Available online at www.CivileJournal.org

Civil Engineering Journal

(E-ISSN: 2476-3055; ISSN: 2676-6957)

Vol. 10, No. 09, September, 2024

Experimental Investigation on Pervious Recycled Aggregate Concrete Made of Waste Porcelain

Ganjeena J. Khoshnaw [1, 2], Khaleel H. Younis [1], Waleed A. Hamad [3*], Ayser J. Ismail [3], Glpa Ali Mahmood Jukil [4], Firas F. Jirjees [1], Hozan K. Yaba [1], Shelan M. Maruf [1]

[1] *Department of Road Construction, Erbil College of Technology-Erbil Polytechnic University, Erbil, Iraq.*

[2] *Department of Civil Engineering, Tishk International University, Erbil, Iraq.*

[3] *Department of Construction Materials and Technology, Erbil College of Technology, Erbil Polytechnic University, Erbil, Iraq.*

[4] *Highway and Bridge Engineering Department, Erbil Technical Engineering College, Erbil Polytechnic University, Erbil, Iraq.*

Received 09 June 2024; Revised 17 August 2024; Accepted 22 August 2024; Published 01 September 2024

Abstract

The current study examines the physical, mechanical, and durability of eco-efficient pervious concrete produced with partial and complete substitutions of natural aggregate (NA) by recycled aggregate (RA) waste from demolished concrete and porcelain. The experimental investigation assessed the workability (slump test), compressive strength, flexural strength, and tensile strength along with the concrete's water permeability, impact, and abrasion resistance. Seven mixes were examined; the first is a control mix with natural aggregate, and the other six are made with various RA ratios, including 30%, 70%, and 100%. The sand was also fully replaced by waste porcelain, even though the ratio of sand used in pervious concrete was low. The results revealed that using waste concrete and porcelain adversely affected the workability of fresh pervious concrete mixes, reducing it by approximately 14%. Furthermore, a decrease in the strength of pervious concrete was noticed, especially in the splitting tensile strength, where the reduction reached 32%. Moreover, the impact resistance of pervious concrete made with RA reduced by 29% compared to that made with NA; the same applies to durability, with an increase of 20% in weight loss. On the other hand, using both recycled concrete and recycled porcelain improved the permeability of the pervious concrete, which reached 30%. Pervious concrete made with waste concrete and porcelain can be an acceptable alternative to that made from natural aggregate due to its improved water permeability and positive environmental impact. However, further investigation is important to consider strength and durability enhancement.

Keywords: Pervious Concrete; Waste Porcelain; Recycled Coarse Aggregate; Concrete Mechanical Properties; Impact Resistance of Concrete; Abrasion and Workability of Concrete.

1. Introduction

For a very long time, the construction industry has been using concrete as a building material. This is because it is inexpensive, versatile, and easy to form. Nevertheless, concrete has been blamed for producing a significant quantity of CO2 throughout its manufacturing, extraction, and transportation phases. This emission raises environmental and sustainability problems [1]. Pervious concrete (PC) is a new type of eco-friendly concrete. PC research and applications started in the 1970s in the United States and Europe; it is made with a water/cement (w/c) ratio of 0.25-0.35 with little or no fine materials. It contains 15-25% porosity, a compressive strength of 3-30 MPa, and a permeability of 0.025-0.61

* Corresponding author: walid.hamad@epu.edu.iq

http://dx.doi.org/10.28991/CEJ-2024-010-09-08

cm/s [2, 3]. There will be a considerable demand for this material in construction, resulting in significant consumption of natural aggregates [4-6].

The massive build-up of construction and demolition waste (CDW) is another environmental issue associated with the construction sector. Nowadays, these kinds of problems are acknowledged globally. The shrinkage of landfill areas and the depletion of raw material supplies are two of these problems [7-9]. There are several strategies to lessen the detrimental effects of these environmental problems. Among these strategies is the reusing or recycling of CDW to replace conventional aggregate, as fine or coarse aggregate is an additional method. One example of this would be the recycling of crushed concrete into coarse aggregate during the process of creating concrete. Furthermore, this contributes to the preservation of our natural environment and improves the potential of concrete to be sustainable [8].

Porcelain is an emerging type of ceramic that is extremely resistant to heat and pressure; however, waste porcelain ceramics cannot be recycled for reuse in plant production lines and are eventually discarded in the environment [10]. An enormous amount of porcelain waste (PW) is produced annually, including sanitary porcelain waste, and efforts are made to use these leftovers in the manufacturing of concrete [10]. Moreover, the CDW aggregates come in a variety of fragment sizes; in addition, they are of extra porosity than those of crushed rocks, which are commonly used in producing normal concrete. As predicted, CDW's substantial porosity is thought to produce permeable concretes, lowering its mechanical strength and altering the material's protective function toward steel corrosion, causing significant structural problems. Yet, what is considered an imperfection in reinforced concrete made with CDW aggregates might be seen as advantageous in the construction of pervious pavements, where the goal is to raise the material's ability to drain. This pavement is commonly used in parking lots, residential streets, low-traffic regions, and sidewalks [11, 12].

On one hand, recycled aggregate concrete (RAC) is a concrete made with recycled coarse aggregate (RCA). While using RCA to produce RAC has advantages over natural aggregate concrete (NAC) concerning sustainability and impact on the environment, its performance is worse [13]. There have been rumors that NAC performs better than RAC. Both fresh and hardened concrete are affected by RCA. Recycled concrete aggregate diminishes both the mechanical properties and workability of concrete. Concrete strengths, including compressive, flexural, and splitting tensile values, may be up to 40%, 25%, and 20% lower, respectively, when compared to NAC [14]. This may be caused by RCA's porous nature. and absorbability that raises the aggregate's water demand significantly and necessitates the addition of more water. This will increase the water-binder ratio significantly and reduce the concrete's strength [13, 15]. The experiment results for high-strength recycled aggregate concrete show that the adhesion of mortar to recycled aggregates, as well as the amount of recycled aggregate used, have a significant impact on the strength of concrete [16]. The use of mineral admixtures and fiber strengthens the bond, significantly increasing the strength of concrete [16, 17].

On the other hand, PW can be useful when used as a fine material in concrete. It may improve concrete's mechanical properties while reducing its workability [18]. The influence of replacing coarse aggregate using three different waste ceramic tile materials at replacement ratios of 20%, 25%, 35%, 50%, 65%, 75%, 80%, and 100% in concrete was assessed by a previous study. The findings showed that waste ceramic can be substituted for natural coarse aggregate without significantly altering its mechanical characteristics. [19]. Another study examined the possibility of using porcelain polishing residue (PPR) as a partial substitution for cement in the making of concrete at 5%, 15%, and 30% levels. The findings revealed that replacing cement with PPR at a certain level improves concrete performance, but increasing the replacement level had a negative impact on concrete properties and performance [20].

The feasibility of using PW as coarse aggregates at contents of 25%, 50%, 75%, and 100% of the natural coarse aggregates in self-compacting concrete SCC was also examined [21]. The authors investigated the workability, mechanical properties, and durability behavior of SCC with and without PW. The findings of the experiments showed that the integration of PW had a favorable influence on the workability, mechanical characteristics, and durability of SCC and that this effect was positive. Particularly noteworthy is the fact that the SCC mixture that included 25% PW exhibited remarkable performance, obtaining the greatest compressive strength of 64.9 MPa after 28 days. In addition, the drop in compressive strength remained below 5% even after considering the possibility of 100% substitution [21].

Alshahwany et al. [22] examined the potential for replacing natural coarse aggregates with coarse aggregates created from ceramic waste on the mechanical properties of concrete. Three distinct maximum aggregate sizes (12.5, 19, and 25 mm) were used, and three levels of partial replacement of natural coarse aggregate (25, 50, and 75%) were evaluated. The findings demonstrated that as the maximum aggregate size increases, the hardened densities, compressive and splitting tensile strengths, and rate of water absorption decrease. These trends hold true regardless of the substitution rate of ceramic waste aggregate. Nevertheless, regardless of the maximum aggregate sizes, the mixture that included 25% ceramic coarse aggregate exhibited a little enhancement in mechanical qualities. The compressive strength improvement ratios at 28 days were 3.7% compared to the reference mixture. However, at contents more than 25% of ceramic waste, the strength slightly decreased [22].

According to our knowledge, very few studies have examined the performance of pervious concrete utilizing PW and RAC in Iraq. Therefore, the objective of the current study is to investigate and assess the fresh and mechanical performance of pervious concrete using PW and RCA in addition to replacing natural fine aggregate with waste fine porcelain. Workability, compressive strength, flexural strength, splitting tensile strength, water permeability, abrasion resistance tests (Bohme abrasion), and impact resistance were performed for the investigation and evaluation.

2. Materials, Methodology and Experimental Testing

2.1. Materials

2.1.1. Cement

The present study used ordinary Portland cement (OPC)/CEM I type that complied with BS EN 197 standards [23]. Tables 1 and 2 show the OPC's chemical composition and physical characteristics, respectively, as given by the manufacturer.

Table 1. OPC chemical composition

Materials	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	Na_2O
CEM I	21.04	4.83	3.01	66.5	0.76	2.65	0.35	0.52	0.56

Table 2. OPC physical characteristics

Property	OPC
Specific gravity	3.15
Fineness (m^2/kg)	446
Initial setting time (min.)	100

2.1.2. Natural Sand

Sand from Aski Kalak was used and it had a density of 2.65 gm/cm^3 and water absorption of 1%. In this study, only 6% of sand was used by weight from the total aggregate for making the pervious concrete mixes. The gradation analysis of the sand is shown in Figure 1 for sieves (4.75 mm, 2.36 mm, 0.6 mm, and 0.15 mm).

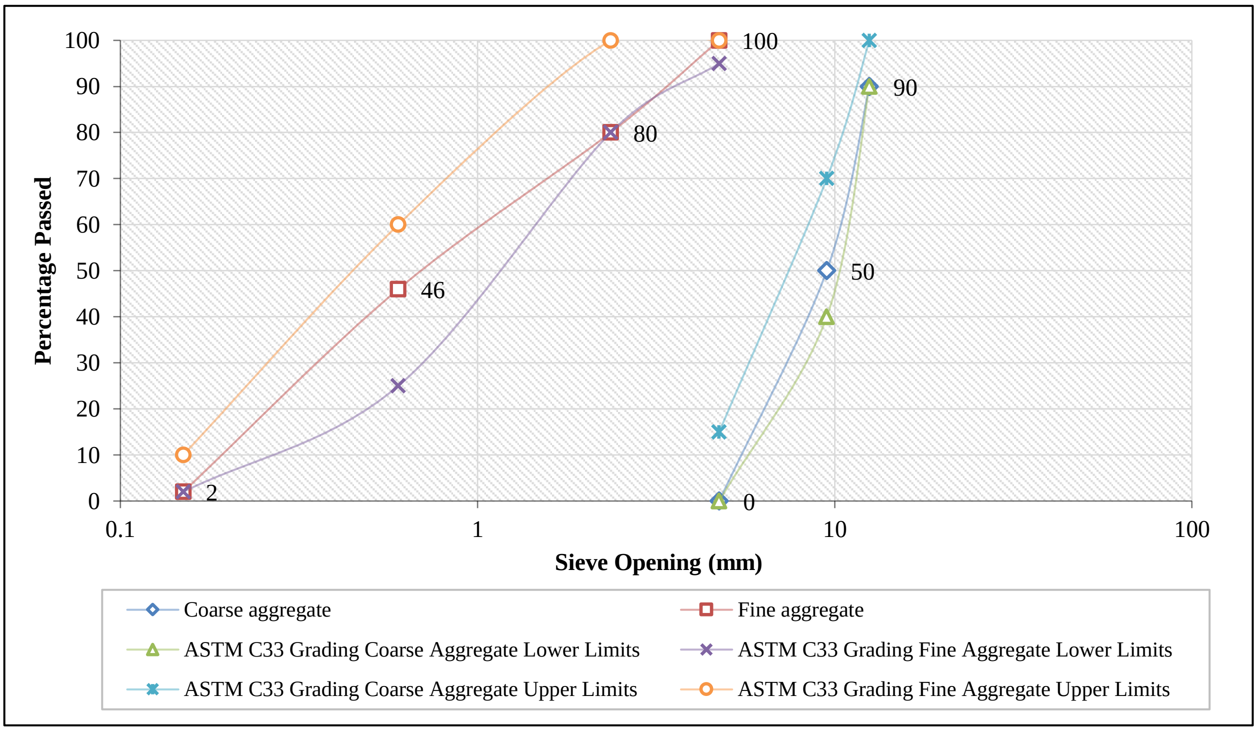

Figure 1. Fine and coarse aggregate gradation curve with passing ratios

2.1.3. Fine Aggregate Porcelain

Waste porcelain from old buildings with a density of 2.265 gm/cm^3 and water absorption of 0.57% was used to replace the natural sand according to the mix design and parameters of this study (same gradation of natural sand).

2.1.4. Natural Aggregate

Granular aggregate from Aski Kalak washer plants was used and had a density of 2.67 gm/cm^3 and water absorption of 0.7%. The gradation analysis of the coarse aggregate is shown in Figure 1 for sieves (16mm, 12.5mm, 9.5mm, and 4.75mm).

2.1.5. Recycled Concrete Aggregate

Waste concrete demolished from old buildings with a density of 2.45 gm/cm^3 and water absorption of 5.34% was used at three different rates replacing the natural coarse aggregate according to the mix design and parameters of this study (same gradation of natural aggregate).

2.1.6. Waste Porcelain

Waste porcelain from old buildings with a density of 2.29 gm/cm^3 and water absorption of 0.57% was used at three different rates replacing the natural coarse aggregate according to the mix design and parameters of this study (same gradation of natural aggregate).

2.1.7. Water

Drinking water from the water supply project was used at a constant rate of w/c.

2.2. Methodology

The study methodology consisted of replacing the coarse NA with (RA and PW) at three rates (30%, 70%, and 100%). It also involves replacing the fine aggregate with fine PW by 100%.

Samples prepared in cubic 10×10×10 cm shape for compressive testing according to BS EN 12390-3 [24], prism samples 10×10×40 cm for flexural testing according to the BS EN 12390-5 [25], 10×20 cm cylinders prepared for permeability according to ASTM D5084-03 [26], and also for splitting tensile tests according to BS EN 12390-6 [27]. In addition, cylindrical discs (15.24cm diameter and 6.35 cm height) were prepared for impact resistance according to the ACI 544.2R-89 standard test [28], also 7×7×7 cm cubes were prepared for the abrasion test according to BS EN 14157 [29]. Three samples were prepared for each test. The tests were done for concrete samples at 28 days of age following the curing process according to BS EN 12390-2 [30].

The practical works included preparing seven mixes, details of the mixes which include the code of each mix and the study variables are shown in Table 3. Table 4 displays the mix proportions details for all mixes which had a constant water/cement ratio of (0.32). Figure 2 shows a flow chart for the experimental work.

Table 3. Code of mixes and variables of the study

Mix code	Mix Designation	Cement	Coarse aggregate (Natural)	Recycled Concrete coarse aggregate	Waste porcelain coarse aggregate	Natural Sand Fine aggregate	Porcelain Fine aggregate
M1	R0PC0PF0	100%	100%	0%	0%	100%	0%
M2	R15PC15PF0	100%	70%	15%	15%	100%	0%
M3	R35PC35PF0	100%	30%	35%	35%	100%	0%
M4	R50PC50PF0	100%	0%	50%	50%	100%	0%
M5	R15PC15PF100	100%	70%	15%	15%	0%	100%
M6	R35PC35PF100	100%	30%	35%	35%	0%	100%
M7	R50PC50PF100	100%	0%	50%	50%	0%	100%

Table 4. Mix proportions in (kg/m^3)

Mix code	Cement	Water	Coarse aggregate (Natural)	Recycled Concrete coarse aggregate	Waste porcelain coarse aggregate	Natural Sand Fine aggregate	Porcelain Fine aggregate
M1	400	128	1381.80	0.00	0.00	88.20	0.00
M2	400	128	967.26	190.19	177.77	88.20	0.00
M3	400	128	414.54	443.78	414.80	88.20	0.00
M4	400	128	0.00	633.97	592.57	88.20	0.00
M5	400	128	967.26	190.19	177.77	0.00	75.39
M6	400	128	414.54	443.78	414.80	0.00	75.39
M7	400	128	0.00	633.97	592.57	0.00	75.39

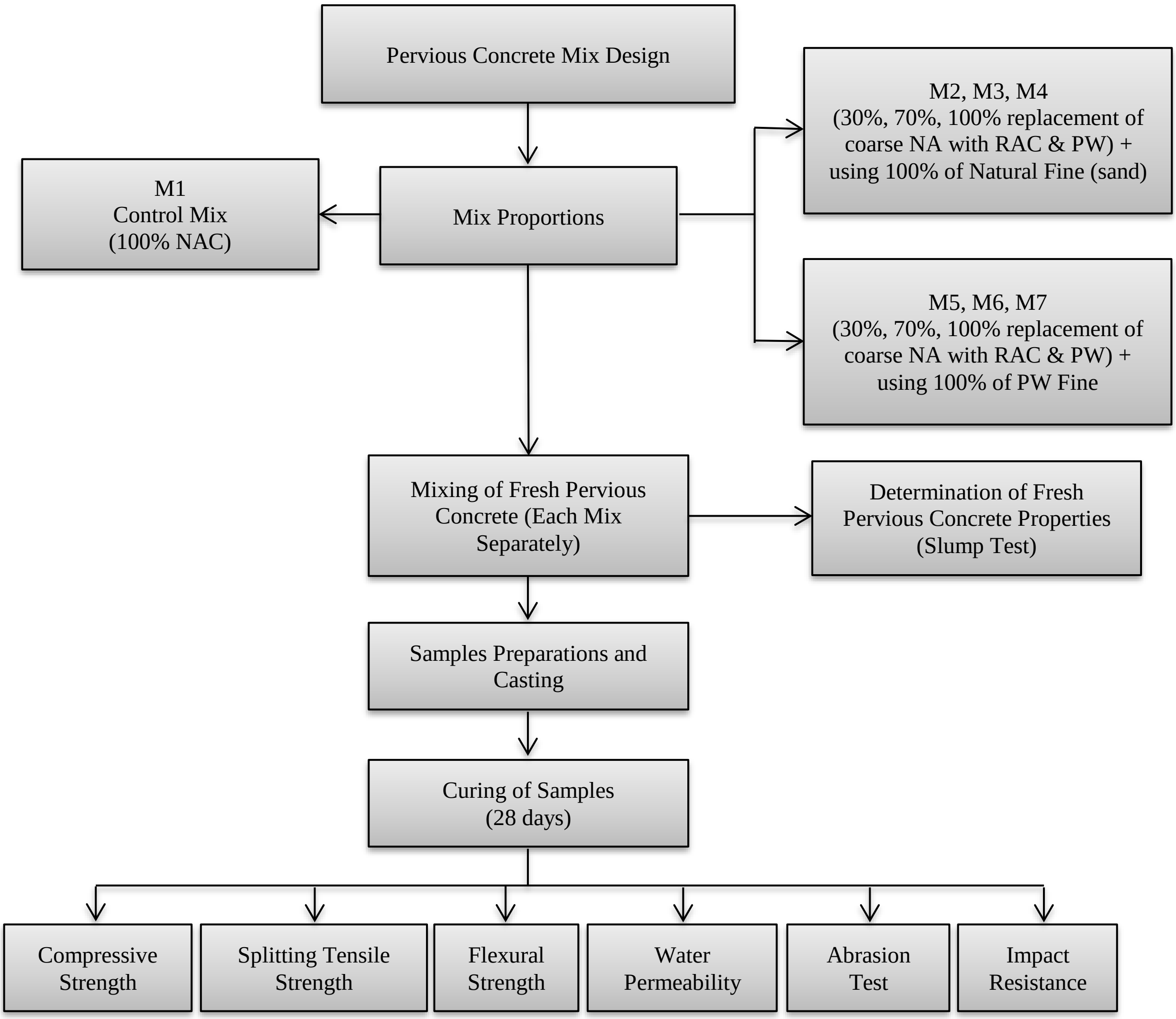

Figure 2. Flowchart for the experimental work

2.3. Experimental Testing

2.3.1. Workability

Standard slump test as shown in Figure 3, all mixes were evaluated for their workability by adopting the BS EN 12350-2 [30].

Figure 3. Slump test

2.3.2. Compressive Strength Test

Standard compressive strength machine used as shown in Figure 4 and according to the BS EN 12390-3 [24]. The 10×10×10 cm cube specimens were evaluated for compression after 28 days of curing.

Figure 4. Standard compressive strength testing machine

2.3.3. Splitting Tensile Strength Test

Standard splitting tensile strength machine used as shown in Figure 5 and according to the BS EN 12390-6 [27]. The 10×20 cm cylinder specimens were tested to assess the tensile strength after 28 days of curing.

Figure 5. Standard splitting-tensile strength testing machine

2.3.4. Flexural Strength Test

Standard flexural strength machine consists of 4-point loading over a span of 300 mm used as shown in Figure 6 and according to the BS EN 12390-5 [25]. The 10×10×40 cm prism specimens were tested to assess flexural strength after 28days of curing.

Figure 6. Standard flexural strength testing machine

2.3.5. Water Permeability Test

The apparatus used for the impact resistance test is shown in Figure 7 and according to ASTM D5084-03 [26].The (10×20)cm cylinder specimens were evaluated for water permeability after 28 days of curing. Water from a standpipe flows through the specimen, and the initial head difference (h1) at time t=0 was recorded. The final head difference at time t=t2 (h2) was also recorded, and the coefficient of permeability was calculated using Equation 1:

$$k = 2.303 \frac{aL}{At} log_{10} \left(\frac{h1}{h2}\right) \quad (1)$$

where k = coefficient of water permeability (cm/s), a =inside cross-sectional area of standpipe, cm^2 ($a = \frac{\pi}{4} d^2$), d = inside diameter of standpipe, L = Length of the sample, cm, A = cross-sectional area of test specimen, cm^2 ($A = \frac{\pi}{4} D^2$), D = inside diameter of permeameter, t = elapsed time of test, s, h1 = water head in the standpipe at time t=0, cm, h2 = water head in the standpipe at a time equal to t_2, cm.

Figure 7. Falling head permeability test

2.3.6. Impact Resistance Test

Figure 8 shows the machine used for the impact resistance test. The cylindrical discs specimens of 152.4 mm diameter and 63.5 mm height were evaluated for impact resistance after 28 days of curing based on the ACI 544.2R-89 standard test [28]. The test involved repeatedly applying impact load in the form of blows with a 4.54 kg compaction hammer dropped from a height of 457 mm onto a ball made of steel with a diameter of 63.5mm placed in the center of the disc's top surface. The number of blows (N1) and (N2) that caused the first apparent crack and failure of the specimen was recorded. The impact resistance energy was calculated using Equation 2.

$$IE= N \times g \times m \times h \quad (2)$$

where IE= Impact energy resistance (N.m), N=Number of blows, g= Acceleration gravity (N/kg) = 9.81 N/kg, m: Hummer mass (kg) = 4.57 kg, and h: Height of drop (m)= 0.457 m.

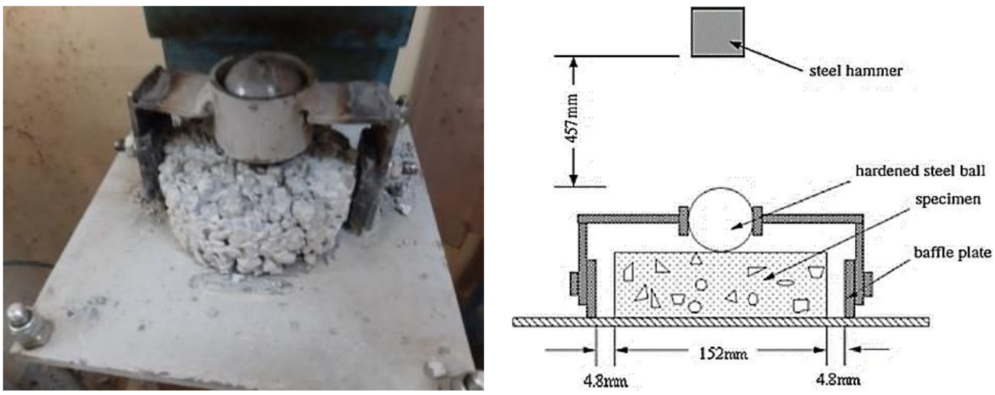

Figure 8. Concrete impact resistance testing machine

2.3.7. Abrasion Resistance Test

Figure 9 depicts the machine used in the Bohme abrasion resistance test. The 70×70×70 mm cube specimens were used to evaluate the abrasion resistance of different concrete mixtures examined in this study [29]. The weight-loss of the cubic specimens was determined after 22 cycles of a steel plate with a diameter of 750mm. The test was repeated 4 times, in which 20g of standard abrasive sand was placed on the test mark each time, and after each cycle, the sample was weighed to an accuracy of 0.1 g, and the front face was cleaned and rotated by 90°.

Figure 9. Concrete abrasion resistance testing machine

3. Results and Discussions

Normally pervious concrete has lower mechanical properties than traditional concrete due to the higher air void rate and porosity while using natural aggregates. Seven mixtures were developed in different replacement ratios of coarse and fine recycled concrete and porcelain aggregates as shown in Table 5 which displays the results of workability, mechanical properties, and permeability of all investigated mixtures.

Table 5. The experimental test results for the investigated mixes

Mix Type	Abrasion (Weight Loss %)	Slump (mm)	Impact resistance (N.m)		Comp. Strength (MPa)	Split Strength (MPa)	Flexural Strength (MPa)	Coefficient of Permeability (K) (cm/sec)
			IE1	IE2				
Mix#1	1.16	35	379.0	532.5	18.4	2.06	2.54	0.44
Mix#2	1.26	35	358.5	502.0	16.49	1.78	2.44	0.51
Mix#3	1.28	30	327.5	440.5	15.75	1.67	2.25	0.52
Mix#4	1.35	30	266.5	399.5	14.40	1.48	2.15	0.56
Mix#5	1.27	35	384.5	481.5	15.90	1.68	2.33	0.52
Mix#6	1.33	30	317.5	409.5	14.90	1.50	2.17	0.54
Mix#7	1.40	30	245.5	379.0	14.07	1.40	1.95	0.57

3.1. Workability

The impact of the use of recycled coarse and fine aggregates on the workability of the pervious concrete is shown in Figure 10. In this figure, it is shown that the slump value of Mix#1 was 35 mm and the rest of the mixes displayed lower slump values. This is because of the use of recycled aggregate which has higher water absorption and angular shape [8, 31, 32]. The porcelain particles have sharp edges and angles which reduces the workability of concrete. Similarly, the rough texture of the recycled concrete aggregate absorbs more water and reduces the workability; therefore, the lowest workability value was found with Mix#7 and it was lesser than the control Mix#1 by 14%. Similar behavior was also observed by other studies [18, 19] as the waste porcelain had a negative effect on the workability highlighting the influence of the sharp edges and angular shape of the porcelain particles.

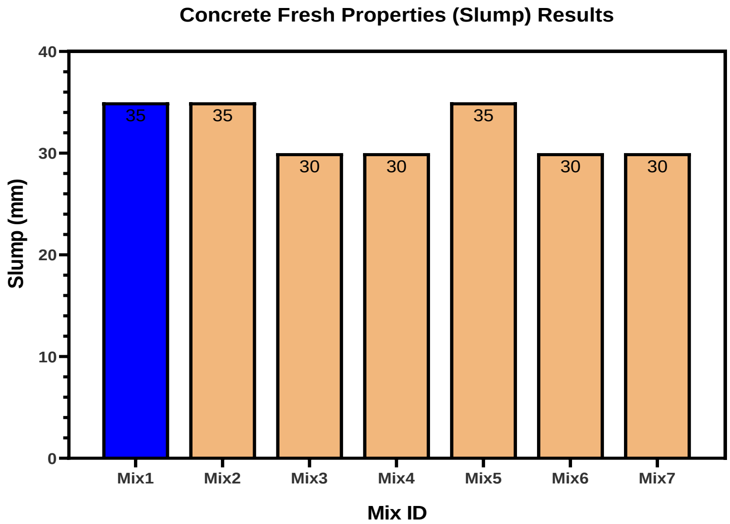

Figure 10. The rate of flow for the investigated mixes

3.2. Compressive Strength

Compressive strengths for different types of pervious concrete mixtures are demonstrated in Figure 11. According to the results, Mix#1which includes natural coarse and fine aggregates has the highest compressive strengths due to the particle shape regularity and surface texture components of aggregate which is more homogeneous. In Mix#2, when the recycled aggregate replaced the natural aggregate, an expected negative impact on the concrete strength is clear as shown in Figure 11. Previous studies [6, 8, 33] observed a similar trend of compressive strength decline. Such a decrease trend in compressive strength was also reported by Sua-iam & Jamnam [21] and Alshahwany et al. [22] but with higher reduction rates at higher replacement ratios (50% and 100%) [21, 22].

The lowest results were obtained from Mix#7 which contains 100% recycled coarse and fine aggregates. The effect of using recycled coarse aggregates (both concrete and porcelain) can be identified in the mixes (#2 to #4). The increase of the content of the recycled coarse aggregates from 0 to 100% reduces the compressive strength from 18.4 MPa to 14.4 MPa. The effect of the recycled fine aggregate combined with the coarse recycled aggregate can be shown in the results of mixes 5 to 7. The addition of the recycled fine aggregate decreased the compressive strength in comparison with Mix#1. For example, the strength of mix Mix#7 decreased from 18.4 MPa to 14.07 MPa which represents a reduction of 24%. This decrease in compressive strength can be attributed to the smoothness of the particle surface of the recycled porcelain, as well as the weak bond that occurs between the aggregate and the cement paste [18, 22].

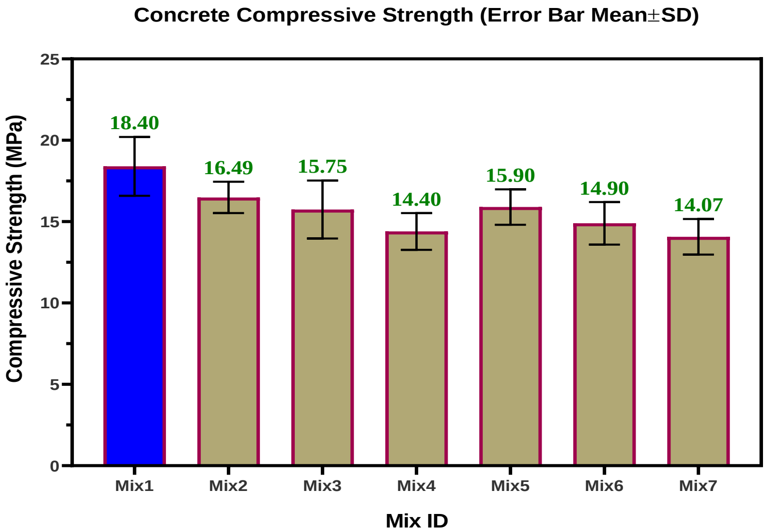

Figure 11. Compressive strength for the investigated mixes

3.3. Splitting Tensile Strength

The splitting-tensile strengths of several types of pervious concrete mixes are displayed in Figure 12. Based on the findings, Mix#1 which consists of natural coarse and fine aggregates, has the highest tensile strength. This might be assigned to the regularity of particle shape and the surface texture components of the aggregate, which contribute to a more uniform composition [5, 8, 31]. The concrete tensile strength is affected by the replacement of natural aggregate with recycled aggregate in the Mix#2. The lowest outcomes were achieved from Mix#7, which comprised entirely of recycled coarse and fine aggregates.

The impact of utilizing recycled coarse aggregates, including both concrete and porcelain, may be observed in the mixtures ranging from 2 to 4. The splitting tensile strength decreases from 2.06 MPa to 1.48 MPa when the proportion of recycled coarse aggregates increases from 0% to 100%. The impact of including the reused fine aggregate in conjunction with the reused coarse aggregate is seen in the outcomes of mixes 5 to 7. The inclusion of the recycled fine aggregate resulted in a small reduction in the splitting tensile strength. For instance, the strength of mix 2 reduced from 1.78 MPa to 1.40 MPa. The highest strength reduction as compared to Mix#1 was 32% as observed for Mix#7. Splitting tensile strength of the concrete incorporating waste porcelain has been found to decrease in previous research as well [18]. This weakening tendency was also noted by Alshahwany et al. [22], however at 50% and 100% replacement ratios, the decline was more rapid [22].

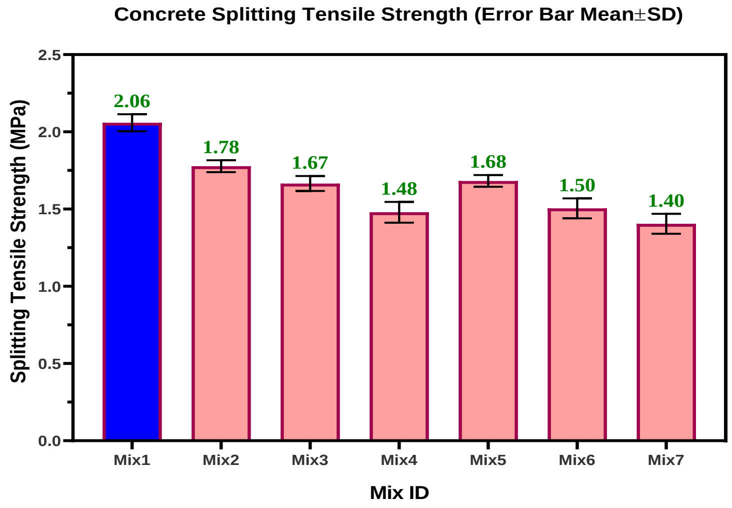

Figure 12. Splitting tensile strength of the investigated mixes

3.4. Flexural Strength

Replacing natural aggregate with recycled concrete and porcelain aggregates showed an adverse impact on the flexural strength of the mixes and resulting lower values especially when the replacing rate was 100% in mixes (Mix#4 and Mix#7) as the strength for these mixes was 2.15 MPa and 1.95MPa, respectively. These values represent reductions of 15.5% and 23.3% respectively in comparison with Mix#1 as shown in Figure 13. This decline in strength can be directed to the particle surface smoothness of the recycled porcelain and a weak bond exists between the aggregate and the cement paste [5, 8]. Additionally, it has been observed in prior studies that the flexural strength of concrete that contains waste porcelain decreases [18]. This weakening trend was also observed in, but the reduction was faster with high replacement ratios [20].

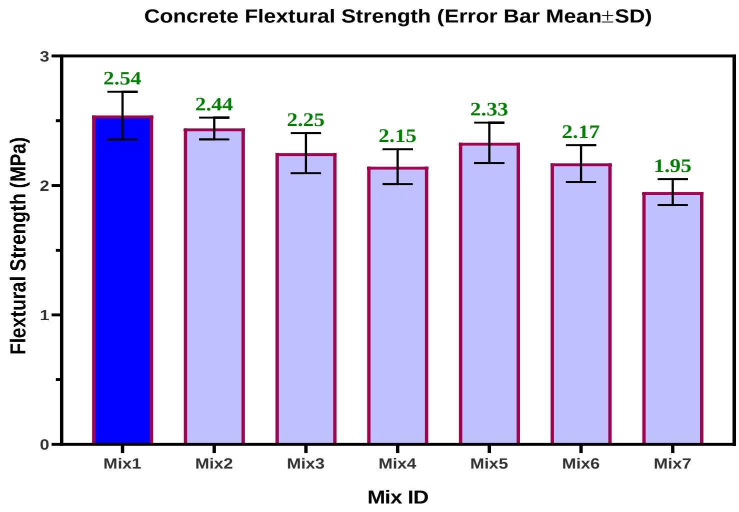

Figure 13. Flexural Strength for the investigated mixes

3.5. Water Permeability

Figure 14 shows the effect of using recycled aggregate on the water permeability of the investigated mixes. Generally, the findings indicate that the recycled aggregates increase the permeability of the developed mixes [6]. This could be partly due to the lack of homogeneity of the aggregate. The control mixture (Mix#1) permeability was 0.44(cm/sec), meaning less permeable to water compared to the rest mixes with recycled aggregates. On the other hand, mixes (Mix#4 and Mix#7) displayed high permeability of 0.56(cm/Sec) and 0.57(cm/Sec) respectively. The reason is that using 100% recycled aggregate with granular shape will produce more air gaps and increase the porosity in the mixture. The maximum increase of the permeability is 30% as observed for Mix#7.

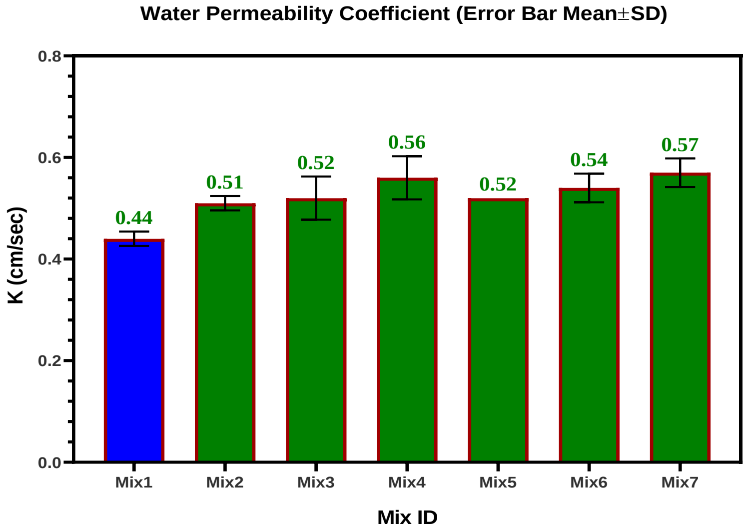

Figure 14. Water permeability for the investigated mixes

3.6. Abrasion Resistance

The results of the abrasion resistance of the examined mixes are displayed in Figure 15. It shows that the first mixture is more resistant to abrasion of aggregates as exhibited, by the lowest weight loss (1.16%). The reason is that the aggregate used in the mixture is natural coarse aggregate. It is clear that the greater the content of the recycled aggregates, the higher the loss in weight [4]. The weight loss in Mix#4 was (1.35%) which contained 100% recycled coarse aggregate and the weight loss showed more increase when 100% coarse aggregate and 100% fine aggregate were replaced with the recycled aggregates showing a (1.4%) weight loss in Mix#7. The higher weight loss indicates lesser resistance to abrasion and lesser durable concrete mixtures.

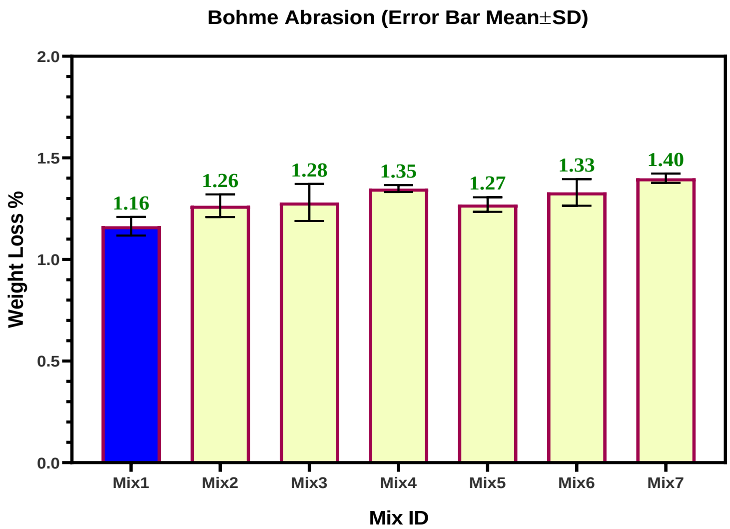

Figure 15. Weight loss due to abrasion for the investigated mixes

3.7. Impact Resistance

Impact resistance refers to the ability of concrete to absorb energy and endure numerous blows without developing cracks or spalling. Figure 16 shows the effect of using recycled aggregates on the initial and final impact energy (before and after failure) for the investigated mixes. According to the results, the first mix is the most resistant to impact forces due to the use of (100%) natural coarse aggregate showing high initial and final impact energies. The weakest mixture is Mix#7 that contains 100% recycled concrete and porcelain aggregates which showed 35% lesser resistance before failure and 29% lesser resistance at failure in comparison with the first mix. The reason for this is because of the weak internal relationship that exists between the components of the particle and the shape of the particle [8]. It has been noticed that the insertion of recycled concrete and porcelain waste reduces the capacity of pervious concrete to absorb energy. This is evidenced by the fact that the initial and final impact energy that are necessary to create the first crack and the collapse has decreased. One possible explanation for this behavior is that waste materials of this kind are less rigid than other materials, which makes them less capable of absorbing energy [8].

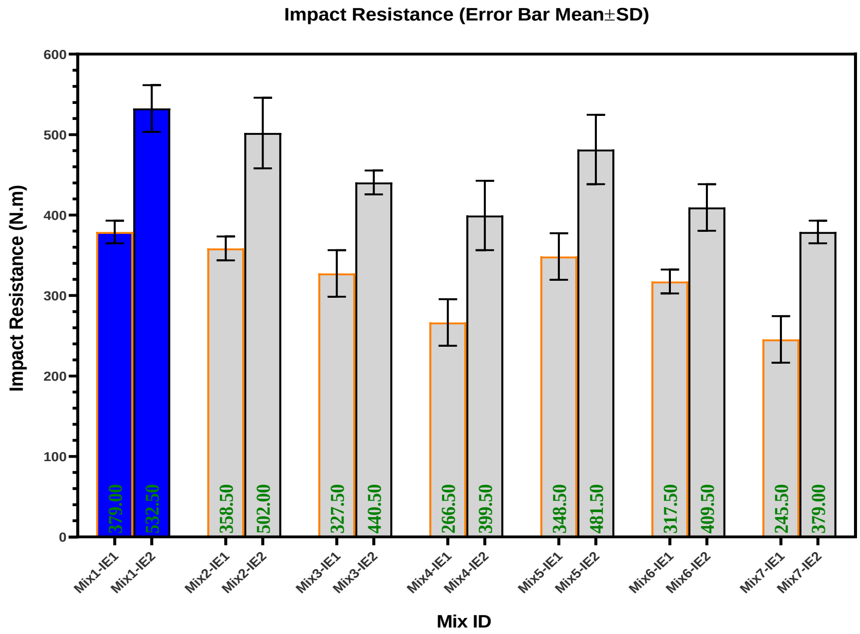

Figure 16. Initial and final impact energy (IE1 and IE2) the investigated mixes

4. Conclusions

The current study is directed to assess the effect of utilizing waste concrete and porcelain as aggregates in concrete mixtures on their mechanical properties. Seven different mixtures were prepared and tested in the laboratory for strength, permeability, and impact resistance. The obtained results can lead to the following conclusions:

- The recycled concrete and porcelain negatively affect the workability of the pervious concrete with a maximum reduction of about 14% for the mix containing 100% coarse concrete and recycled porcelain aggregates as well as 100% of recycled fine porcelain.
- The use of recycled concrete and porcelain declined the compressive, flexural strength, and splitting tensile of the pervious concrete by up to 24%, 23%, and 32%, respectively.
- Using recycled concrete and recycled porcelain improved the permeability of the pervious concrete and the highest improvement was 30%.
- The abrasion resistance and the impact energy of the pervious concrete declined as recycled concrete and recycled porcelain were added to the mixes.
- The addition of recycled concrete and recycled porcelain to the mixes resulted in a decrease in the impact energy of the pervious concrete. The incorporation of both recycled concrete and recycled porcelain led to the reduction in energy absorption capacity of 35% at the initial crack and 29% at failure, compared to the mixture without recycled aggregate.
- Despite the reduction in mechanical properties and abrasion resistance, the pervious concrete mixes containing recycled concrete and recycled porcelain exhibit acceptable strength and improved water permeability. This suggests that using such waste materials in pervious concrete mixtures can be a viable and sustainable alternative to using natural aggregates. These findings could have significant implications for the construction industry and for reducing the environmental impact of concrete production.

5. Declarations

5.1. Author Contributions

Conceptualization, G.J.K. and K.H.Y.; methodology, G.J.K., K.H.Y., and W.A.H.; validation, G.J.K. and K.H.Y.; resources, A.J.I., G.A.M., H.K.Y., and S.M.M.; data curation, F.F.J.; writing—original draft preparation, K.H.Y., F.F.J., W.A.H., and S.M.M.; writing—review and editing, K.H.Y., G.J.K., and F.F.J.; supervision, G.J.K and K.H.Y. All authors have read and agreed to the published version of the manuscript.

5.2. Data Availability Statement

The data presented in this study are available in the article.

5.3. Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

5.4. Acknowledgements

The authors would like to thank Erbil Polytechnic University and Tishk International University for their valuable support given to access the labs during conducting this research.

5.5. Conflicts of Interest

The authors declare no conflict of interest.

6. References

[1] Younis, K. H., Jirjees, F. F., Khoshnaw, G., & Ali, B. H. (2019). Experimental study on performance of recycled aggregate concrete: Effect of reactive mineral admixtures. International Journal of Civil Engineering and Technology, 10(1), 2566–2576.

[2] Gesoılu, M., Güneyisi, E., Khoshnaw, G., & Ipek, S. (2014). Abrasion and freezing-thawing resistance of pervious concretes containing waste rubbers. Construction and Building Materials, 73, 19–24. doi:10.1016/j.conbuildmat.2014.09.047.

[3] Gesoğlu, M., Güneyisi, E., Khoshnaw, G., & Ipek, S. (2014). Investigating properties of pervious concretes containing waste tire rubbers. Construction and Building Materials, 63, 206–213. doi:10.1016/j.conbuildmat.2014.04.046.

[4] Guo, L., Guan, Z., Guo, L., Shen, W., Xue, Z., Chen, P., & Li, M. (2020). Effects of recycled aggregate content on pervious concrete performance. Journal of Renewable Materials, 8(12), 1711–1727. doi:10.32604/jrm.2020.013415.

[5] Leon Raj, J., & Chockalingam, T. (2020). Strength and abrasion characteristics of pervious concrete. Road Materials and Pavement Design, 21(8), 2180–2197. doi:10.1080/14680629.2019.1596828.

[6] Kacha, S. A. P. S. (2016). Utilization of waste materials in the production of pervious concrete–A Review. International Journal for Scientific Research & Development, 4(9), 442-449.

[7] Denisiewicz, A., Śliwa, M., Kula, K., & Socha, T. (2019). Experimental investigation of concrete with recycled aggregates for suitability in concrete structures. Applied Sciences (Switzerland), 9(23), 5010. doi:10.3390/app9235010.

[8] Amin, A. A., Younis, K. H., Jirjees, F. F., & Ibrahim, T. K. (2021). Experimental study on mechanical properties of pervious concrete containing recycled aggregate. Civil Engineering and Architecture, 9(6), 1735–1743. doi:10.13189/cea.2021.090607.

[9] Habeeb, M. M., Younis, K. H., Jirjees, F. F., Maruf, S. M., & Ibrahim, T. K. (2022). Behaviour of sustainable slag enriched concrete: Effect of fully replacement of natural coarse aggregate with construction waste. Materials Today: Proceedings, 57, 806–811. doi:10.1016/j.matpr.2022.02.389.

[10] Keshavarz, Z., & Mostofinejad, D. (2019). Porcelain and red ceramic wastes used as replacements for coarse aggregate in concrete. Construction and Building Materials, 195, 218–230. doi:10.1016/j.conbuildmat.2018.11.033.

[11] Tavares, L. M., & Kazmierczak, C. S. (2016). The influence of recycled concrete aggregates in pervious concrete. Revista IBRACON de Estruturas e Materiais, 9(1), 75–89. doi:10.1590/s1983-41952016000100006.

[12] Sai Sindhu, K., & Suresh Babu, T. (2015). Study and Comparison of Mechanical Properties, Durability and Permeability of M15, M20, M25 Grades of Pervious Concrete with Conventional Concrete. International Journal of Applied Research 2015, 1 (10), 676-681.

[13] Fanijo, E. O., Kolawole, J. T., Babafemi, A. J., & Liu, J. (2023). A comprehensive review on the use of recycled concrete aggregate for pavement construction: Properties, performance, and sustainability. Cleaner Materials, 9, 100199. doi:10.1016/j.clema.2023.100199.

[14] Yaba, H. K., Naji, H. S., Younis, K. H., & Ibrahim, T. K. (2021). Compressive and flexural strengths of recycled aggregate concrete: Effect of different contents of metakaolin. Materials Today: Proceedings, 45, 4719–4723. doi:10.1016/j.matpr.2021.01.164.

[15] Théréné, F., Keita, E., Naël-Redolfi, J., Boustingorry, P., Bonafous, L., & Roussel, N. (2020). Water absorption of recycled aggregates: Measurements, influence of temperature and practical consequences. Cement and Concrete Research, 137, 106196. doi:10.1016/j.cemconres.2020.106196.

[16] Niu, H., Taright, J., Na, H., Wang, X., Zhang, X., & Hui, C. (2021). Residual compressive and flexural strength of a high strength recycled aggregate concrete. International Journal of Scientific Development and Research, 6(6), 182-195.

[17] Çakir, O. (2014). Experimental analysis of properties of recycled coarse aggregate (RCA) concrete with mineral additives. Construction and Building Materials, 68, 17–25. doi:10.1016/j.conbuildmat.2014.06.032.

[18] Al-Luhybi, A. S. (2017). Studying the Effect of Adding Marble and Porcelain Waste on Mechanical Properties of Concrete Containing Recycled Aggregate. Engineering and Technology Journal, 35(7), 668–674. doi:10.30684/etj.35.7a.1.

[19] Anderson, D. J., Smith, S. T., & Au, F. T. K. (2016). Mechanical properties of concrete utilising waste ceramic as coarse aggregate. Construction and Building Materials, 117, 20–28. doi:10.1016/j.conbuildmat.2016.04.153.

[20] El-Abidi, K. M. A., Mijarsh, M. J. A., & Abas, N. F. (2022). Properties of porcelain influenced concrete. European Journal of Environmental and Civil Engineering, 26(3), 879–890. doi:10.1080/19648189.2019.1684383.

[21] Sua-iam, G., & Jamnam, S. (2023). Influence of calcium carbonate on green self-compacting concrete incorporating porcelain tile waste as coarse aggregate replacement. Case Studies in Construction Materials, 19, 2366. doi:10.1016/j.cscm.2023.e02366.

[22] Alshahwany, R. B., Abdulkareem, O. M., & Shlla, R. D. (2024). Influence of Ceramic Wastes as a Recycled Coarse Aggregate with Different Maximum Sizes on the Concrete. The Open Civil Engineering Journal, 18(1). doi:10.2174/0118741495298085240326062433.

[23] BS EN 197-1. (2019). Cement - Composition, specifications and conformity criteria for common cements. British Standard Institute (BSI), London, United Kingdom.

[24] BS EN 12390-3. (2009). Testing Hardened Concrete Part 3: Compressive Strength of Test Specimens. British Standard Institute (BSI), London, United Kingdom.

[25] BS EN 12390-5. (2009). Testing Hardened Concrete Part 5: Flexural Strength of Test Specimens. British Standard Institute (BSI), London, United Kingdom.

[26] ASTM D5084-03. (2010). Standard Test Methods for Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter. ASTM International, Pennsylvania, United States. doi:10.1520/D5084-03.

[27] BS EN 12390-6. (2009). Testing Hardened Concrete Part 6: Splitting tensile Strength of Test Specimens. British Standard Institute (BSI), London, United Kingdom.

[28] ACI 544.2R-89. (1999). Measurement of Properties of Fiber Reinforced Concrete. American Concrete Institute (ACI), Michigan, United States.

[29] BS EN 14157. (2017). Natural stone test methods. Determination of the abrasion resistance. British Standard Institute (BSI), London, United Kingdom.

[30] BS EN 12350-2. (2009). Testing fresh concrete Part 2: Slump-test. British Standard Institute (BSI), London, United Kingdom.

[31] Taffese, W. Z. (2018). Suitability Investigation of Recycled Concrete Aggregates for Concrete Production: An Experimental Case Study. Advances in Civil Engineering, 2018, 8368351. doi:10.1155/2018/8368351.

[32] Silva, R. V., de Brito, J., & Dhir, R. K. (2018). Fresh-state performance of recycled aggregate concrete: A review. Construction and Building Materials, 178, 19–31. doi:10.1016/j.conbuildmat.2018.05.149.

[33] Silva, R. V., De Brito, J., & Dhir, R. K. (2014). Properties and composition of recycled aggregates from construction and demolition waste suitable for concrete production. Construction and Building Materials, 65, 201–217. doi:10.1016/j.conbuildmat.2014.04.117.