concrete Mixtures

As shown in **Table 2** below, four mixtures were prepared: for reference mixture, a cement content was 415 kg/m^3, coarse aggregate to cement ratio 3:1, Water to cement ratio 0.3 and Superplasticizer 2.07kg/m^3.

Table 2. Description of prepared mixtures

Mixes Symbol	Details of mixes
MR	Reference pervious concrete
MC	Pervious concrete with 30% ceramic waste.*
MCM	Pervious concrete with 30% ceramic waste and 10 % Metakaolin**
MCMF	Pervious concrete with 30% ceramic waste, 10% Metakaolin and 1 % carbon fibers.***

*After many trials with different percentages (30,60,100)% of waste, this ratio has been selected due to its mixture giving higher compressive strength compared with other percentages.
*The percentage of metakaolin which has been adopted after 3 trials with percentages (5, 10, 15%). The mixture with 10% metakaolin gives higher compressive strength.
*** Carbon fiber percentages have been adopted based on a previous study **(Khaleel et al., 2021)**

After that, the coarse aggregate was replaced by 30% volume with crushed Ceramic; then the Cement was replaced with Metakaolin with 10% of the cementitious material weight . Finally, carbon fibers were added by 1% by weight of the cementitious material.
According to **(ASTM C192, 2002)**, hand mixing was performed with a used trowel and bowl. In mixtures that contain metakaolin, it is mixed first with cement. Mix the superplasticizer with half the amount of mixing water and add to the mixture. To prepare the mixture, add

the coarse aggregate with half the amount of water, add the cementitious materials, and then add the superplasticizer mixture. The addition of carbon fibers is done carefully to avoid agglomeration.

2.3 Casting of Specimens and Curing

Cubes of (100*100*100) mm were prepared to test compressive strength. Cylinders with dimensions of (100*200) mm were ready to test the splitting .The specimens were de-molded after 24 hrs. From casting, compressive specimens were cured in Water until the day of the test, while Specimens of splitting were cured in Water for 7 days and stayed in air dry for 21 days, then taken to test. The curing method for tensile samples was based on the notes of the tensile test specification for lightweight concrete.

2.4 Tests

2.4.1 Density

Density is determined by Eq. (1) according to **(ASTM C 567, 2010) (Fig. 1)**. After 24 hours of casting, the molds were opened and the test procedure was conducted directly. Note that molds with dimensions of (100 * 200) mm were used instead of (150 * 300) mm

Figure 1. Density test of pervious concrete mixtures. A) Oven dry B) and C) for suspension sample in water and SSD weight

$$Mesured\ oven - dry\ density = \frac{D*997}{F-G} \quad (1)$$

where D is the mass of the oven-dry cylinder (kg), F is the mass of the saturated dry cylinder (kg), and G is the apparent mass of the submerged cylinder in water (kg).

2.4.2 Compressive Strength

Three cubes are used, and the average of the results was taken at 7, 28 days by Eq. (2) according to **(En B.S.12390-3, 2002)**. The sample and device used are shown in **Fig. 2**.

$$f_c = \frac{F}{A_C} \tag{2}$$

where F is the maximum load at failure (MPa), and A_c is the cross-section area of the specimen (mm^2).

Figure 2. The sample under the compressive strength test

2.4.3 Splitting Strength

The results were taken in 28 days by Eq. (3) and complied with **(ASTM C496/C496M–11, 2011). Fig. 3 s**hows the sample under test**.**

Figure 3. The sample under Splitting strength

$$T(splitting\ strength\ , MPa) = \frac{2\,p}{\pi\,dl} \tag{3}$$

where p is the maximum applied force, (N), *l* is the span length, (mm), and *d* is the diameter of the specimen (mm).

3. RESULTS AND DISCUSSION

3.1 Density

As shown in **Table 3** and **Fig. 4** below the density of MC decreased compared with MR by 19.45% due to replacement coarse aggregate by ceramic waste. Because the Ceramic Waste were lighter than the traditional coarse aggregate, the loosely packed inner matrix may have contributed to the lower density **(Marshdi et al., 2021)**

Table 3. Density of Pervious Concrete Mixes

Mixes Symbol	Density kg/m^3	Change in density compared with Reference mixture (MR) %
MR	1876.9	-
MC	1511.8	-19.4
MCM	1554.3	-17.18
MCMF	1548.2	-17.51

Replacing cement with metakaolin in MCM led to an increase in density by a percentage of 2.8 % compared with MC. This result was that when cement is partially substituted with Metakaolin, it combines with calcium hydroxide, producing more C-S-H gel. But the density stayed less than MR.
Adding carbon fibers to the mixture MCMF resulted in reducing the density by a percentage of 17.51 % compared with MR. The decrease in density after adding carbon fibers was consistent with a research result **(Rehman, 2012).**

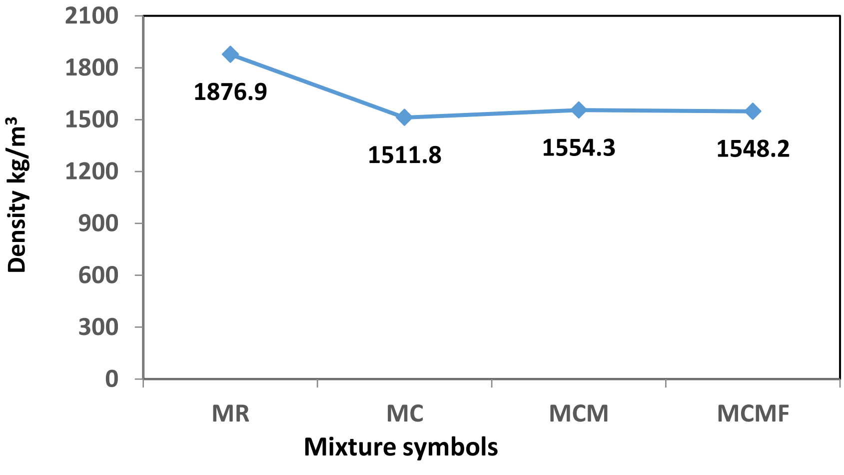

Figure 4. Density of pervious concrete mixtures

3.2 Compressive Strength

As shown in **Table 4** and **Fig. 5** below the compressive strength MC decreased compared with MR by (26.85 and 14.28 %) at 7 and 28 days respectively due to the replacement of coarse aggregate by ceramic waste which caused poor bounding between cement paste and ceramic waste especially from the Glazed side.

Table 4. Results of compressive strength

Mixes Symbol	Compressive strength MPa		Change in compressive strength compared to the reference mixture (MR)%	
	7 days	28 days	7 days	28 days
MR	10.13	14.7	---	---
MC	7.41	12.60	-26.85	-14.28
MCM	8.33	13.06	-17.77	-11.15
MCMF	8.84	14.09	-12.73	-4.14

Replacing cement with metakaolin in MCM led to an increase in Compressive strength by a percentage of 12.4, 3.65 % compared with MC. At 7 and 28 days respectively

This result was that when cement is partially substituted with Metakaolin, it combines with calcium hydroxide, producing more C-S-H gel. The primary cause of strength development in cement and cement-based concrete is C-S-H gel **(AL-Jumaily et al., 2015)**. But the compressive strength stayed less than MR. Adding carbon fibers in the mixture MCMF resulted in increasing the compressive strength by a percentage of 6.12 and 7.88 % compared with MCM at 7 and 28 days, respectively. But the compressive strength stayed less than MR.

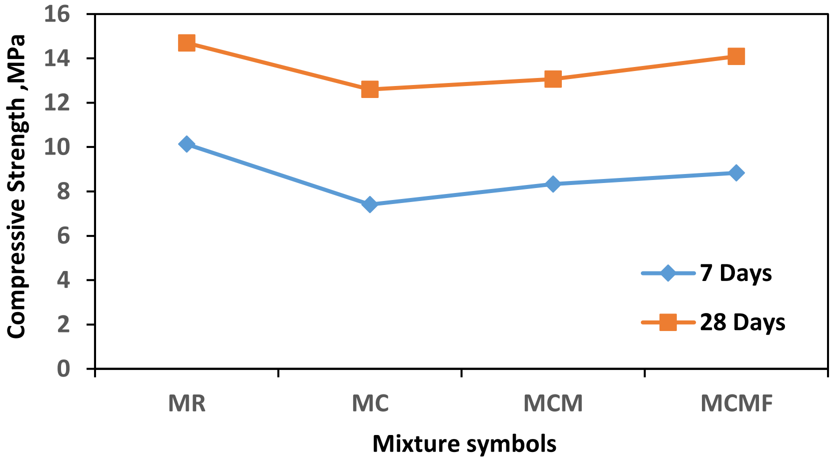

Figure 5. Compressive strength of pervious concrete mixtures

3.3 Splitting Strength

As shown in **Table 5** and **Fig. 6** below the results showed that the Splitting strength of MC decreased due to replacement coarse aggregate by ceramic waste. Replacing cement with metakaolin in MCM led to a decrease in splitting strength by a percentage of 6.91% compared with MR.

Table 5. Results of splitting strength of pervious concrete mixtures

Mixes Symbol	Splitting strength MPa	Change in Splitting strength compared to the reference mixture (MR), %
MR	2.17	--
MC	1.66	-23.50
MCM	2.02	-6.91
MCMF	2.82	29.95

When comparing MCM with MC, it was noted that the replacement with metakaolin had a good effect in the presence of ceramic waste Where the splitting strength increased by 21.6%. Adding carbon fibers in the mixture MCMF resulted in increasing the splitting strength by a percentage of 29.95 % compared with MR

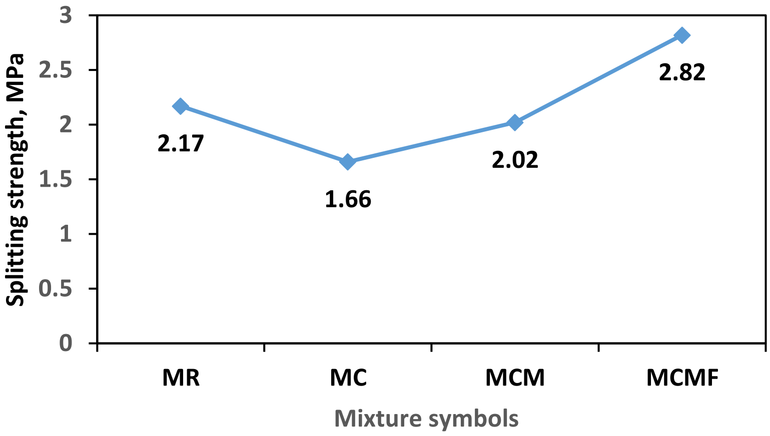

Figure 6. Splitting strength of previous concrete mixtures.

4. CONCLUSIONS

As a result of the characteristics of porous concrete, the most prominent of which is its lightweight, this research focused on producing porous concrete mixtures sustainably to reduce environmental pollution through recycling ceramics and using local metakaolin. Based on the experimental results,

- Replacing (30%) of the volume of aggregate with crushed ceramic reduced the compressive strength by (14.28%) and splitting strength by (23.50%) compared with the reference mixture at 28 days.
- Replacing (30%) of the volume of aggregate with crushed ceramic and replacing (10%) of the weight of cement with metakaolin reduced the compressive strength by (11.15%) and splitting strength by (6.91%) at 28 days.
- Replacing (30%) by the volume of aggregate with crushed ceramic, replacing (10%) by the weight of cement with metakaolin and adding carbon fibers with 1% by weight of cementitious material reduced the compressive strength by (4.14%) and increased splitting strength by (29.95%) at 28 days**.**
- The density of the mixture with (30%) by volume of aggregate crushed ceramic, replaced (10%) by the weight of cement with metakaolin and added carbon fibers with 1% by weight of cementitious material reduced by (17.51%) compared with the reference mixture.

Credit Authorship Contribution Statement

Demoa Jawad Kazem: Investigation, Formal analysis, Writing –original draft. Nada Mahdi Aljalawi: Supervision, Writing –review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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بعض خصائص الخرسانة النفاذة المستدامة المسلحة بألياف الكاربون

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الخلاصة

نتيجة لارتفاع كمية مخلفات السيراميك الناتجة عن عمليات الهدم وتكسر منتجات السيراميك أثناء عمليات النقل والإنتاج، زادت الحاجة للتخلص من هذه المخلفات. بالإضافة إلى أهمية الحفاظ على الموارد الطبيعية، فقد بدأ الاتجاه لاستغلال هذه المخلفات كبديل جزئي للركام. تم في هذا البحث دراسة استبدال(30%) حجماً من الركام الخشن بالسيراميك المكسر واستبدال(10%) وزناً من الأسمنت بالميتاكاولين المحلي و إضافة ألياف الكربون بنسبة(1%) وزناً من المادة الأسمنتية لتحقيق انتاج الخرسانة النفاذة المستدامة. تم إجراء اختبارات قوة الضغط ومقاومة الشد غير المباشر والكثافة. أظهرت النتائج أن كثافة الخليط المحتوي على (30%) سيراميك مكسر انخفضت بنسبة 19.4% مقارنة بالخليط المرجعي. أما بالنسبة لنتائج الخلطة التي تحتوي على (30%) سيراميك مكسر، (10%) ميتاكاولين،(1%) ألياف كربون، فقد انخفضت قوة الضغط بنسبة(4.14%) وازدادت في الشدغير المباشر بنسبة (29.95%) مقارنة بالخليط المرجعي عند 28 يوماً.

الكلمات المفتاحية: الخرسانة الخالية من الرمل ,الياف الكاربون , ميتاكاولين, مخلفات السيراميك, الكثافة.