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CERAMIC WASTE POWDER: AN ALTERNATIVE INGREDIENT FOR GREEN CONCRETE

SAMA ALY[1], DIMA KANNAN[1], AMR EL-DIEB[1], MAHMOUD REDA TAHA[2], and SAMIR ABU-EISHAH[3]

[1]*Civil & Environmental Engineering, United Arab Emirates University, UAE*
[2]*Civil Engineering, University of New Mexico, USA*
[3]*Chemical & Petroleum Engineering, United Arab Emirates University, UAE*

Producing "greener" concrete that meets various construction/industrial needs will have significant positive impacts on both the construction field and the environment. This paper investigates the use of ceramic waste powder (CWP); a waste material from the final polishing process of ceramic tiles, in producing different concrete types; conventional concrete (CV), self-compacting concrete (SCC), and geopolymer concrete. The conducted study highlights the feasibility of using CWP as a cement replacement in producing conventional concrete, as a filler and cement replacement in making SCC, and as a main binder in developing geopolymer concrete. The study signifies the promising opportunities of utilizing CWP as an alternative ingredient in producing green concrete. Different concrete mixtures were prepared and tested for various properties: slump retention for conventional concrete, flowability, passing ability, segregation resistance and viscosity for judging fresh properties of SCC. Strength development for all three concrete types, chloride ion permeability for evaluating the durability characteristics of conventional and SCC, in addition to resistivity test for the produced geopolymer. Results indicated that CWP can be used 10-30% as partial replacement of cement in CV, and 40% in SCC for producing concrete with acceptable fresh and hardened properties. While for the geopolymer a main conclusion was the use of alkali activating solutions with a concentration of 12M to obtain compressive strength for structural applications.

Keywords: Conventional concrete, Self-compacting concrete, Geopolymer, Sustainability.

1 INTRODUCTION

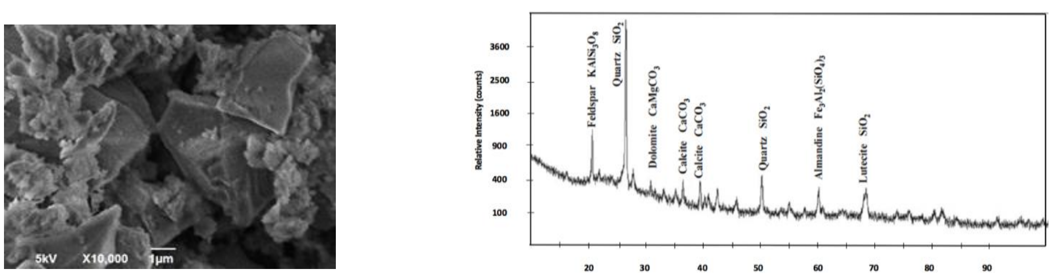
The concrete industry is keen to successfully integrate into the world of sustainable construction. The key objective is to reduce the reliance on Portland cement, which is the main ingredient in concrete production as it unfortunately imposes huge unfavorable environmental impact during its manufacturing process. The current use of the natural resources places huge strains on the environment in terms of pollution and depletion of natural resources. The challenge is to produce green concrete that is durable and sustainable with the maximized use of industrial waste by-products. Sustainability in concrete industry can be implemented through partial (i.e., conventional and self-compacting concrete) or complete cement replacement (i.e., geopolymer). This study reports the use of ceramic waste powder (CWP); a waste material from the final polishing process of ceramic tiles, to act as a sustainable replacement for cement. The efficient utilization of the large unused amounts of this waste material will contribute significantly towards having a greener environment and offering a safe alternative for the disposal of the waste material instead of landfills. This powder was incorporated into concrete lately by multiple researchers (Cheng *et al*. 2016) and (Steiner *et al*. 2015), yet it needs further investigations to understand its promising opportunities in the field of making green concrete.

2 EXPERIMENTAL INVESTIGATION

2.1 Materials

Ordinary Portland cement Type I conforming to ASTM 150 was used. Natural crushed stone was used as coarse of aggregate with maximum size of 10 mm and 19 mm. The bulk specific gravity and water absorption of the coarse aggregate were 2.65 and 1% respectively. Natural crushed sand (i.e., C. Sand) and dune sand (i.e., Dune) were used are fine aggregates. The bulk specific gravity was 2.63. The fineness modulus values were 3.5 and 0.9 for the crushed sand and the dune sand respectively. Two types of chemical admixtures were used; polycarboxylic ether based superplasticizer (SP) Glenium® sky 504 and a high molecular weight synthetic co-polymer viscosity modifying admixture (VMA) RheoMATRIX® 110 to improve the rheological properties of the SCC mixtures.

Chemical analysis of CWP was conducted and showed SiO_2 to form about 69.4% of the material. Furthermore, alumina also represented another major compound of CWP making about 18.2%. The total silica and alumina oxides in CWP exceed 80% of the total material weight. Specific surface area (SSA) measurements using Blaine fineness method showed CWP to have SSA of 555 m^2/kg. The morphology of CWP was observed using scanning electron microscope (SEM), Figure 1(a). Major chemical compounds of CWP are also shown in X-ray diffraction (XRD) spectrograph, Figure 1(b). Sodium hydroxide (laboratory grade) was used as reagent for the geopolymer concrete. It was prepared 24 hours before being used in the mixture.



(a) (b)

Figure 1. (a) SEM image of CWP particles, (b) XRD spectrograph for CWP.

2.2 Mix Proportions

2.2.1 Conventional concrete (CV)

Table 1 presents the 25 and 50 MPa CV mixtures proportions. For the two concrete grades, a partial replacement of cement by CWP at 0%, 10%, 20%, 30% and 40% by weight was studied. The mixtures' designations are Cxx-yy, where xx is the design concrete grade, and yy is the percentage of CWP replacing cement (e.g., C25-30: conventional concrete with target compressive strength of 25 MPa and 30% of the cement replaced by CWP).

Table 1. Conventional concrete mix proportions by weight (kg/m^3).

Mixture Designation	Mixture Ingredients						
	Cement	CWP	Fine Aggregate		Coarse Aggregate		Water content
			C. Sand	Dune	10 mm	19 mm	
C25-0	310	0	448	301	--	1102	190
C50-0	485	0	404	271	--	993	208

2.2.2 Self-compacting concrete (SCC)

During the production of SCC, cement was partially replaced by the CWP in 20%, 40% and 60% The mixtures' designations used are SCC-zz, where zz is the percentage of CWP replacing cement (e.g., SCC-20: means 20% of the cement was being replaced by CWP). The water content was kept constant for all mixtures. The details of the mixture proportions are given in Table 2.

Table 2. Self-compacting concrete mix proportions by weight (kg/m^3).

Mixture Designation	Mixture Ingredients								
	Cement	CWP	Fine Aggregate		Coarse Aggregate		Water content	SP	VMA
			C. Sand	Dune	10 mm	19 mm			
SCC-0	500	0	392	479	871	--	175	8.33	1.6

2.2.3 Geopolymer

The geopolymer paste was synthesized by mixing CWP with NaOH activation solution with different molarities (i.e., 8M, 10M, 12M, 14M and 16M). A liquid/solid ratio of 0.4 was used. Specimens were sealed with polyethylene film and kept in an oven at a temperature of 60^{o}C and under ambient pressure. After 72 hours, the specimens were de-molded and cured at 60^{o}C through the testing date.

2.3 Specimens and Testing

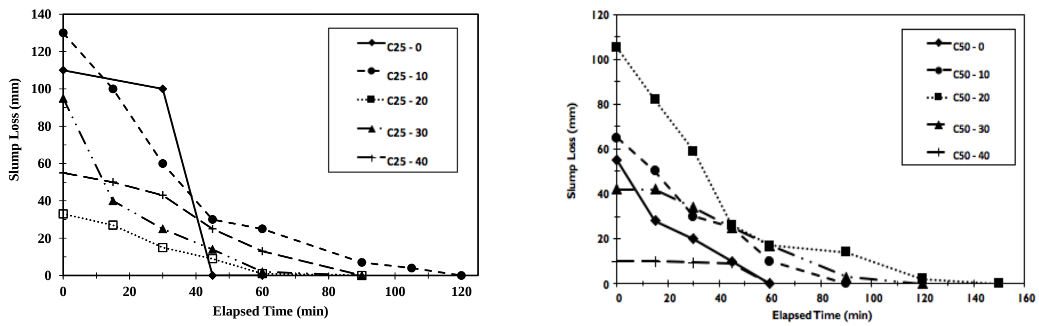
Several tests were conducted to investigate the effect of CWP on both fresh and hardened properties of the three produced concrete types. Slump test was performed in terms of slump and slump loss as per ASTM C143 to evaluate the fresh properties of the conventional concrete (CV). The unconfined and confined flowability and segregation resistance of the produced SCC mixtures were assessed using slump flow and the J-ring tests in accordance to ASTM C1611 and ASTM C1621 respectively and the GTM segregation column test according to ASTM C1610. Finally, the viscosity of SCC mixtures was assessed using the V-funnel test as described in EFNARC-2005 guidelines. Compressive strength was conducted for both the CV and the SCC mixtures at two test ages (i.e., 28, and 90 days) on 100 mm cubes. While for the geopolymer, strength was measured at 28 days of age using cubic specimens with dimensions 50 mm. The durability characteristics of the CV and SCC mixtures were judged at two ages (i.e., 28 and 90 days) by conducting the rapid chloride permeability test (RCPT) as per ASTM C1202. While, the durability of the geopolymer mortar was evaluated through electrical resistivity at 28-days of age. A SEM was used to study the microstructural characteristics of a freshly fractured surface of the geopolymer mortar.

3 RESULTS AND DISCUSSIONS

3.1 Conventional Concrete

3.1.1 Slump and slump loss

Slump test and slump loss were performed to assess workability and workability retention by measuring the slump value at different elapsed time intervals of 15 minutes. The mixture was mixed for 30 seconds before each slump measurement. The slump and slump loss results of C25 and C50 mixtures are shown in Figure 2. From the results, initial slump value gradually decreases as the level of CWP increases, while workability retention was improved.



(a) (b)

Figure 2. Slump/slump loss results for (a) C25 and (b) C50 mixtures.

3.1.2 Compressive strength

Table 3 presents the compressive strength results. It can be observed that for both strength grades, at the two test ages, the highest strength achieved among all replacement mixtures was at 10%, yet it was slightly lower than those of the control mixture for C50-10 mixture. Moreover, it should be noted that at late age, for all replacement levels, the measured strength achieved the target strength.

Table 3. Measured compressive strength and RCPT values for CV mixtures.

Mix Grade				**C25**					**C50**		
CWP %		**0**	**10**	**20**	**30**	***40***	***0***	***10***	***20***	***30***	***40***
Comp. Strength (MPa)	28D	22.7	27.8	26.8	25.5	25.8	51.5	50.1	47.2	49.0	42.6
	90D	27.5	33.6	33.0	32.3	30.1	63.8	57.5	51.3	53.0	50.5
RCPT (Coulombs)	28D	4695	2899	1748	864	589	4691	2890	1517	462	521
	90D	1748	690	477	366	258	1572	626	433	318	257

3.1.3 Chloride ion permeability

The RCPT test results for the produced conventional concrete mixtures at both 28 and 90 days of age follow a similar trend, with significantly reduced values of total passing charge at late ages as presented in Table 3. The effect of CWP was more prominent at late ages for example, the 10% mixtures, the chloride permeability was characterized as “Moderate” at 28 days compared with “Very Low” at 90 days of age as per ASTM C1202.

3.2 Self-Compacting Concrete

3.2.1 Fresh properties

The general trend observed was a slight decrease in the measured slump flow values and enhanced passing ability, segregation resistance, and viscosity of all the mixtures as the amount of CWP was increased. All recorded values are presented in Table 4.

Table 4. Measured fresh properties of the produced self-compacting concrete mixtures.

Mix ID	CWP (kg/m^3)	Slump flow (SF) (mm)	SF-(J-ring) (mm)	Passing ability	Segregation (%)	V-Funnel (sec)
SCC-0	0	780	50	Moderate	12.49	10.40
SCC-20	100	770	45	Moderate	8.57	10.01
SCC-40	200	745	30	Moderate	7.21	11.00
SCC-60	300	725	25	High	3.44	12.82

3.2.2 Compressive strength and chloride ion permeability

The effect of incorporating CWP in SCC mixtures on both compressive strength and chloride ion permeability is presented in Table 5. The 90 days' strength was improved up to 40% replacement, while the total charge passing was significantly reduced up to the 60% replacement.

Table 5. Measured compressive strength and RCPT values for SCC mixtures.

Mix I.D.		SCC-0	SCC-20	SCC-40	SCC-60
Comp. Strength (MPa)	28D	78.3	84.3	77.5	68.7
	90D	84.0	94.2	90.0	79.0
RCPT (Coulombs)	28D	2999	743	386	104
	90D	1534	248	188	49

3.3 Geopolymer

3.3.1 Compressive strength and electrical resistivity

The highest compressive strength was obtained with the 12M-activation solution, Table 6, after which any increment in the solution molarity caused a gradual reduction in the measured strength. The bulk electrical resistivity for the tested saturated specimens increased with the increase in the molarity of the NaOH solution.

3.3.2 Microstructure investigation

The obtained micrographs at 28 days of age are presented in Figure 3. The matrix is mainly formed of continuous homogeneous hydration product mainly aluminosilicate gel. At low alkalinity (i.e., 8M and 10M), a more porous microstructure with some unreacted powder was observed. The phenomenon of unreacted particles was also evident in the high alkalinity pastes (i.e., 14M and 16M) suggesting that very high alkaline solutions were not completely utilized. On the other hand, at 12M, the microstructure obtained was denser and compact with fewer connected pores, perhaps due to the formation of amorphous gel as the major component of the paste, therefore, leading to the highest compressive strength and the increase in the resistivity.

Table 6. Measured compressive strength and resistivity values for geopolymer mixtures.

	Activation Solution Molarity (Mole)				
	8M	**10M**	**12M**	**14M**	**16M**
28 Days Comp. Strength (MPa)	28.0	30.7	28.0	33.6	21.2
28 Days Resistivity (Ω.cm)	500	600	600	1100	1800

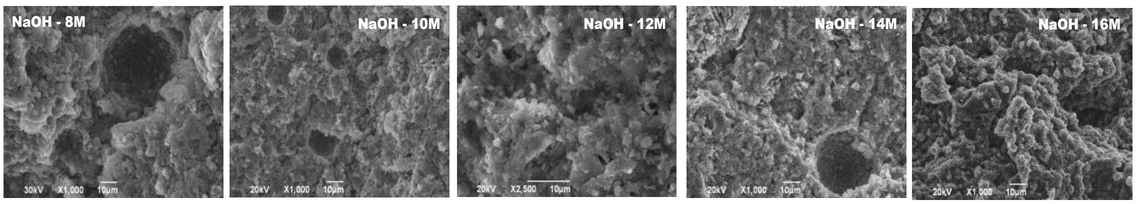


Figure 3. Microstructure of ceramic waste geopolymer at different NaOH concentrations.

4 CONCLUSIONS

Based on the results of the present study, the following conclusions can be drawn out:

- Although the initial slump and slump flow values were reduced, the slump retention and other SCC fresh properties were improved. This can be attributed to the physical properties of CWP having relatively high SSA of 555 m^2/kg and irregular particle shape.
- For both the CV and SCC, the late strength gain signifies that the reactivity of CWP takes place at later ages indicating possible pozzolanic reactivity.
- Durability tests indicated the beneficial use of CWP in improving the resistance to chloride ion permeation and increasing resistivity.
- CWP has proven its feasibility in making both CV and SCC with satisfactory fresh properties and improved hardened and durability characteristics using 10-30% for CV and 40% in SCC. Also, CWP is a promising ingredient in making geopolymer concrete for green sustainable structures.

Acknowledgments

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