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Research paper

Mechanical Properties of the Concrete Containing Porcelain Waste as Sand

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Abstract

The demand of concrete have been increases on a daily bases which consume a lot of natural resource such as sand and gravel, there is an immediate need for finding suitable alternative which can be used to replace sand partially with another materials with high proportion . Ceramic waste is one of the strongest research areas that include the activity of replacement in all the sides of construction materials. This research aims to improve the performance of concrete using ceramic waste, and demonstrate the performance of mechanical properties to the concrete with partial replacement of sand by using waste porcelain. For these, we analyzed the mechanical properties of the concrete such as compressive strength, split tensile and flexural strength, the specimen were measured based on 10% ,20% ,30% ,40%, and 50% weight ratio of replace sand with waste porcelain at different time under water for 7 days , 28 days , 60 days . The optimum consideration were given to mechanical properties of the concrete, at different amount of ceramic waste as sand.

Keywords: *Cement; Ceramic Waste; Mechanical Properties Porcelain; Sand.*

1. Introduction

Concrete is a composite of cement (binder), sand (fine aggregate) and gravel or broken stone (coarse aggregate) [1]. It has been used for more than a century in all construction work [1-2]. In recent years, a variety of new materials in the field of concrete technology have been developed, with the continuous demand of the construction industry to meet the functionality, strength, economy and durability demand. India's ceramic production is 100 million tons per year. India ranks as the world largest tile producer [3]. Around 2011-2012 more than 600 million square kilometers was cover concrete materials which consume a lot of the available sand we have, so there is need to overcome this demand [4-5]. This huge ceramic production is due to the prosperity of the housing sector, coupled with government policies to promote the strong growth of the real estate industry [6, 7]. In the ceramic industry, about 15% to 30% of total waste is generated from all production, although the reuse of ceramic waste has been implemented, the amount of waste recycled in this way is still negligible [4-8]. Therefore, its application is needed in many industries and cities development. The construction industry can become the end user of all ceramic waste, and in this way can help solve this environmental problem [9-11].

This research aims to replace sand with waste porcelain in the production of concrete materials. However, the mechanical properties and tensile strength have been study ensure the composites is promising for concrete production.

2. Materials

Materials used in this study include cement, sand, coarse aggregate, fine aggregate, waste porcelain and water.

2.1. Experimental method

The research method of this work mainly involves investigating the potential use of waste ceramic (waste porcelain) and concrete mixture. At present, as with other solid wastes, ceramic waste generated from recycled materials is also thrown into the dump. Waste is usually produced by dismantling the building's containers, but also different buildings and rebuilt and waste. In addition, the study also used ceramic waste as sand and ceramic waste as a partial replacement for sand mixed with the ceramics to form fresh concrete and study the effect of the ceramics on the properties of the concrete. Porcelain, can be used to replace natural aggregates by replacing some natural materials with recycled materials that produce the same functions, the possible benefits are as follows: Many ceramic wastes are now being through into the environment. The current experimental procedure is to explore the effect of the use of powdered spent ceramic parts in the ASTM test procedure specification as a ceramic in a normal concrete mixture on the compression properties for the hardened concrete.

All the materials used in research study locally exist. In this study, Portland cement will be used as ceramic waste. Sand with a size of 4.75 mm will replace 0%, 10% and 20% 30%, 40% and 50% ceramics. Table 1 contain composition of includes a description of the materials used, mixed design, mixing procedures, placement, curing, fresh and mechanical, thermal characterization procedures.

2.2. Cement

Table 1: The oxide composition of ordinary PC

Common name	oxide	Abbreviation	Approximate composition limits (%)
Lime	CaO	C	60-66
Silica	SiO2	S	19-25
Alumina	Al2O3	A	3-8
Iron oxide	Fe2O3	F	1-5
Magnesia	MgO	M	0-5
Alkalis-soda	Na2O	N	0.5-1
Polassa	K2O	K	0.5-1
Sulfurtnoxide	SO3	P	1-3

2.3. Fine aggregate

The term "sand" used in the construction and construction industry is synonymous with fine-grained material having a particle size of less than 5 mm. Sand is located in the construction industry all over the world and is an important raw material for providing infrastructure and housing. The main purpose of sand is to make concrete and concrete products, such as ready-mixed concrete block products, columns, stumps, manholes, pipes, plates, beams, walls, roof tiles and various other products. Standards require sand to have physical and chemical characteristics such as particle size distribution limitations, hardness, inertness, water absorption limit, density, mineral type, durability, and no harmful substances (see Figure 1) [10].

Table 2: Sieve analysis of fine aggregate

Sieve size (mm)	%passing	% passing according ASTM C330-87
4.75	95	90-100
2.36	90	85-100
1.18	85	75-100
0.60	70	60-79
0.30	25	12-40
0.15	5	0.10

2.4 Coarse aggregate

The typical structure of aggregates are shown in the Figure 1, the cement requirement to fill the voids can be reduced to maintain the workability and strength of the concrete [10]. Polymers have been classified into two types, such as coarse aggregates having a size in excess of 2.36 mm to 12.5 mm. The coarse aggregates typically have the maximum permissible dimensions for gravel and crushed stone with 2.36 to 12.5 mm size for the coarse aggregate left on the screen. The function of course Aggregate is to serve as the main load-bearing component of concrete.

Fig.1: Coarse Aggregate

Table 3 tabulate the analysis of coarse aggregate, therefore natural coarse aggregate is major part of concrete samples, in this study, ceramic waste was proposed as a substitute for coarse aggregate because it helps to increase the productivity of concrete production. Partially substituted ceramics help reduce roughness of the materials integrated use of natural resources.

Table 3: Sieve analysis of coarse aggregate

Sieve analysis (mm)	% passing	% passing ASTM C330-87
12.5	95	90-100
9.5	70	40-80
4.75	15	0-20
2.36	5	0-10

2.5 Water

Water is an important part of concrete because it actually participates in the chemical reaction with cement. It also helps to generate cement gels, therefore the amount and quality of water need to be carefully studied. It was tabulate in table 4 that the materials for the first mixing ratio experiment will be OPC Type 1, coarse sand aggregates and waste ceramic tiles, which have selected porcelain as a substitute for natural aggregates. The quantity of cement, sand, and water will be constant, while the crushed porcelain will partially be change for 0%, 10%, 20%, 30%, 40%, and 50% aggregates. Table 5 shows the actual number of materials that determine the replacement of porcelain into fine aggregate substitutes, which was ranging from 0%, 10%, 20%, 30%, 40%, 50% respectively, among these samples the best results was chosen and its mechanical properties was measured in both case (concrete microphones and ceramic tiles) to determine the best point with high compressive strength and tensile strength as well, so as to doped with certain amount of polymer (polyester) into the mixture

3. Characteristic of Materials Used

3.1 Waste porcelain

Waste porcelain is available a large amount especially in medal east countries, some of Arab countries such as Iraq depend only on the importations of porcelain in a large quantity to supply for consumers [2]. Thus, during transportation some of them damage and therefore the landfill site becoming overcrowding. Therefore, the waste porcelain will be free for used in certain experiment and other purposes, among others, from there, we select the landfill site and crushed in crusher machine to make the sand [8]. Thus, the using this system to crush waste porcelain is possible to obtain fine aggregate and porcelain powder that after sieving (4.75-0.15) mm can be used without extra work and the cost is minimal. The typical image of the ceramic waste is shown in the Figure 2

Table 4: Percentages of concrete mix proportion fine aggregate (sand) partially replacement (porcelain).

Materials S.N	Cement in kg/ m3	W/C Ratio	Sand in kg	Waste porcelain as sand Replacement %	Coarse aggregate	Water in lit
1	180	0.5	270	0	540	90
2	180	0.5	243	27	540	90
3	180	0.5	216	54	540	90
4	180	0.5	189	81	540	90
5	180	0.5	162	108	540	90
6	180	0.5	135	135	540	90

Table 5: Concrete mix ratio for recycle (porcelain) replaced with sand

Materi-als	Ce-ment in kg/m3	W/C Ra-tio	Coarse aggre-gate	sand in kg	Waste porcelain as sand Re-place-ment %	Water in lit
S.N						
1	100%	0.5	100%	100%	0	100%
2	100%	0.5	100%	90%	10%	100%
3	100%	0.5	100%	80%	20%	100%
4	100%	0.5	100%	70%	30%	100%
5	100%	0.5	100%	60%	40%	100%
6	100%	0.5	100%	50%	50%	100%

3.2 Cement

The Iraqi ordinary cement was used throughout the survey and was based on the standard specification ASTM C150-02 Portland cement [2]. Store it in a dry place (air-tight plastic container) to reduce the effects of humidity and temperature. Tables (6) and (7) show the chemical and physical properties for the X-RAY diffraction of the cement used in this paper respectively.

Table 6: Chemical composition and main compounds of the cement used in this investigation

Abbreviation of Oxide	% by weight	Limits of Iraqi Specification
SiO2	19.90	-
CaO	60.80	-
MgO	1.50	≤5.0
Fe2O3	3.00	-
Al2O3	5.69	-
SO3	2.30	≤ 2.8
Loss on Ignition	1.50	≤ 4.0
Insoluble residue	1.10	≤1.5
Lime saturation factor	0.85	0.66-1.02
Main Compounds (Bogue's equation)		
C3S	47.14	-
C2S	21.57	-
C3A	10.00	-
C4AF	9.12	-

Figure 2: Ceramic waste

Table 7: physical properties of the cement used in this study

Physical property	Test Results	Limits of Iraqi Specification No.5/1984
Specific surface area (Blaine method), m2/kg	318	≥ 230
Setting time (vicat's method) Initial :by minutes Final, by minutes	121 230	≥ 1 hr ≤10.00 hrs
Compressive strength (70.7mm cube) (N/mm2) 3days 7days	19.20 28.50	≥15 ≥23
Soundness (autoclave method) %	0.22	≤0.8%

3.3 Coarse Aggregate

Coarse aggregate with a maximum size of 12.5mm are used in the mixture. It was tabulated in Table 8, it showed the grading of coarse aggregate which conforms to the (ASTM C330-87). The specific gravity, sulfate contain an absorption of coarse aggregate are illustrated in (Table 9).

Table 8: the grading for coarse aggregate

Sieve size (mm)	Selected % passing	% passing ASTM C330-87
12.5	95	90-100
9.5	70	40-80
4.75	15	0-20
2.36	5	0-10

Table 9: Physical properties of coarse aggregate

Physical properties	Test result	Limits of Iraqi specification
Specific gravity	2.630	-
Sulfate content	0.06%	≤ 0.1%
Absorption	0.63%	-

3.4 Fine Aggregate

Table 10 shows the sieve analysis of the used natural sand. From the sand grading Figure it is observed that the sand falls within zone three according to the requirement of the Iraqi specification. The chemical and physical properties of natural sand are illustrated in Table 11.

Table 10: Grinding of fine aggregate

Sieve Size (mm	% Passing	% Passing according to limits of I.O.S No. 45/1984
4.75	95	90-100
2.36	90	85-100
1.18	85	75-100
0.60	70	60-79
0.30	25	12-40
0.15	5	0-10
Fineness Modulus = 2.15		

Table 11: physical and chemical properties of sand

Property	Specification	Result	Iraqi materials
Specific gravity	ASTM C128-88(14)	2.63	-
Absorption, %	ASTM C128-88(14)	0.75	-
Dry loose- unit weight, kg/m3	ASTM C29-89(43)	1592	-
Sulphate content as SO3 ,%	I.O.S No.45/1984(42)	0.08	≤ 0.5
Material finer than 75µm sieve , %	I.O.S No.45/1984(42)	3.8	≤ 5

3.5 Water

Water is an important part of concrete because it actually participates in the chemical reaction with cement [12]. Since it provides strength for cement concrete, it requires very careful study of the quantity and quality of water. Tap water does not contain any harmful oils, acids, alkalis, sugars, salts and organic matter. Its PH value is 7.0±1, which complies with the requirements of IS: 456-2000. It is also used for mixing concrete and curing specimens.

3.6 Mix design

-Mix proportioning for a concrete of M30 is as follows:

a. Grade designation: M30

b. Type of cement: OPC Iraqi cement
c. Maximum nominal size of aggregate: 12.5 mm
d. Maximum water-cement ratio: 0.5
e. Workability (slump): 100 mm
f. Exposure condition: severe
g. Method of concrete placing: pumping
h. Degree of supervision: Good
i. Type of aggregate: crushed angular aggregate

Mixture proportion
Cement = 180 kg/m^3
Water = 90 kg/m^3
Fine aggregate = 270 kg/m^3
Coarse aggregate = 540 kg/m^3

3.7 Compressive strength (MPa)

Compressive strength test is the most common test conducted on concrete, because it is the desirable characteristic properties of concrete are quantitatively related to its compressive strength [12-13]. Compressive strength was determined by using Compression Testing Machine (CTM) of 2000 kN capacity. The compressive strength of concrete was tested using 100 mm x 100 mm x 100 mm cube specimens. The test was carried out by placing a specimen between the loading surfaces of a Compression Testing Machine (CTM) and the load was applied until the specimen fails. Three test specimens were cast for each proportion and used to measure the compressive strength for each test conditions and average value was considered. The average value of compressive strength of 3 specimens for each category at the age of 7 days, 28 days and 60 days are shown Fig. 3, below.

Fig. 3: Compressive strength machine test

Table 12: Compressive strength for the cubes

Sample No	Compressive strength (MPa) 7 days	Compressive strength (MPa) 28days	Compressive strength (MPa) 60 days
S0	35.7	47.3	48.1
S10%	28.7	35.4	40.7
S20%	29.3	46.2	50.6
S30%	32.5	47.7	54.4
S40%	32.9	45.1	56
S50%	33	43.2	55.5

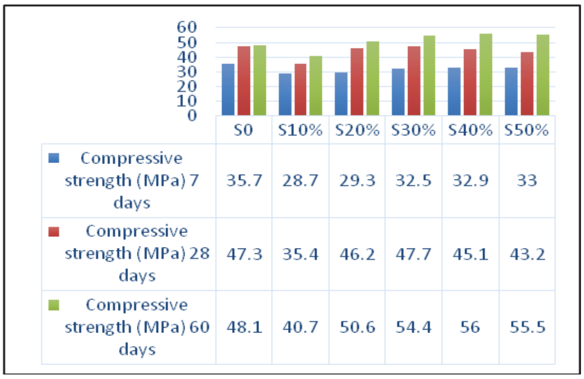

Fig. 4: compressive strength (MPa)

Figure 4 illustrates the comparison for compressive strength of a concrete that has been constructed within 7 days, 28 days and 60 days. As it can be seen from fig. 4 that the compressive strength for the control has been constructed and tested after 7 days tend to be nearly equal to the conventional concrete at approximately 50%. On other hand, there is moderate increase`s size and strength for the period of 28 days at 30% compare to the conventional concrete with 47.7 MPa and 47.3MPa respectively while in 60 days the result increase to 55.5 for the 50% and 56 for the replacement of 40%. In addition, it is clear that using porcelain as a replacement of the sand has good effect on the compressive strength development.

3.8 Splitting Strength (MPa) for the Cylinder

Comprehend of splitting strength of concrete is a very important sector to obtain the best results. Splitting strength was determined using Compression Testing Machine (CTM) of 2000 kN capacity. The split tensile strength of concrete was tested using 100 mm x 200 mm cylinder specimens and carried out by placing a specimen between the loading surfaces of a CTM and the load was applied until the failure of the specimen. Three test specimens were cast for each proportion and used to measure the splitting strength for each test conditions and average value was considered. The average values of 3 specimens for each category at the ages of 7 days, 28 days and 60 days are shown in the Figure 5.

Fig 5: Splitting tensile machine test

Table 13: Splitting strength (MPa) for the cylinder

Sample No	Splitting strength (MPa) 7days	Splitting strength (MPa) 28days	Splitting strength (MPa) 60days
S0	3.12	3.47	4.1
S 10%	3.17	3.32	4.04
S 20%	2.91	3.78	3.87
S 30%	2.79	4.41	4.42
S 40%	2.75	3.7	4.32
S 50%	3.24	4.06	3.9

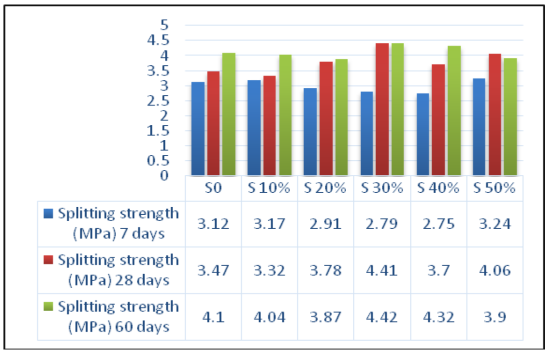

Fig.5: Splitting Strength (MPa) for the Cylinder

Figure 5 shows the comparison for splitting strength of a concrete that has been constructed within 7 days a, 28 days and 60 days. As it can be seen from fig. **5** that the splitting strength for the control sample has been constructed and tested after 7 days achieved a high strength at 50% compared to the concrete with replacement of porcelain over the sand at a small scale as in the 7 days 3.12 MPa and in the 50% increased to 3.24 and for the 60 days the control were 4.1 MPa while for the highest achieved on the 30% which is 4.42 MPa that approve that the porcelain replacement can increase from the splitting of the concrete which not good by the incensement of porcelain percentage . On other hand, there is a remarkable increase for the concrete after 28 days at 30% compare to the conventional concrete with 4.41 MPa and 3.47 MPa respectively.

3.9 Flexural Strength (MPa) for the Beam

Flexural strength is a measurement that indicates the resistance of a material to deformation when placed under a load. The values needed to calculate flexural strength are measured by experimentation, with rectangular samples of the material placed under load in a 2 point loading testing setup. The strength of a material in bending, expressed as the stress on the outermost fibres of a bent test specimen, at the instant of failure. Prism specimens were tested for flexural strength. The tests were carried out confirming to IS: 516-1959 (8). The specimens are tested under two-point loading. The average value of two specimens for each category at the age of 7 days, 28 days and 60 days is shown in Figure. 6.

Fig. 6: Flexural strength test

Table 14: Flexural strength (MPa) for the beam

Sample No	Flexural strength (MPa) 7days	Flexural strength (MPa) 28days	Flexural strength (MPa) 60days
S0	4.58	9.25	13.89
S 10%	3.18	7.37	9.34
S 20%	2.83	7.65	10.33
S 30%	3.163	8.73	12.76
S 40%	3.24	8.89	12.32
S 50%	3.37	8.05	12.63

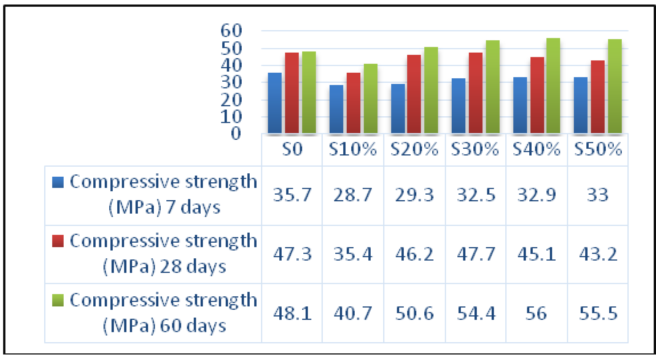

Fig. 6: Flexural strength (MPa) for the beam

Figure 6 shows the flexural strength of a concrete that has been constructed within 7 days, 28 days and 60 days. As it can be seen from figure that the flexural strength for the conventional concrete that has been constructed and tested after 7 days achieved a high strength at 50% compared to the conventional concrete. While for the 28 and 60 days the flexural had increment to 9.25 MPa and 13.89 MPa for the control sample respectively, while for the additive of porcelain replacement the achieved result were 12.76 for the 30% of replacement to the specimen On other hand, there is a remarkable increase for the concrete after 28 days at 30% compare to the conventional concrete with 4.41 MPa and 3.47 MPa respectively.

4. Conclusion

The modern approaches of porcelain replacement are being adopted by this experiment in order to produce sustainable concrete particularly in developing countries like Malaysia, Iraq, Iran, India and Yemen, among others, using new materials for the concrete with efficient and good effect to the improvement of the mechanical and physical properties of concrete. A number of the issues associated to the demolition waste of building and solid waste has been addressed by various researchers. However, the developments of concrete elements by substitute its materials such sand aggregate can be replaced by ceramic waste such as porcelain with high performance increasing the mechanical and physical properties to the concrete in general. This is why this study was undertaken to investigate the characteristics of porcelain as partially replacement of sand with 10%, 20%, 30%, 30%, 40%, and 50%. An extensive experimental work was carryout to address this issue associated with increase in demand of concrete for industries as well as for domestic purposes. A remarkable enhancement in compressive strength was observed due to increase in the ratio porcelain in the concrete mixture. Compressive strength was conducted in the entire sample with different ratio of porcelain at different period of time (7, 28, 60 days). It was observed that the mechanical strength of the concrete that have high ratio of porcelain at long period of time is high

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