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Experimental Investigation of Sustainable Concrete Containing Recycled Porcelain

Ibrahim M. Ibrahim [a *], Mohamed H. Makhlouf [b], Tarek S. Mostafa[c], and Gehan A. Hamdy [c]

[a] October High Institute for Engineering & Technology, Egypt.
b Department of Civil Engineering, Faculty of Engineering Benha University, Egypt.
c Department of Civil Engineering, Faculty of Engineering at Shoubra Benha University, Egypt.
* Corresponding Author
E-mail: ibrahim.mohamed.ibrahim94@gmail.com., mohamedmakhlouf83@yahoo.com., tarek.mohamed@feng.bu.edu.eg., gehan.hamdy@feng.bu.edu.eg.

Abstract: Concrete ranks as one of the most important building materials, many researchers in recent years have been interested in developing and strengthening concrete by replacing concrete components with waste materials in order to eliminate these wastes and enhance the concrete's tensile, compressive, and flexural strengths. In order to continue this path, this study aims to do an experimental work to replace the waste of porcelain instead of the coarse aggregate of concrete at the rates of 25%, 50%, 75%, and 100%. For this purpose, 90 samples were poured and cured for the tests of the concrete's tensile, compressive, and flexural strengths. The results show that the mix containing 25% of the porcelain was the closest to the control mix, because the concrete's compressive strength and tensile strength decreased for the mixture containing 25% of the porcelain compared to the control mix by 2% and 4% at the age of 28, and this decline continued with the gradual increase in the proportion of porcelain in mixtures. However, Concrete's flexural strength increased at the level of 25% replacement of porcelain by 40% compared to the control mixture and was enhanced by 24% and 9% at the levels of 50% and 75% replacement of porcelain, respectively.

Keywords: Porcelain waste aggregate (PWA) –Flexural Strength-Compressive strength - Tensile strength.

1. INTRODUCTION

The field of scientific research focused on shedding light on the manufacture of green concrete by replacing one of the materials that make up concrete with one of the types of waste that is thrown into the environment in order to minimize the damage done by throwing these wastes into the environment and reducing the use of raw materials that make up concrete such as sand, cement and coarse aggregates, and enhancing concrete's tensile, compressive, and flexural strengths among other mechanical properties.

According to concrete, it has ceramic waste resulting from manufacturing, transportation, storage, and installation waste, Among the other sources that produce ceramic waste are the removal and demolition processes of the violating and old structures, but the ceramic waste resulting from these sources sticks bits of mortar on the surface of them, so it leaves a limited impact on the mechanical characteristics of concrete, and also this mortar doesn't really provide any features for concrete properties, so the best option is to use waste mortar-free ceramic.

The mechanical characteristics of concrete, especially its tensile, flexural, and compressive strengths, and its elastic modulus, may be improved by adding Some types of porcelain contain many clay materials, and porcelain may also strengthen the concrete's resistance to chemicals. There is a study that says that the reinforced concrete's compressive strength increased by 9% when waste porcelain was used to replace 9% of the coarse aggregate [1], in an anther study Comparing the experimental mix to the control mix, the concrete's compressive strength increased by 8% after ceramic waste was used in place of 100% of the coarse aggregate [2].

The concrete's compressive strength test was enhanced by 14% compared to the control mix at the replacement level of 100% [3], a 11 % improvement in the material's compressive strength occurred at 5% of the replacement level [4]. However, the concrete's compressive strength test dropped by 34% and 9% in comparison to the control mix at the replacement level of 100%[5-6], at the 30% and 50% replacement levels for coarse aggregate, a decline in the concrete's compressive strength test occurred by 24 % compared to the control mixture[7-8].

The difference in results is due to the type of ceramic used, such as ceramic kitchenware, sanitary ceramics, or bricks used in concrete [7,9], but in general replacing coarse aggregate with red ceramic has a detrimental impact on the concrete’s compressive strength in the mixtures [10,11,12,13].

In other experiments, researchers used sanitary ceramics [1, 14, 4, 15, 16]. As an alternative to coarse aggregate, but the results proved that it improved concrete's compressive strength [1, 14,4, 17, 18, 19].

Some researchers studied the impact of chloride penetration of ions and electrical resistance on concrete with durability after replacing coarse aggregate with sanitary ceramic waste at rates of 20% and 25%, and the results showed an increase in chloride penetration into concrete containing sanitary ceramics with constant durability indicators. Also, the electrical resistance of concrete containing sanitary ceramic waste increased and the durability was significantly improved [19].

In other researches, the effect of replacing the coarse aggregate with (PWA) and red ceramic waste at rates of 25%, 50%, 75%, and 100% was tested. The results revealed that, in comparison to the control mixture, the concrete’s compressive strength containing 100% porcelain waste increased by 41% and that of concrete containing 100% ceramic waste enchased by 29% [20].

Researchers employed porcelain waste in further research [21- 31]. As an alternative to coarse aggregate, cement, and other materials used in concrete. The present research aims to conduct a laboratory study of concrete that contains waste porcelain, study its mechanical properties and compare it with ordinary concrete.

Experimental Program

Materials. In order to complete this study, 52.5 Beni Suef cement and sand ranging in diameter from 0 mm to 4.75 mm were used, as well as coarse aggregates from 10 mm to 20 mm in diameter. Table No. 1 also shows the results of laboratory tests for the manufacturer to determine the properties of the porcelain used in the study and the properties of sand and coarse aggregate such as (bulk density-percentage, water absorption-percentage of clay and other fine materials in aggregate).

Table 1. shows the results of tests to determine

Material	Bulk density D	Water absorption WS	Percentage of clay PC
Gravel	2.6435	1.03%	1.5%
Sand	2.608	1.8%	1%
Porcelain	2.36	%0.5	

Porcelain.

The "porcelain" is baked at extreme temperatures to achieve its glasslike appearance, or glassy, with characteristics like a diaphanous and limited porosity. Porcelain is a component consist of some materials created under extreme pressure in nature then it is subsequently processed in a factory under the influence of high temperatures, and for this reason it acquires a high resistance. Porcelain has a high hardness due to its low porosity and its low ability to absorb water, Due to the increased demand for the porcelain industry, the production of porcelain has increased significantly.

The advantages of porcelain are many, the most important of which are: a) huge flexural strength, b) highly poor water absorption and excellent resistance to the frost c) good resistance to chemicals d) high resistance to abrasion in addition to surface harden and based on the above-mentioned advantages and the resistance of porcelain to chemicals and fire, it made it impossible to throw these wastes into nature, and it should be used on a better scale.

Mix Proportions. To accomplish the objectives of the research, 90 samples were tested to investigate the mechanical properties of concrete with different proportion of porcelain, 45 samples were used for a test of compressive strength, 30 samples for a tensile strength test, and 15 samples for a flexure strength test. The control mixture is denoted by the letter CO, and the mixtures that contain porcelain in different proportions of replacement for coarse aggregates are denoted by the letter P as shown in Table No. 2.

The concrete from which the control mixture is made consists of 400 kg of Portland cement N52.5, a ratio of water / cement equal to 0.54, the weight of sand is 700 kg, and the coarse aggregate weight is 1045 kg, in the other mixture, coarse aggregate was substituted with (PWA) at rates of 25%, 50%, 75%, and 100%, and constant values of W/C and slump value were constant in all the mixes.

Table 2. Mixture ratios of concrete mixtures per cubic meter

Mix.	Percentage of porcelain	P	Corse aggregate
CO	------	-------	1045
P25%	25%	247.8754	783.4503
P50%	50%	496.57	523
P75%	75%	743.83	261.12
P100%	100%	1016	---------

Procedures for Preparing and Testing Specimens. The five mixes of concrete were mixed mechanically, poured into the forms, and allowed to cure until the test was conducted. All tests were done in the RC Laboratory, Benha faculty of engineering. Figure 1 show concrete samples during and after pouring. AS well figure 2 show the testing apparatuses for mechanical properties.

Slump Test. Based on ASTM C143/C143M-00, a slump test was performed to determine how easily the fresh concrete could be shaped.

Test for Compressive Strength. Based on ASTM C39/C39M-18, this test was performed on three standard concrete cubes of dimensions (150x150x150mm) for each mixture at ages of 7, 28, and 56 days.

Test for Tensile Strength. this test was carried out by using standard cylinders with dimensions of (150x300 mm). Three specimens were tested for every mixture based on ASTM C 496 at the ages of 7 and 28 days.

Test for Flexural Strength. The samples that were used in this test had standard specifications of (100x100x500mm). According to ASTM C78/C78M-18, three unreinforced beams from each mix are evaluated 28 days after pouring.

(a) (b)

Fig 1. Materials used: (a) porcelain waste and (b) coarse aggregate

(a) (b) (c)

Fig 2. Test specimens: (a) Forms, (b) cylinders and (c) cubes and beam specimens

Experimental Results

The Evaluation of Compressive Strength Study results. Table 3 presents the results of compression tests performed on the standard cubes of every mixture after 7, 28, and 56 days. Figure 3 depicts the average results for three concrete cubes of every mixture to demonstrate how replacing coarse aggregate with (PWA) affects the concrete's compressive strength. As shown in Figure 3, it is obvious that the mixture P25% was the closest to the control mixture CO, because the compressive strength of P25% decreased from that of CO by 3%, 2%, and 1% at ages 7, 28, and 56 days.

The decrease in the concrete's compressive strength continues with the increase in the percentage of (PWA) in the mixture, the compressive strength of the P100% mixture decreased by 12%, 9%, and 11%, the compressive strength test of the P75% mixture decreased by 11%, 8%, and 8% and the compressive strength test of the P50% mixture decreased by 3%, 7%, and 4%, compared to the control mixture CO at the ages of 7, 28, and 56 days.

Due to inadequate cohesiveness between the surfaces of the porcelain and the cement paste, the concrete's compressive strength decreases with an increase in the percentage of porcelain.

TABLE 3. compressive strength test results

Mix	Days	Compressive Strength (MPa)					
		Cube 1	Cube 2	Cube 3	Average (MPA)	Stand Dev. (MPA)	COV (%)
CO	7	22.9	22.5	22.8	22.7	0.20	0.91
P25%	7	22	22.4	22.1	22.2	0.208	0.93
P50%	7	21.7	22.3	22.2	22	0.32	1.45
P75%	7	19.8	20.4	20.2	20.1	0.30	1.51
P100%	7	19.75	20.3	19.9	20	0.28	1.42
CO	28	29.8	30.1	30.3	30	0.25	0.83
P25%	28	29.3	29.8	29.4	29.5	0.26	0.89
P50%	28	27.8	27.9	28.2	28	0.20	0.74
P75%	28	27.456	27.76	27.9	27.7	0.22	0.81

P100%	28	27.6	27.2	27.4	27.3	0.2	0.72
CO	56	34.26	34.8	34.4	34.5	0.28	0.81
P25%	56	34.19	34.09	34.5	34.3	0.21	0.62
P50%	56	33	32.8	33.1	32.96	0.15	0.46
P75%	56	31.2	32	31.9	31.7	0.40	1.37
P100%	56	31.15	30.7	30.75	30.9	0.24	0.79

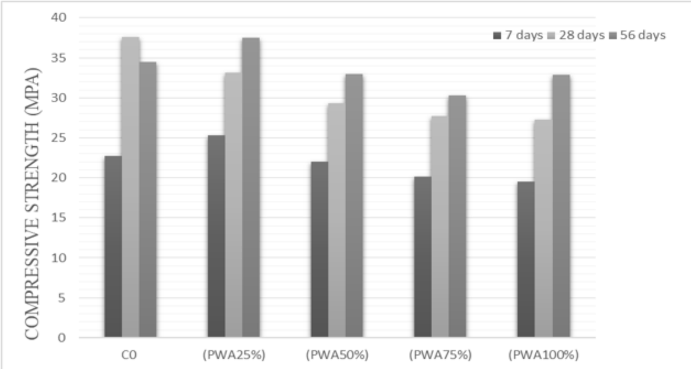

Fig 3. Effect of using (PWA) as coarse aggregate on compressive strength

TABLE 4. Results of splitting tensile test

Mix	**Days**	**Tensile Strength (MPa)**					
		Cyl. 1	**Cyl. 2**	**Cyl. 3**	**Average (MPA)**	**Stand. Dev. (MPA)**	**COV (%)**
CO	7	1.39	1.4	1.40	1.39	0.007	0.51
P25%	7	1.38	1.39	1.37	1.38	0.01	0.72
P50%	7	1.27	1.29	1.27	1.27	0.01	0.80
P75%	7	1.27	1.28	1.26	1.27	0.01	0.78
P100%	7	1.23	1.22	1.24	1.23	0.01	0.81
CO	28	2.82	2.85	2.83	2.826	0.015	0.53
P25%	28	2.71	2.69	2.67	2.693	0.02	0.74
P50%	28	2.59	2.63	2.61	2.611	0.02	0.76
P75%	28	2.55	2.59	2.56	2.575	0.02	0.81
P100%	28	2.57	2.53	2.54	2.538	0.02	0.81

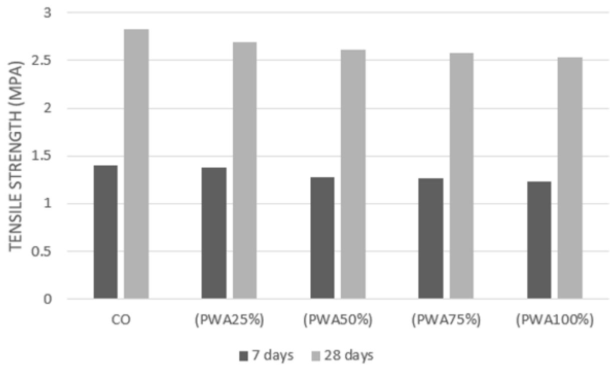

Fig4. Effect of using (PWA) as coarse aggregate on tensile strength

The Evaluation of Tensile Strength Study results. Table 4 presents the test results for three concrete cylinders for every mixture tested at ages 7 and 28 days, for concrete mixes including (PWA) as a substitute for coarse aggregate. Figure. 4 shows the average values plotted. Based on the test results, the decrease in concrete tensile strength occurred. At ages 7 and 28 days, the P25% mixture declined by 2% and 5%, respectively, while the p100% mixture decreased by 13% and 11%, respectively, compared to the control mixture. As illustrated by Figure 4, increasing the percentage of (PWA) decreases the tensile strength of mixes.

The Evaluation of Flexural Strength Study results test. Table 5 demonstrates the results of a test for concrete flexural strength performed on three unreinforced beam samples for every mixture at age 28 days. Figure. 6 shows the failure of concrete mix specimens resulting from testing. The results of the average flexural strength are shown in Figure 5. At age 28 days, the concrete's flexural strength mixes containing 50% and 75% of the (PWA) increased by 24% and 9%, respectively, in comparison to the control mixture, while the mixture containing 25% of the (PWA) increased by 40%. At the age of 28 days, the P100% mixture was 15% less than the control mixture. The results of the previous analysis demonstrated that increasing the proportion of (PWA) to 25% enhanced the flexure strength of concrete to, then it decreased by increasing the percentage of (PWA).

TABLE 5. The flexural strength test results

Mix	Days	Flexural Strength (MPa)					
		Beam 1	Beam 2	Beam 3	Average (MPa)	Stand. Dev. (MPa)	Coeff. of variation (%)
CO	28	4.41	4.45	4.44	4.4	0.020	0.46
P25%	28	6.19	6.18	6.2	6.18	0.01	0.16
P50%	28	5.41	5.46	5.47	5.47	0.0323	0.59
P75%	28	4.76	4.83	4.8	4.80	0.035	0.73
P100%	28	3.77	3.76	3.71	3.75	0.032	0.85

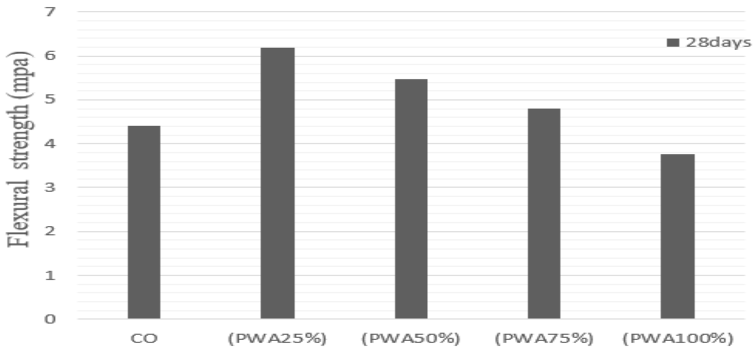

Fig. 5. Effect of using (PWA) as coarse aggregate on flexural strength

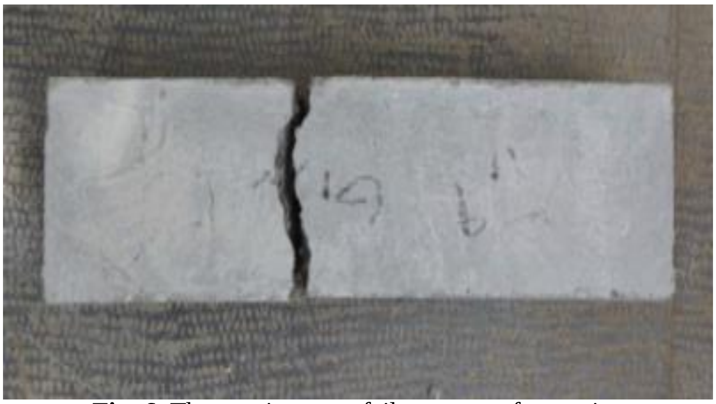

Fig. 6. The specimens at failure stage after testing

Conclusions

In this work, (PWA) is used as a coarse aggregate. Tests were done for concrete. According to the results of experimental work, the major conclusions can be can be derived are as follows:

- (PWA) was observed to reduce the concrete's compressive strength to 9% with a 100% substitution of the porcelain level. At the age of 28 days, porcelain has a detrimental impact on concrete's compressive strength when compared to the control mixture.
- The PWA had a detrimental impact on the concrete's tensile strength as well, as 100% replacement of the porcelain resulted in a 10% reduction in tensile resistance in comparison to the control mix.
- In comparison to the control mixture, the PWA enhanced the concrete's flexural strength by 40% at the 25% replacement level, and it improved by 24% and 9% at the 50% and 75% replacement levels of porcelain, respectively.
- The mixture closest to the control mixture CO was P25%, which reduced the compressive, and tensile strength of the concrete by 2% and 5% at the age of 28 days, respectively.

Based on the results of this research, which show the importance of using porcelain waste in green concrete and improving its mechanical properties, the civil engineer should not dispose of this waste in a harmful way, such as by burying it or throwing it in the environment, but disposing of it by delivering it to the concrete Plan for reuse.

Recommendations for Future Studies

The following parameters can be added to the current experimental research studies in order to better understand the behavior of fully and partially green concrete using (PWA):

- The impact of using (PWA) as a replacement for coarse aggregate in various replacement ratios.
- The effect of replacing (PWA) as a partial and complete substitute for sand.
- The effect of substituting (PWA) as a substitute for coarse aggregates on the flexural, and shear strength of the concrete beams.

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