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Mechanical Strength of Concrete by Replacement of Sand with Porcelain Waste with Addition of Superplasticizer

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Abstract— The demands for concrete increases on a daily basis, consuming a lot of natural resources such as sand and gravel, hence there is an urgent need to find suitable substitutes. This work is to determine the mechanical properties of concrete via substitution of sand with porcelain waste and the addition of superplasticizer. Three samples of concrete have been casted into cube, cylinder and beam. Superplasticizer and water were homogeneously mixed for 2 minutes and added to the composition of concrete for casting process. Then the samples were stored at room temperature for 24 hours and cured in a clean and fresh water tank instantly at different curing ages of 7, 28 and 60 days. The samples were then determined the compressive, splitting and flexural strength. The highest compressive, splitting and flexural strength were measured at 78.2 MPa, 5.64 MPa and 9.93 MPa respectively at 50 % replacement and 60 days. The usage of waste porcelain in concrete has a great potential in construction industry.

***Keywords*— Mechanical Strength of Concrete; Porcelain Waste; sand; Superplasticizer.**

I. INTRODUCTION

The concrete is used as construction material for sidewalks, bridges and skyscrapers as well as concrete pavements. It is a Portland material including gravel, sand, cement and water [1]. The water ratio to cementitious material used in the mixture affects many important characteristics of concrete. By reducing the amount of water, the cement paste will have a higher density, which leads to higher paste quality, thus leading to higher compressibility and bending strength, reduce permeability, increase weather resistance, and reduce the tendency of shrinkage and cracking [2,3]. A mixture is a material that is added to concrete to alter the properties of hardened and fresh concrete. The chemical additives include three basic categories, such as water reducers, air entraining agents and curing agents [4]. In addition, the use optimal dose of the mixture is also necessary, as little doses may lead to the loss of fluidity, excess may result in separation of superplasticizers, set delays and uneconomical use.

Ceramic industries, construction industries and demolished buildings are the main source of porcelain waste. Researchers estimated the amount of ceramic industry waste and put the value at about 30 % of the total production. Presently, the ceramic wastes are not sustainability recycled. Research shows that, porcelain wastes are normally hard, durable and have high chemical, biological and degradation forces resistance. Proper disposal of porcelain waste has been the major challenge of ceramic industries due to huge amount of waste produced daily [5]. Recently,

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a study is proposed by on the hardened and fresh concrete with the addition of porcelain waste as fine aggregate revealed and enhanced mechanical properties compared with the properties of conventional concrete [6]. Thus, it is further reported that, porcelain waste as coarse aggregate can be used in concrete for 10 % and 20 %, without affecting its structural significance [7].

Recently, from 2011 to 2012 more than 600 million square kilometers was covered with concrete materials which consume a lot of the available sand we have, hence a need for remedy to the issue at sake [8]. Due to government policies to promote a strong growth of the real estate industry, there is huge porcelain production as a result of prosperity of the housing sector [9]. In the porcelain industry, about 15% to 30% of total waste is generated from all production, although the reuse of porcelain waste has been recently introduced, the amount of waste recycled in this way is still negligible [10]. Therefore, its application is needed in many industries and cities development. The porcelain waste can be used in construction industry, and in this way can help solve this environmental problem [11].

Also fine aggregate is a natural resource which should be preserved. Highest percentage of wastes worldwide is about 75% and came from construction and demolition (C&D) wastes. Furthermore porcelain materials such as porcelain waste have the highest contribution rate in C&D waste (54%) [12]. The porcelain waste that is usually dumped at the industry area lead to environmental pollution causing effect to human lives and agricultural lands [13]. To avoid this situation, fine aggregate can be replaced fully or partially by materials like M-sand, quarry dust, saw dust, rice husk ash, and porcelain waste in concrete. Therefore, to reduce the consumption of natural resources, the advancement of concrete technology is paramount [14].

Increase the rheological properties of the hardened concrete, superplasticizers are widely used in concrete processing. Does not affect the solidification and hardening behavior of cement-based systems, superplasticizers are used which are chemical admixture that maintains sufficient processability of fresh concrete at low water/cement ratios in a reasonable amount of time,

A research on mechanical properties of concrete with addition of superplasticizer reported that, both physical properties and mechanical such as compressive strength and workability were found to increase [15]. Furthermore, the result revealed that hardened concrete properties improved by adding different types of superplasticizers, use of Glenium 140 clearly indicate a more pronounced and improved result, these include the concrete compressive strength, workability, water reduction, and cement saving requirements. It is therefore important to note that, by addition of superplasticizer the workability of concrete is improved. However, addition of huge amount of superplasticizer SP negatively affect to the cohesion of concrete. The use of chemical admixtures can reduce slump loss. However, the use of superplasticizer concrete is more effective.

II. MATERALS AND METHOD

A. Materials

Porcelain waste crushed by crusher machine is presented in Figure 1 and Figure 2 (a and b) which show the porcelain waste before and after grinding. Porcelain waste used in this study are brought from landfill in Baghdad. The Iraqi ordinary cement produce by the (ALjasar) cement factory was used. Natural gravel of mix size 12.5 mm as coarse aggregate, natural sand brought from AL-Ekadir zone and tap water was used. The superplasticizer (Sika ViscoCrete® -5930 L) is obtained from Sika Company. The chemical and physical properties of Portland cement compound from Central Organization for Standardization and Quality Control (COSQC) are shown in Table1 and Table 2.

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Fig. 1 crusher machine

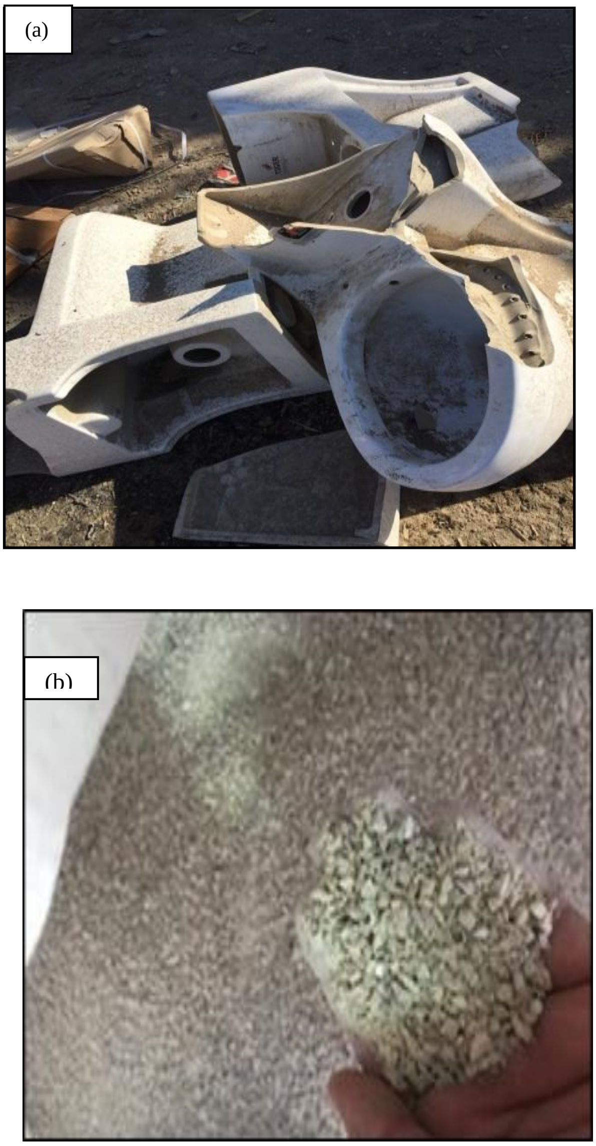

Fig. 2 (a) before grinding, (b) after grinding

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TABLE I
Chemical properties of cement

Abbreviation of Oxide	Weight Percent (wt%)	Limits of Iraqi Specification
SiO_2	19.90	-
CaO	60.80	-
MgO	1.50	≤5.0
Fe_2O_3	3.00	-
Al_2O_3	5.69	-
SO_3	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

Source: COSQC

TABLE II
Physical properties of cement

No.	Property	OPC
1	Specific Surface area (Blaine Method) m^2/kg	290
2	Setting time (Vicat Apparatus) Initial setting, hr:min Final setting, hr:min	1:48 4:47
3	Compressive strength, MPa 3 days 7 days	 25.6 31.8
4	Soundness (Autoclave Method) ,%	0.05

Source: COSQC

Table 3 and 4 show the chemical and physical properties of natural sand and physical properties of coarse aggregate and Table 5 shows the chemical properties of porcelain waste.

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TABLE III
Chemical and physical properties of natural sand

Property	Specification	Result	Iraqi Specification No.45/2002
Specific gravity	ASTM C128-88	2.63	-
Absorption, %	ASTM C128-88	0.75	-
Dry loose-unit weight, kg/m^3	ASTM C29-89	1592	-
Sulphate content as SO3 ,%	I.O.S No.45/1984	0.08	≤ 0.5
Material finer than 75μm sieve , %	I.O.S No.45/1984	3.8	≤ 5

TABLE IV
Physical properties for coarse aggregate

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

TABLE IV
Chemical properties of porcelain waste

Abbreviation of Oxide	% by weight
MgO	0.0255
Al_2O_3	18.74
SiO_2	59.76
P_2O_5	0.6293
SO_3	0.1325
Cl	0.3018
K_2O	1.895

Crushed porcelain waste and sand were sieved pass through sieve size of 4.75 mm to 0.15 mm.

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Table 6 shows the sieving percentage for the porcelain waste.

TABLE VI
Seiving percentage for porcelain waste

Sieve size (mm)	% passing	Remain
4.75	100%	0
2.36	59.8%	40.2
1.18	32.8%	27
0.6	18.4%	14.4
0.3	10%	8.4
0.15	5.6%	4.4
	0	5.6

B. *Method of Experimental Work*

Three different samples of concrete have been casted (cube, cylinder and beam) to measure the compressive, splitting and flexural strength. The standard cast iron mould is used for cube is 10 × 10 × 10 cm, for cylinder is 20 mm long × 10 cm diameter and for beam is 10 × 10 × 50 cm. To clean the mould and remove the particles from dust, mineral oil was applied to both sides of the mould. Superplasticizer and water were homogeneously mixed for 2 minutes and added to the composition of concrete. A three layer concrete are adopted and the mould is filled with concrete, at each layer a tamping rod is used 25 times. Hence a trowel is therefore used to remove the excess concrete from the surface and smoothened. After casting the samples are stored at room temperature in laboratory for 24 hours and the specimens are cured after removed from moulds in a clean and fresh water tank instantly with different curing ages at 7, 28 and 60 days. Mechanical properties such as compressive, splitting and flexural strength are conducted to determine the effect of replacement and addition of superplasticizer.

The mixing process of concrete was done according to IS 10262:2009, IS 456:2000 and IS 383:1997. Water-cement (w/c) ratio is 0.37. Table 7 and Table 8 show the quantities of the mixture for one cubic meter of concrete and replacement percentage from porcelain waste and also the added of super plasticizer at 0.75 wt. % of cement.

TABLE VII
The quantities of mixture for concrete

Materials	Quantity
Cement	180 kg
Sand	270 kg
Coarse aggregate	540 kg
Water	67.5 lit
Waste porcelain	67.5 kg
Superplasticizer	1.35 lit

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TABLE VIII
The percentage of porcelain waste and superplasticizer (0.75%) from cement weight

Porcelain waste (%)	Cement (kg /m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)	SP (lit)	Water (lit)
0	30	45	90	0.225	11.25
10%	30	40.5	90	0.225	11.25
20%	30	36	90	0.225	11.25
30%	30	31.5	90	0.225	11.25
40%	30	27	90	0.225	11.25
50%	30	22.5	90	0.225	11.25

III. RESULTS AND DISCUSSION

A. Compressive Strength

The compressive strength analysis is one of the most important part of the mechanical properties for concrete and it was carried out with compressive testing machine (CTM). For efficient testing, a force of 3000 KN was applied to the sample perpendicular to the surface of the cube until the sample is crack/break. The compressive strength of the cubes were determined at different curing ages of 7, 28 and 60 days and is presented in Table 9 and Figure 4.

Fig. 3 Machine Compressive

TABLE IX
Compressive strength with porcelain waste at different curing age

Sam ple No.	Compressive Strength (MPa) 7 days	Compressive Strength (MPa) 28 days	Compressive Strength (MPa) 60 days
S 0	47.1	52.3	57.2
S 10%	59.3	66.1	71.9
S 20%	63.3	71.3	73.4

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S 30%	64.8	71.7	75.8
S 40%	65.6	73.4	76.4
S 50%	64.4	72.3	75.2

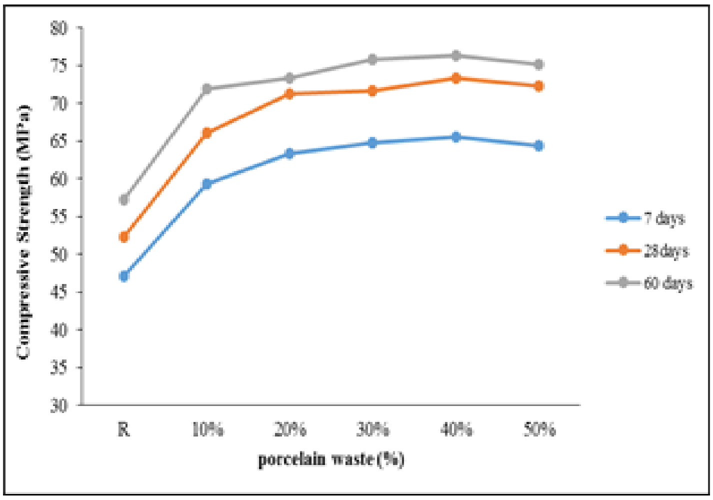

Figure 4: compressive strength with porcelain waste

Table 9 illustrates the result of the compressive strength of a concrete that has been cured within 7, 28 and 60 days. From Figure 4, for the control sample, curing period plays a vital role for the compressive strength were obtained 47.1, 52.3 and 57.2 MPa for 7, 28 and 60 days respectively. Then, it is worthy to note that, by adding porcelain waste at 10 wt.% of sand, the compressive strength significantly increases to 59.3, 66.1 and 71.9 MPa for 7, 28 and 60 days respectively. The maximum compressive strength was achieved at 50 wt. % addition of porcelain waste with the maximum value of 64.4, 72.3 and 75.2 MPa for 7, 28 and 60 days respectively. The increase in compressive strength is attributed to the addition of superplasticizer that lead to reduction for water to cement (w/c) ratio and subsequently increased the compressive strength.

B. Splitting Strength for Cylinder (MPa)

Splitting strength of concrete is a very important sector to obtain the best results. The “split tensile strength of concrete” was tested using 10 cm diameter × 20 cm long of cylinder specimens. The samples were placed between the surfaces of a CTM and the load was applied on the specimen until it’s failure. Three test specimens were moulded for each proportion. To estimate the splitting strength for each test conditions, the average value was considered. The average value of 3 specimens for each category at the ages of 7, 28 and 60 days are shown in the Table 10 and Figure 6.

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Fig. 5 Splitting Machine

TABLE X
Splitting strength with porcelain waste with different curing age

Sample No.	Splitting Strength (MPa) 7 days	Splitting Strength (MPa) 28 days	Splitting Strength (MPa) 60 days
S 0	3.93	4.53	4.63
S 10%	4.41	4.66	4.79
S 20%	4.6	5.2	5.31
S 30%	4.91	5.39	5.48
S 40%	5.2	5.48	5.56
S 50%	5	5.34	5.42

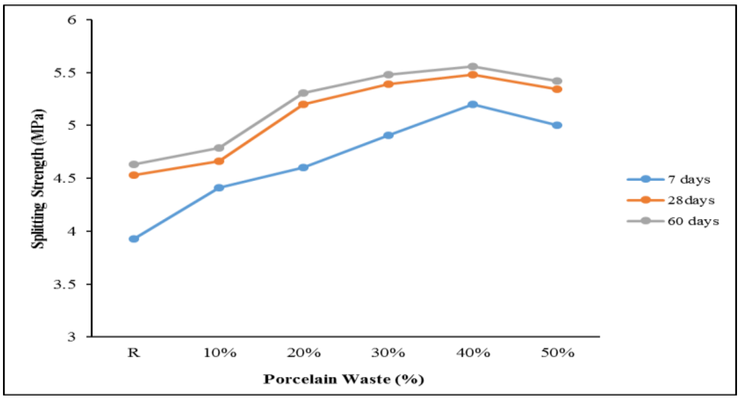

Fig. 6 Splitting strength with porcelain waste

Table 10 shows the result for splitting strength of a concrete that has been constructed within 7, 28 and 60 days. Figure 6 shows the splitting strength for the control sample was the minimum value for all the curing age as 3.93, 4.53 and 4.63 MPa for 7, 28 and 60 days respectively. As the addition of porcelain waste was introduced to the sample then the splitting strength increased for 10, 20, 30, 40 and 50 % respectively. The maximum value was attained at 50% addition as 5, 5.34

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and 5.42 MPa for 7, 28 and 60 days respectively. This can be attributed to the use of superplasticizer that leads to formation of continuous three-dimensional network of superplasticizer molecules throughout concrete which increases the binder system due to good bonding characteristic of the superplasticizer

C. Flexural Strength for Beam (MPa)

This measurement refer to the resistance of a material to the deformation when the samples were placed under a load and is called flexural strength. The average values of 3 specimens for each category at the ages of 7, 28 and 60 days are shown in the Table 11 and Figure 8.

Fig. 7 flexural Machine

TABLE XI
Flexural strength with porcelain waste with different ages

Sample No.	**Flexural Strength (MPa) 7 days**	**Flexural Strength (MPa) 28 days**	**Flexural Strength (MPa) 60 days**
S 0	7.17	7.65	7.89
S 10%	7.41	7.91	8.56
S 20%	7.69	8.28	8.89
S 30%	8.81	9.59	9.78
S 40%	9.13	9.62	9.88
S 50%	8.91	9.33	9.64

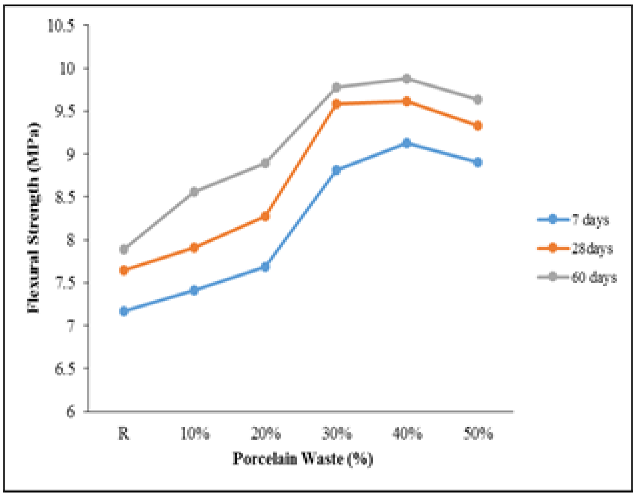

Fig. 8 Flexural strength with porcelain waste

Figure 8 shows flexural strength of concrete with substitution of porcelain waste with sand. It can be denoted that, the control sample has the lower flexure strength compare to the other samples. It is also important to note that, the addition of porcelain waste has significant impact on the flexural strength as the values keep increasing for 10, 20, 30, 40 and 50 wt. % of sand. The maximum strength reported was at 50 wt. % of sand as 8.91, 9.33 and 9.64 MPa for 7, 28 and 60 days respectively. This trend is pronounced to be due the use of superplasticizer leads to the formation of continuous three-dimensional network of superplasticizer molecules throughout concrete which increases the binder system due to good bonding characteristic of the superplasticizer.

IV. CONCLUSION

Porcelain waste is clearly indicated to be good alternative used as sand in concrete production. From this result it is inferred the increases of strength gradually with the increament in replacement of porcelain waste and superplasticizer. It was noted that 40 % replacement of porcelain waste yield higher strength and give better results than other percentage and control mix. It was also observed that at 50 % replacement, the mechanical properties decreased slightly and could be attributed to the effect of superplasticizer which reduced the water cement ratio, thus reducing the workability which lead to decrease in the mechanical properties. Therefore, it is concluded that porcelain waste can be used as sand replacement in concrete up to 40 % with addition of superplasticizer there by improving the strength as well as saving the natural resources. The effect of superplasticizer on concrete is an important factor where it gave coherence and lead to increase of the workiability of concrete thus increase the mechanical strength.

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