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CERAMIC WASTE POWDER AS SUPPLEMENTARY CEMENTING MATERIAL IN CONCRETE MIXTURES

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Green environment is a challenging concern to accomplish in today's world. This could be achieved through a beneficial recycling procedure by reusing solid waste materials. Ceramic tiles are widely used in most structures; its production creates waste powder. Concrete that contains solid waste is referred to as "Green" concrete. Using ceramic waste powder (CWP) as an alternative ingredient in concrete will have a positive environmental impact furthermore will help reserve natural resources. In this study CWP will be investigated as supplementary cementing material (SCM) in making concrete. The ceramic waste powder will be used as SCM with different dosages replacing cement. The effect of ceramic waste powder as SCM on the properties of fresh concrete will be investigated such as slump, slump loss and setting time. The properties of hardened concrete will be assessed through compressive strength development, drying shrinkage and durability characteristics was evaluated by rapid chloride permeability test (RCPT) and bulk electrical resistivity. Test results show that CWP can be used as SCM in making concrete. The outcomes of the study shed light on how CWP could be utilized effectively as an alternative ingredient of concrete and the optimum dosage for use which will result in an effective way for using solid waste and protecting the environment.

Keywords: Green Concrete, SCM, Replacement level, Fresh concrete, Hardened concrete, Compressive strength, Durability.

1 INTRODUCTION

Construction industry has been looking for techniques that might effectively decrease the elevated energy and environmental impacts of cement making. Production of 1 ton of Portland cement is an energy intensive process and also generates about 1 ton of CO_2 (Chindaprasirt *et al.* 2007), which represents about 7% of the global green-house gas produced annually. The use of industrialized solid wastes in concrete-making to partially replace cement will lead to a greener environment. This concern has drawn the attention of several investigators all over the world. Usage of substitution materials as partial or complete replacement of cement is considered an efficient solution. Silica fume, fly ash and slag are used as supplementary cementing materials (SCM) in daily concrete production (Van Deventer *et al.* 2012). This step has made its effect on reducing the CO_2 emission. With Abu Dhabi development plans, there will be an increasing demand on cement and therefore an expected increase in CO_2 emission which will have negative impact on the environment and the society.

Ceramic tiles production creates waste powder (CWP). In Abu Dhabi, the average ceramic waste powder produced from one company is estimated at 10,000 tons/year. This brings a major challenge with respect to its environmental impact. On the other hand, it represents a good opportunity as an alternative concrete ingredient if it could be utilized in making concrete. Several studies investigated the use of ceramic waste powder as an alternative ingredient in concrete (Pacheco-Torgal and Jalali 2010, Senthamaria *et al.* 2011, Medina *et al.* 2013) and concluded that ceramic waste powder (CWP) has the potential to be used as a concrete ingredient but needs further investigations.

2 STUDY OBJECTIVES

Evaluate the suitability of CWP to be used in concrete as alternative ingredient. The CWP will be utilized as a SCM in concrete mixtures with different dosages to assess its effect on fresh and hardened concrete properties.

3 EXPERIMENTAL WORK

3.1 Methodology

The study includes two experimental phases. Phase one involves several tests on the CWP as received to determine its characteristics such as moisture content, specific surface area, and particles' shape. Also, the main oxides of its chemical composition will be examined. The morphology of the ceramic waste powder whether crystalline or amorphous will be examined by X-ray diffraction (XRD). In Phase two, the ceramic waste powder will be used as cement replacement with different mass replacement (0, 10, 20, 30 and 40 %) as SCM in concrete mixtures with different strength grades (25, 50 and 75 MPa). The effect of using CWP on the fresh and hardened concrete properties will be studied. For fresh concrete, slump, slump loss and setting time will be measured. For hardened concrete, compressive strength development and drying shrinkage will be measured. Durability will be assessed through rapid chloride permeability test (RCPT) and bulk electrical resistivity. Chloride ions permeability and electrical resistivity were used as durability indices of the concrete which mainly depends on the microstructure of the concrete. In this paper only the results of the 25 MPa mixtures are reported.

3.2 Materials

Ceramic waste powder was obtained from the polishing process of final ceramic products from a ceramic factory in Abu Dhabi, UAE. The ceramic powder was delivered as wet powder as produced from the factory. The as-delivered ceramic powder was dried in an oven at 110^{o}C for 24 hours. The average moisture content was 36% by mass. Due to the process of producing the ceramic waste powder, many dried ceramic powder particles coagulated together in several large particles, which could be manually subdivided back into powder particles. In this study the dried CWP was ground to an average specific surface area 537 m^2/kg. It should be noted that the main composition are SiO_2 and Al_2O_3. They represent 84.4% by mass, with 67.5% SiO_2 and 16.92% Al_2O_3. Also, the CWP included very small mass percentages of calcium oxide (CaO), magnesium oxide (MgO), sodium oxide (Na_2O) and potassium oxide (K_2O). Scanning electron microscope (SEM) image of the ceramic powder showed that it consists of irregular and angular particles that resemble cement particles in shape. The XRD analysis showed that 67% of the ceramic powder is amorphous material.

Cement used in this study was ordinary Portland cement (i.e. Type I). The coarse aggregate was natural crushed stone with nominal sizes of 10 and 19 mm (mixed in 1:1 by mass), with a specific gravity of 2.65, and absorption of 1.0%. Two types of sand, mixed in 1:1 by mass, were used in the mixture namely crushed natural sand with fineness modulus of 3.5 and specific gravity of 2.63, and dune sand with fineness modulus of 0.9 and specific gravity of 2.63. The concrete mixture was designed to have a slump ranging from 80 to 100 mm. Concrete ingredients proportions of the 25 MPa mixture is given in Table 1.

Table 1. Ingredients proportions for 1 cubic meter for the 25MPa concrete mixture.

Cement (kg)	Fine Aggregate (kg)	Coarse Aggregate (kg)	W/C
310	749	1102	0.61

3.3 Specimens and Testing

Compressive strength test was conducted at 7 days and 28 days of age. The rapid chloride permeability (RCPT) and bulk electrical resistivity tests were conducted at 28 days of age. The compressive strength and bulk electrical resistivity tests were conducted on concrete cubes (100x100x100 mm). The RCPT test was conducted on concrete discs with a thickness of 50 mm cut from 100 mm diameter cylinders. Drying shrinkage was conducted on 80x80x300 mm prisms. The tested specimens were freshly fractured pieces. Tests were conducted on 3 replicates and the average values were used in the analysis.

4 RESULTS AND DISCUSSIONS

4.1 Fresh Concrete

4.1.1 *Slump and slump loss*

The initial slump and slump values with time are shown in Figure 1. The control mix achieved a slump value of 110 mm. As the replacement level of CWP increased the initial slump value decreased except for the 10% replacement level. This could be attributed to the high specific surface area of the CWP compared to that of the cement which is approximately 1.5 times that of cement. The slump values decreased with time owing to the hydration of the cement. For the control mixture the slump reached “zero” after 45 minutes. It was observed that for the mixtures including CWP the slump loss has reduced (i.e. slump retention increased), the slump values reached “zero” at around 90 minutes indicating good slump retention. This could be attributed to the fact that the CWP has little hydraulic reaction due to its very low CaO content and its reaction is mainly pozzolanic, therefore, will not consume water at the beginning of the mixing rather its reaction will be at later age.

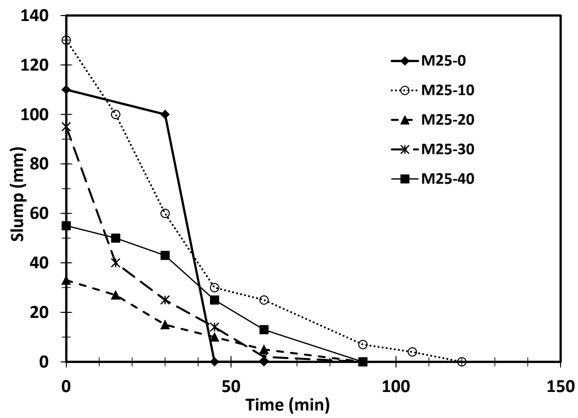

Figure 1. Slump and slump loss with time.

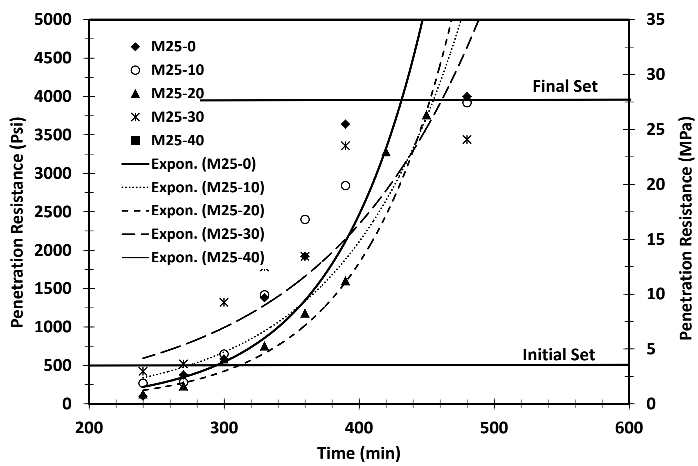

Figure 2. Setting time for M25 mixtures.

4.1.2 *Setting time*

Using CWP as SCM influenced the concrete setting time of the concrete mixture by showing moderate retardation. The influence on the initial setting time was not significant as it was on the final setting time. Mixtures with CWP up to 30% replacement levels showed final setting retardation from 20 to 30 minutes compared to the control mixture, while the mixture with 40% CWP showed 78 minutes retardation of the final setting, as shown in Figure 2. It should be highlighted that the addition of CWP increased the quantity of fine materials in the mixes so the content and rate of bleeding of these mixtures was reduced. With the bleeding reduction and retarded setting, moderate plastic shrinkage cracking were observed.

4.2 Hardened Concrete

4.2.1 *Compressive strength*

Properties of the hardened concrete are given in Table 1. Inclusion of CWP increased the 28 days compressive strength compared to the control mixture. The results at 7-days strength for high CWP % were lower than the control mixture which might be due to the fact that CWP has no hydraulic reaction to contribute to the early age strength rather its pozzolanic reaction contributes to the 28 days strength.

4.2.2 *Drying shrinkage*

Table 1 shows the 60 days drying shrinkage strain. It was noticed that the drying shrinkage for the mixtures including 10% and 20% CWP did not differ significantly than the control mixture. Using CWP with replacement levels 30% and 40% resulted in increasing the drying shrinkage by 10% to 24% respectively, compared to the control mixture.

Table 1. Hardened concrete properties of the M25 mixtures.

Mix I.D.	CWP %	Compressive Strength (MPa) 7 Days*	Compressive Strength (MPa) 28 Days*	60 Days Dry Shrinkage (με)*	28 Days RCPT (coulombs)*
M25-0	0	19.6 (2.27)	22.7 (1.10)	2650 (242)	4691 (657)
M25-10	10	20.4 (0.10)	27.8 (0.29)	2777 (477)	2899 (727)
M25-20	20	19.6 (2.27)	26.8 (0.91)	2555 (103)	1517 (289)
M25-30	30	17.2 (0.50)	25.5 (1.80)	3296 (473)	864 (57)
M25-40	40	15.6 (0.25)	25.0 (1.55)	2942 (77)	589 (28)

* Values between parentheses are standard deviation of measured replicates

4.2.3 *Rapid chloride permeability test (RCPT)*

RCPT values are given in Table 1. The chloride permeability of the control mixture is classified as “High”. The inclusion of the CWP resulted in significant decrease in the total charge passing as the CWP dosage increased. The chloride permeability of the 10% and the 20% CWP is classified as “Medium” and “Low” respectively, while mixtures with 30% and 40% CWP is classified as “Very Low” which indicates very high resistance to chloride penetration and hence very good protection to corrosion. This improvement could be attributed to the pozzolanic action of the CWP and its role in densifying the concrete microstructure.

4.2.4 *Bulk electrical resistivity*

Figure 3 shows the measured bulk electrical resistivity and the corrosion protection level. The control mixture showed moderate corrosion protection. It was noticed that including CWP increased the electrical resistivity of the mixtures and the increase was proportional to the CWP replacement level. Using 20% CWP as cement replacement improved the corrosion protection to high level while using 30% and 40% significantly increased the resistivity values to very high corrosion protection. This could be attributed to the pozzolanic reaction of CWP which leads to denser microstructure and lower pores' connectivity as observed in the RCPT results.

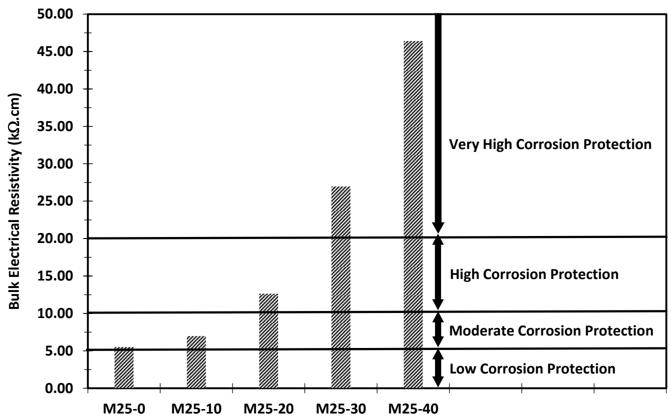

Figure 3. 28 days bulk electrical resistivity and corrosion protection level of M25 mixtures.

5 CONCLUSIONS

The experimental study indicated that ceramic waste powder "CWP" and its use as "SCM" in concrete production is feasible and beneficial. Fresh concrete properties showed that the addition of CWP to the concrete mix improved its workability retention and had modest retarding effect. CWP mixtures were sensitive to dry conditions especially with the delay of the setting time and reduced bleeding. Modest contribution to 28 days strength was achieved using CWP (i.e. 10 to 23%). Inclusion of CWP resulted in significant improvement of the concrete durability.

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