Properties and Sustainability of Ceramic Waste Concrete

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***Abstract*—The utilization of different types of industrial wastes is considered an essential tool to achieve sustainable development and reduce the environmental deterioration. Ceramic Waste Powder (CWP) is a by-product of the ceramic industry, resulting from polishing of ceramic tiles. The utilization of CWP will not only reduce the dumped solid waste and the required landfills, but it can also be utilized as a supplementary cementitious material in concrete, as a cement replacement, which will increase the sustainability and help protecting the environment for the future generations. CWP was used as a partial replacement of cement in different percentages (0%, 15%, 30% and 45%) with two W/C ratios (0.4 and 0.6). Fresh and hardened concrete properties were examined and tested such as (slump, unit weight, compressive strength, split tensile strength, absorption, and electrical resistivity). Also, the characteristics of CWP were investigated (chemical composition analysis, particle size distribution and pozzolanic reactivity). XRF analysis of CWP showed a good indication of being a pozzolanic material by having more than 70% silicon oxide (SiO_2). It was found that the introduction of CWP shows improvement and acceptable results in concrete properties. The optimum value of 15% resulted in increasing compressive strength, increasing tensile strength, reducing absorption, increasing modulus of elasticity and toughness, and improving electrical resistivity and corrosion rate. Higher values, up to 30%, maybe also used for greener more sustainable concrete with an acceptable reduction in properties.**

***Keywords*—ceramic waste powder, concrete, durability, sustainability**

I. Introduction

Sustainable or green buildings is designing, constructing, and perfectly maintaining the buildings to use minimum pollution and cost in order to increase the comfort, health, and safety of the people in them. It is also considering the interrelationships between a building, its components, its surroundings and its occupants. Sustainability considerations are essential to assure the continuation of life on earth. Sustainable developments will result in saving resources and raw materials for the coming generations. Waste material recycling through utilization in concrete manufacturing will not only provide promising resources to produce a high-quality concrete, but also helps to properly encounter the problem of solid waste and associated landfills. The utilization of some type of pozzolanic material is one of the concrete durability improvement methods especially in the presence of both sulphates and chlorides such as in Kuwait [1]. Slag and fly ash are the most common types of pozzolanic materials. However, those types are imported which reflects on the concrete cost. Utilization of other locally available pozzolanic materials such as crushed glass and rice husk has been investigated [2].

Recently many researches and experiments were performed on the utilization of recycled ceramic waste in concrete. Ceramic waste powder which results from the polishing process of ceramic tiles possess a pozzolanic properties [3]. It is also produced locally in more than one factory. Therefore, CWP is available in Kuwait and may be utilized in concrete production. The utilization of Ceramic Waste Powder (CWP) will mainly protect the environment, achieve sustainable development and use cheaper concrete ingredient that is equivalent to other Supplementary Cementitious Material (SCM) already used in concrete industry.

Ceramic waste may be used as aggregates or ground and used as cement replacement. Ceramic waste can be used as replacement materials for river sand in concrete and satisfies the compressive strength with 10% & 20% replacement [4]. De Brito *et al.* [5] investigated the mechanical behavior of non-structural concrete made with recycled ceramic aggregates intended for the production of 50 mm thick pavement slabs. Senthamarai and Devadas [6] examined the concrete with ceramic waste aggregate. A similar investigation carried out by Guerra *et al.* [7], reported the effects of using recycled ceramic material from sanitary installations on the mechanical properties of concrete.

Another recent work carried by Kanaan and El-Dieb [8], found that using Ceramic Waste Powder (CWP) as an ingredient to partially replace cement in concrete have a positive and progressive environmental impact in addition will help reserve natural resources. A similar study was done by Vaniya [9], in using of ceramic waste powder in concrete would benefit in many ways in saving energy & protecting the environment. In other research study the (OPC) cement has been replaced by ceramic waste powder [10], which improved mechanical properties.

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The use of nano-SiO_2 can improve the effects of ground ceramic powder on the properties of concrete [11]. Work on ceramic waste also includes the characterization of ceramic waste powder [12], the use of ceramic waste in foamed light weight concrete [13] and the utilization of waste broken tiles in concrete [14].

In the current study the use of waste ground ceramic produced in Kuwait, as a pozzolanic partial cement replacement in concrete was investigated.

II. Materials, Mix and Samples Preparations

The Ceramic Waste Powder (CWP), Fig. 1, used in this study was produced from the polishing process of final ceramic tiles in National Industries Ceramic Company. The Factory located in Shuaiba Industrial Area, Kuwait. During the factory visit, it is found that the industry produced about 1 ton of CWP per day. As this is not the only factory producing ceramic, it is estimated that the total amount produced in Kuwait from the ceramic industries is about 2 tons per day. Therefore, the estimated total amount will be around 730 ton/year in Kuwait. This waste is not reused in any form and they are dumped away in nearby pits which causes pollution in the environment. CWP was delivered wet from the factory and it was dried under 105 ℃ for 48 hours.

Figure 1. Ceramic waste powder.

Ordinary Type I cement produced in Kuwait and complying with the Kuwaiti Standard Specifications (KSS 381-383) and the American Standard Specifications (ASTM C150-05) was used. Locally produced sand was used in the mix with Gabbro quartzite coarse aggregates imported from UAE were used. Three sizes of aggregates of 9.5 mm (3/8), 12.5 mm (1/2) and 19 mm (3/4) were used as coarse aggregate in Saturated Surface Dry (SSD) condition.

The mix was designed with two different W/C ratios of 0.4 and 0.6. The mix was designed for about 40 MPa strength and 50–100 mm slump. Superplastisizer admixture was introduced to achieve the required workability. The mix design is shown in Table I.

CWP was introduced as partial cement replacement. Four different replacement ratios of 0% (control mix), 15%, 30%, and 45% were used for each mix.

TABLE I. Mixture Proportion (Per 1 m3)

Material Used	Weight Value	
W/C	0.4	0.6
Cementitious Materials (Kg/m^3)	410	410
Water (Kg/m^3)	164	246
Sand (Kg/m^3)	705	705
SSD Coarse Aggregate 3/8” (Kg/m^3)	500	500
SSD Coarse Aggregate 1/2” (Kg/m^3)	340	340
SSD Coarse Aggregate 3/4” (Kg/m^3)	260	260
Super-Plasticizer Dosage (L/100Kg CM)	variable	variable
Air Temperature (°C)	22-23	22-23

CWP was tested for chemical composition using XRF analysis, Table II. The XRF analysis indicates that the material contains more than 70% silicon Oxide, indicating that the CWP has a high chance of being a pozzolanic material.

The material was also tested for size distribution using the Milli-Q apparatus, Fig. 2. The results, Fig. 3, indicate that more than 95% of the CWP has a size of about 1.1 μm.

96 concrete cubes of 150 mm dimensions and 88 cylindrical specimens of 150 mm diameter and 300 mm height were cast, compacted and cured under water

TABLE II. XRF Analysis for CWP

Oxide	SiO_2	Al_2O_3	Na_2O	MgO	K_2O	CaO	Fe_2O_3
%	73.15	15.92	3.57	2.47	2.18	0.99	0.77

Oxide	ZrO_2	SO_3	TiO_2	P_2O_5	MnO	Rb_2O	ZnO
%	0.45	0.03	0.22	0.04	0.03	0.02	0.01

III. Results and Discussion

A. *Fresh Concrete Results*

Concrete was tested for workability using the slump test and for air content. Results are shown in Table III, where the slump was found to be almost in the required range except for mix4 where the maximum amount of superplastisizer (SP) was used. It is clear that the increase in the CWP percentage reduce workability. Unit weight and specific weight were also determined as shown in Table IV. It can be seen that the use of CWP reduce the unit weight of the resulting concrete.

B. *Hardened Concrete Results*

Cubes and cylinders were tested for compressive strength after 7, 28 and 56 days. The average cube compressive strength is shown in Figs. 4 and 5 respectively for the used W/C ratios of 0.4 and 0.6. It can be seen that the strength increases with time and that the optimum CWP percentage is 15% for the 0.4 mix which resulted in a noticable increase in strength especially after 56 days where an increase of 20.5% was detected. For weak mix of 0.6 W/C the use of CWP did not increase the strength. Same results were obtained for the cylinder specimens.

Split tensile strength for all mixes were determined for all mixes using standard cyclinders cured for 28 days, Figs. 6 and 7. As for compressive strength the optimum tensile strength for the 0.4 W/C mix of 3.47 MPa was noticed for the 15% CWP and for the 0.6 W/C ratio the maximum tensile strength was noticed for the mix without CWP. The introduction of 15% CWP increased tensile strength by 50.2%.

Absorption after water immersion and boiling was also detrmined for all mixes after 28 days of curing. Test samples are cylinders of 80 mm in height and 73 mm in diameter that were prepared from cubes using core cutting machine as shown in Fig. 8.

The results are shown in Fig. 9. The lowest absorption, which is an indication of higher durability, was noticed for the 0.4 W/C mix with 15% CWP where a reduction of 3.7% was noticed. For mixes with W/C ratio of 0.6, the introduction of CWP resulted in an increase in absorption.

Corrosion is the most common cause of deterioration in Kuwait due to high temperature. The durability of mixes containing CWP was investigated through determining the electrical resistivity and the corresponding corrosion rate. Concrete electrical resistivity can be measured by applying a current into the concrete and obtaining the response voltage. The four-point method (Wenner Probe) which is nondestructive, fast and simple method was used in this study, Fig. 10. The resulting average electrical resistivity and corrosion rates are shown in Table V. It is clear that the introduction of CWP increases the electrical resistivity and improve durability especially for the 0.4 W/C ratio. The electrical resistivity was found to increase with the increase in the CWP ratio. Highest value of 19 KΩ.cm was noticed for the 0.4 W/C with 45% CWP. The increase in electrical resistivity with the CWP percentage for both W/C ratios is also shown in Fig. 11.

Figure 2. Millie-Q apparatus.

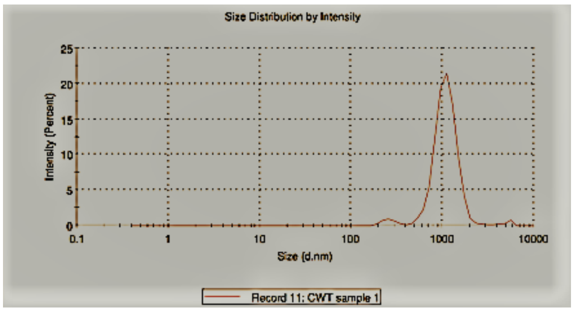

Figure 3. CWP size distribution.

TABLE III. FRESH CONCRETE PROPERTIES

#	Mix #	W/C	CWP %	SP (Kg)	Slump (mm)	Air (%) Content
1	1	0.4	0	0.948	45	2.8
2	6	0.4	15	1.422	40	2.8
3	7	0.4	30	1.896	52	2.6
4	8	0.4	45	2.370	25	3.0
5	2	0.6	0	0.275	64	2.6
6	3	0.6	15	0.460	91	2.3
7	4	0.6	30	0.645	95	2.4
8	5	0.6	45	0.830	93	2.1

TABLE IV. UNIT WEIGHT AND SPECIFIC GRAVITY

#	Mix #	W/C	Wt. (g)	Unit Wt. (Kg/m^2)	S.G.
1	1	0.4	3510.1	2402.9	2.403
2	6	0.4	3534.9	2427.7	2.428
3	7	0.4	3506.3	2399.1	2.399
4	8	0.4	3489.7	2382.5	2.383
5	2	0.6	3422.4	2315.2	2.315
6	3	0.6	3378.4	2271.2	2.271
7	4	0.6	3401.2	2294.0	2.294
8	5	0.6	3381.7	2274.5	2.275

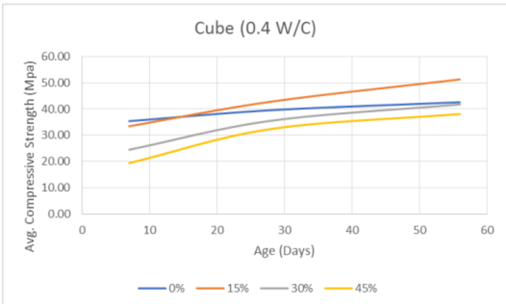

Figure 4. Compressive strength for 0.4 W/C.

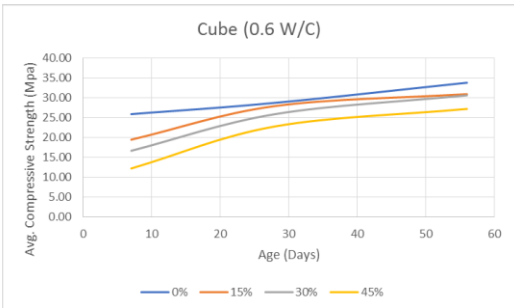

Figure 5. Compressive strength for 0.6 W/C.

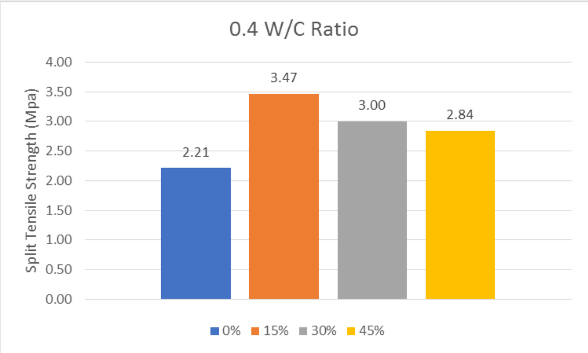

Figure 6. Split tensile strength for 0.4 W/C.

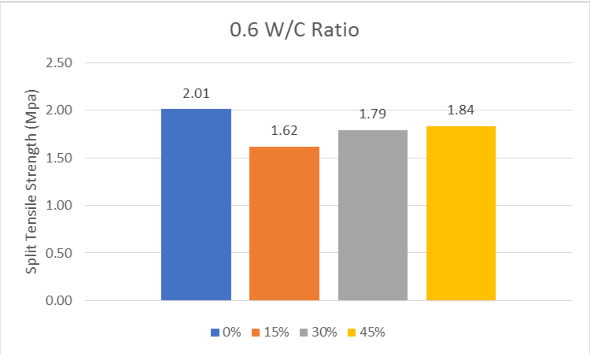

Figure 7. Split tensile strength for 0.6 W/C.

Figure 8. Absorption cores cut from cubes.

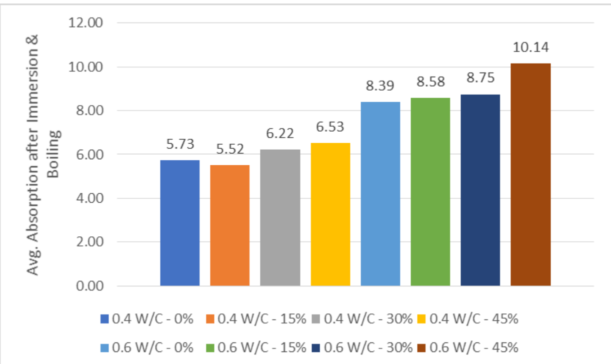

Figure 9. Absorption values for all mixes.

Figure 10. Electrical resistivity measurement.

C. *Pozzolanic Reactivity*

The chemical analysis of CWP indicated the high possibility of pozzolanic reactivity as mentioned before. The pozzolanic reactivity was assured by calculating the Strength Activity Index (SAI) using mortar cubes. Control mortar was prepared by mixing 1350 g of Ottawa sand, 450 g of cement type I and 225 g of water. The blended mortars were prepared with 15%, 25%, 30% and 45% of the cement mass replaced by CWP. Mortar was mixed for 4 minutes and cast in 50mm cubes. Samples were cured for 28 days. SAI was calculated as:

$$SAI = A/B \times 100$$

where:

A = is the unconfined compressive strength of the pozzolan mortar (Mpa)

B = is the unconfined compressive strength of the control mortar (Mpa)

The SAI for the 15, 25, 30 and 45% CWP were found to be 103.22, 109.59, 104.31 and 93.32, respectively. Thus, as stated by ASTM C618, the SAI results at 28 days which are more than 75% indicate acceptable pozzolanic reactivity. CWP is, therfore, a pozzolanic material.

TABLE V. AVERAGE ELECTRICAL RESISTIVITY

Mix #	W/C	CWP %	Avg. Electrical Resistivity KΩ.cm	Corrosion Rate
1	0.4	0	8.75	High
2	0.6	0	4.60	Very High
3	0.6	15	6.55	High
4	0.6	30	11.45	Low to Moderate
5	0.6	45	17.575	Low to Moderate
6	0.4	15	12.75	Low to Moderate
7	0.4	30	18.425	Low to Moderate
8	0.4	45	19.025	Low to Moderate

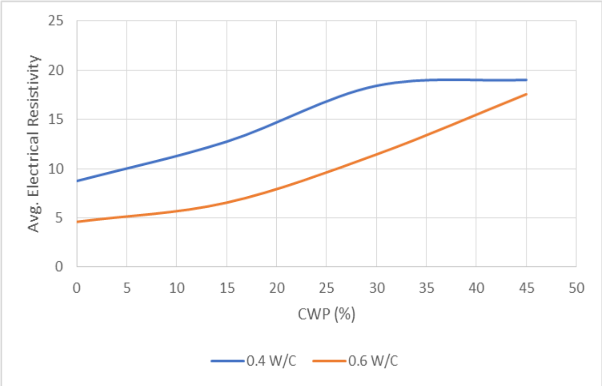

Figure 11. Increase in electrical resistivity with CWP%.

IV. CONCUSIONS

The use of Ceramic Waste Powder as partial cement replacement in concrete production was investigated. The following may be concluded:

- CWP is available in Kuwait. Its amount is estimated as 730 tons per year.
- CWP is finer than cement and contains more than 70% Silicon Oxide.
- The introduction of CWP in concrete reduce workability, air content and unit weight of resulting concrete.
- The CWP mixtures requires a prolonged curing time in order to gain higher strength.
- Highest compressive strength was achieved for the W/C ratio of 0.4 and 15%CWP. CWP did not increase the strength for the 0.6 W/C mixes.
- As for compressive strength, tensile strength increased for 15% CWP for the 0.4 W/C mix.
- Absorption was increased with the introduction pf CWP except for the 15% CWP, 0.4 W/C mix.
- The introduction of CWP was found to increase electrical resistivity and reduce possibility of corrosion.
- CWP was found to be pozzolanic material
- The introduction of CWP will increase concrete sustainability as it will reduce the amount of cement by the same ratio, reduce solid waste and increase resulting concrete durability.
- It is recommended to use 15% CWP as cement replacement with low W/C ratio. This will increase compressive strength and tensile strength, reduce absorption, reduce corrosion and increase sustainability.

CONFLICT OF INTEREST

The authors declare no conflict of interest related to this submitted work.

AUTHOR CONTRIBUTIONS

Moetaz M. El-Hawary initiated the research idea and the research steps and reviewed the results; Mubarak performed the experimental work. Both authors participated in writing the paper, and had approved the final version.

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