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Reusing Waste Ceramic and Waste Sanitary Ware in Concrete as Pozzolans with Nano-Silica and Metakaolin

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Abstract: Ceramic wastes are one of the largest waste materials among construction materials. Using waste materials in concrete is a good way to recycle them. This study works on the mechanical and durability properties of pozzolanic concrete containing ceramic tile and sanitary ware wastes as pozzolans incorporation metakaolin and nano-silica. This study was conducted in two parts: in the first part, properties of concrete with different percentage of ceramic tiles and sanitary ware wastes as pozzolans was studied. In the second part, the simultaneous effect of ceramic wastes with nano-silica and metakaolin was studied. The results determined that using of different ceramic wastes as a pozzolan in concrete has negligible effect in mechanical properties and improves durability. Moreover, using waste ceramic powder with metakaolin and nano-silica simultaneously leads to improve mechanical properties and durability. Due to the reduction of cement consumption and the recycling of ceramic waste, it can be said that the use of ceramic waste in concrete is a step towards for sustainable development.

Keywords: concrete, ceramic waste, nano-silica, metakaolin, sustainable development.

1. Introduction

Concrete is one of the environmental pollutants. Cement as a main part of the concrete is one of the largest greenhouse emitters. So, searching for a solution to reduce negative environmental impacts of concrete production can be valuable (Pacheco-Pacheco-Torgal, 2014). Ceramic tile and sanitary ware are among the most commonly used materials in construction. World production of ceramic tiles in 2016 was about 13 billion square meters (Heidari & Tavakoli, 2013). The amount of waste in the different production stages of the ceramic industry ranges from 3 to 7 percent of daily production (Meyer, 2009). The nature of construction industry, especially the concrete industry, is such that ceramic wastes can be used safely with no need for dramatic change in production and application process. On one hand, the cost of deposition of ceramic waste in landfill will be saved and, on the other, raw materials and natural resources will be replaced, thus saving energy and protecting the environment. According to some authors the best way

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for the construction industry to become a more sustainable one is by using wastes from other industries as building materials (Mehta, 2001; Hosseinpourpia *et al.*, 2014).

The production of cement requires high energy input (850 kcal per kg of clinker) and implies the extraction of large quantities of raw materials from the earth (1.7 tons of rock to produce 1 tons of clinclinker). On the other hand the production of one tone of cement generates 0.94 tons of CO2 which 0.55 came from the raw materials and 0.39 from fuels (Gartner, 2004). Therefore, the replacement of cement in concrete by ceramic wastes represents a tremendous saving of energy and has important environmental benefits (Pacheco-Pacheco-Torgal *et al.*, 2013). Besides, it will also have a major effect on decreasing concrete costs, since the cost of cement represents more than 45% of the concrete cost. Ceramic ware can be divided into two groups, depending on the materials used for its production. The first group includes products of burned red paste (bricks, structural wall and floor tiles, roof tiles). Products made of white paste: technical ceramics (ceramic electrical insulators), ceramic sanitary ware (wash bowls, lavatory pans, bidets and bath tubs), and medical and laboratory vessels, belong to second group.

Using ceramic wastes in concrete were considered in previous studies by researchers. Crushed ceramic waste was used as a substitute for some part of aggregate (Tavakoli *et al.* 2013; Correia et al, 2006; Binici, 2007; Guerra *et al.*, 2009; Torkittikul & Chaipanich, 2010; Senthamarai *et al.*, 2011; Medina *et al.*, 2012; Alves *et al.*, 2014; Gonzalez-Corominas &Etxeberria, 2014) and the powder obtained from crushed ceramic waste was used partial cement replacements as pozzolan (Ay & Ünal, 2000; Heidari &Tavakoli, 2012; Puertas *et al.* 2008; Pacheco-Torgal & Jalali, 2011; Vejmelková *et al.*, 2012; Medina *et al.*, 2013; Lavat, 2009). Ay and Ünal (2000) recognized the pozzolanic activity of ceramic powder. Pacheco-Torgal and Jalali (2011) observed that this substitution process would decrease slightly the compressive strength and decline in water permeability and chloride ion diffusion with waste ceramics used as Portland cement replacement. Heidari and Tavakoli (2013) investigated the mechanical properties of concrete including ceramic as a replacement of cement and concluded positive findings. Nevertheless, research carried out so far are scarce and high strength concrete made from ceramic powder in combination with pozzolan has been evaluated rarely. Researches have indicated that concrete incorporating metakaolin present comparable performance to the ones with other mineral admixtures in terms of mechanical properties as well as durability features (Oliveira *et al.*, 2005; Kim *et al.*, 2007; Ramezanianpour & Jovein, 2012; Dinakar *et al.*, 2013; Arel & Anuk, 2014; Kannan & Ganesan, 2014).

Furthermore, a number of researches have been fulfilled for use nano particles in cement based materials (Heidari & Tavakoli 2013; Kim & Lim, 2007; Belkowitz & Armentrout, 2009; Said *et al.*, 2012; Tavakoli & Heidari, 2013; Tavakoli *et al.*, 2014). Due to its ultra-fine particle size, nano-silica can possess a distinct pozzolanic reaction at a very early age. Therefore, properties of concrete were ameliorated with the use of nano-silica and other pozzolan together (Zhang & Islam, 2012; Shaikh *et al.* 2014). Heidari and Tavakoli (2013) measured a slight increase in compressive strength for cement replacement by ceramic powder and nano SiO_2 simultaneously.

Concrete investigation could be experimental or numerical method (Tarighat *et al.*, 2016; Tavakoli *et al.* 2017) that in this study we focus on experimental method. The aim of this research project is the assessment of the mechanical properties of high-strength concrete containing ceramic wastes integration with, nano-silica and metakaolin as a partial replacement for cement.

2. Materials and Methods

In this study, the ground tile ceramic waste was obtained from recycled floor ceramic supplied by Arzhang ceramic tile Company in Iran and The wastage of ceramic sanitary ware was obtained from Pardis Company in Iran. Ceramic wastes were crushed by a hammer crusher. Then, the ceramic wastes were milled with a ball mill to gain powder. The resulting powders were sieved through a 200# (75-µm) sieve. The preparation of ceramic waste powder procedures is illustrated in Figure 1.The paper must be with page size of A4. Body of paper should be formatted in one column, with 2.54 cm (1”) top, 2.54 (1”) bottom margins and 2.54 (1”) margins on sides.

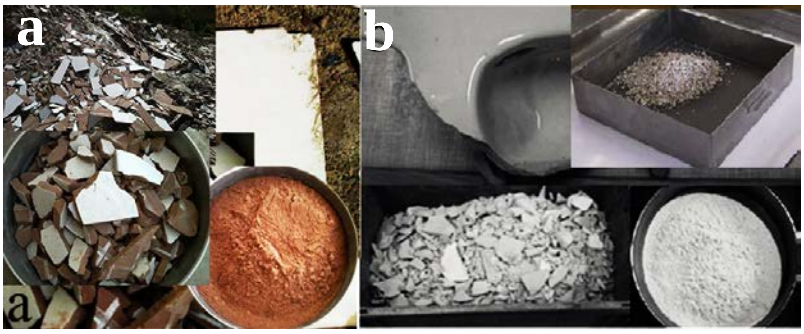

Fig. 1 - Ceramic waste powder preparation process
(a) Ceramic tile; (b) Sanitary ceramic ware

The chemical compositions of ceramic powder are shown in Table 1. Furthermore, some physical properties of the ceramic wastes are reported in this table.

Table 1 - Chemical composition and physical properties of the ceramic wastes powder

Chemical Compositions	Sanitary Ceramic Ware	Ground Ceramic Tile	Physical Properties	Sanitary Ceramic Ware	Ground Ceramic Tile
SiO_2	67.63%	68.85	Moisture Content	0.2%	0.2%
Al_2O_3	24.05%	18.53%	Autoclave Expansion	0.06%	0.08 %
Fe_2O_3	0.55%	4.81%	Particle Size	<75 µm	<75 µm
CaO	0.1%	1.57%	SSA	33.0 m2/g	34.1 m2/g
Na_2O	1.25%	2.01%	Density	2.6 g/cm3	2.57 g/cm3
K_2O	3.0%	1.63%			
MgO	0.36%	0.72%			
TiO_2	0.3%	0.737%			
SO_3	0.01%	0.06%			
L.O.I	1.1%	0.48%			

Table 2 - Physical properties of ceramic wastes powder

Physical Properties	Sanitary Ceramic Ware	Ground Ceramic
Moisture Content	0.2%	0.2%
Autoclave Expansion	0.06 %	0.08%
Particle Size	<75 µm	<75 µm
SSA	33.0 m2/g	34.1 m2/g
Density	2.6 g/cm3	2.57 g/cm3

The pozzolanic properties of ceramic wastes were investigated and are shown in Table 3. The pozzolanic properties conform to ASTM C 618-03 (2004). According to this table, it is clear that ceramic wastes satisfy the requirements of pozzolanic materials.

Table 3 - Comparison of pozzolanic properties of ground ceramic waste with ASTM C 618.

Parameter	ASTM C 618, %	Sanitary Ceramic Ware, %	Ground Ceramic, %
(SiO_2+Al_2O_3+Fe_2O_3)	>70	92.23	92.19
SO_3	<3.0	0.01	0.06
L.O.I.	<10	1.1	0.48
Autoclave expansion	<0.8	0.06	0.08
Moisture content	<3.0	0.2	0.2
Fineness + 325 Mesh	<34		21

The SiO_2 and Al_2O_3 in the ceramic powder could be reacted with $Ca(OH)_2$ in the cement paste to produce crystalline C–A–H and low density C–S–H gel, which can fill micro pores in concrete, increase the bond strength between the interface of aggregates, decrease the permeability and improve the durability of the concrete.

Nano-silica was purchased from Wacker, Germany chemical company, and its main properties are given in Table 4. Range of particle size by SEM analysis in the materials laboratory has been confirmed. The SEM and TEM analysis is shown in Fig. 2.

Table 4 - Properties of Nano-silica

Chemical Compositions	Value	Physical Properties	Characteristics
SiO_2	>99%	APS	11-14nm
Ti	<100ppm	SSA	190-685m2/g
Ca	<77ppm	Bulk Density	<0.11g/cm3
Na	<63ppm	True Density	2.2g/cm3
Fe	<20ppm	Purity	+99%
		Color	White

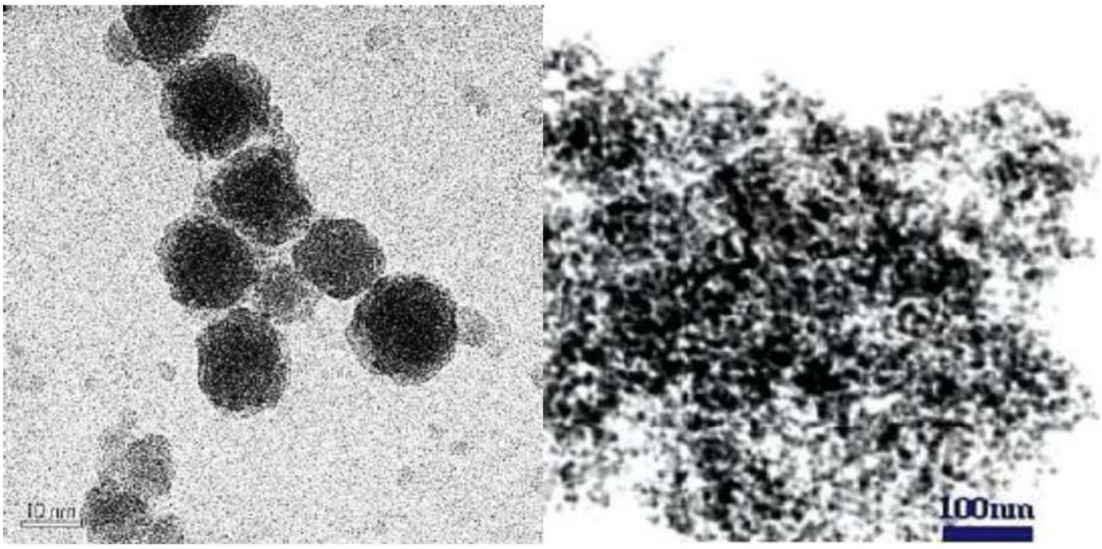

Fig. 2 - The SEM and TEM Analysis of Nano-silica

Metakaolin consumed in making concrete samples, produced domestically (Iran) and their main properties are given in Table 5.

Table 5 - Properties of Metakaolin

Chemical Compositions	Value (%)	Physical Properties	Value
SiO_2	52.8	SSA	$16.3m^2/g$
Al_2O_3	36.3	Density	$2.629g/cm^3$
Fe_2O_3	4.21		
CaO	<0.1		
MgO	0.81		
K_2O	1.41		
Na_2O	<0.1		
SO_3	-		
L.O.I	3.53		

Locally available Portland cement (ASTM Type II, Shahrekord Cement Company) was used. The specifications of the cement are shown in Table 6.

The sand and the coarse aggregate used in this research were supplied by the mines in Shahrekord (in Iran). In order to prevent gradation changes, all of the materials as lump were bought and stored. The grading curve of the sand in use has revealed that the sand falls into the allowable range defined by the ASTM-C33 standard (Siddique & Klaus, 2009). However, the gravel in use did not fall in the allowable range. Therefore, grading of the gravel was first modified according to the aforementioned standard and then the gravel was used.

Table 6 - Properties of Portland cement

Chemical Properties	Percent	Physical Properties	Value
SiO_2	21.2-21.8	Initial Setting	90-110 min
Al_2O_3	4.8-5.2	Final Setting	150-190 min
Fe_2O_3	3.86-4.12	Fineness (Blain)	≥2900 cm2/g
CaO	64.5-64.9		
MgO	≤1.7	Autoclave Expansion	≤0.15 %
CL	≤0.03		
SO_3	≤1.7.	3 Days Compressive Strength	≥22 Mpa
L.O.I	≤1.3		
LnR	≤0.65	7 Days Compressive Strength	≥36 Mpa
C3A	≤7.5		
Total Alkali	≤0.7	28 Days Compressive Strength	≥53 Mpa

The water absorption, particle size distribution, density and fineness modulus of the aggregates were specified as the tests methods described in ASTM. The physical properties of the aggregates are given in Table 7.

Table 7 - Physical and mechanical properties of the aggregates

Property	Fine Aggregate	Coarse Aggregate
Specific Gravity	2.62	2.6
Fineness Modules	2.9	-
Water Absorption (%)	1.5	0.5
Maximum Size (mm)	4.75	9.5
Bulk Density (kg/m3)	1530	1583
Abrasion Value (%)	-	20.16

The water used in the concrete, was the drinking water of Shahrekord city. The PH, sulfate content and chloride content of the water used in the study were 7.8, 29 mg/lit and 40 mg/lit, respectively. The superplasticizer used is based on Polycarboxylate. The properties of the superplasticizer used in this study were a pH of 5.6, a yellow color, a specific gravity (g/cm³) of 1.2, free of chlorides and has solubility in water.

The present investigation studied the partial replacement of cement by ceramic wastes powder (Phase A) and reduced the cement content by adding several combinations of nano-silica and metakaolin (Phase B). The mixture was designed according to ACI-211. At the beginning of the mixture design, the cement content (570 kg/m3) and water-cement ratio (0.37) were chosen.

Part A: In this phase, cement was replaced with three percentages (5%, 10%, and 15%) of ground ceramic waste powder and sanitary ceramic ware waste powder separately as a pozzolan. The amount of aggregate and water, is similar to reference mixture (C0). The amounts in the concrete mixtures are shown in Table 8. In all mix design W/C was constant (0.37) and to acquire a consistency denned by slump values of between 3 and 6 cm a super plasticizer was used.

Table 8 - Concrete mixture proportions - Phase A (kg/m3)

Mixture Name	C	S.C	G.C	CA	FA	W
C0	570	0	0	724	836	211
C5	541.5	-	28.5	724	836	211
C10	513	-	57	724	836	211
C15	484.5	-	85.5	724	836	211
CS5	541.5	28.5	-	724	836	211
CS10	513	57	-	724	836	211
CS15	484.5	85.5	-	724	836	211

C: cement, SC: sanitary ceramic ware, GC: ground tile ceramic, CA: coarse aggregate, FA: fine aggregate, W: water

Part B: The objective was to produce high strength pozzolanic concretes using ceramic powder in combination with nano-silica and metakaolin. Accordingly, concrete mixtures using different mix proportions and several combinations of ceramic powder and nano-silica were initially performed. Six high strength concrete mixes were used in the current phase. Mixes contained 0.5 and 0.8 percent nano-silica and different proportions of ceramic powder (ground ceramic and sanitary ceramic ware) (5, 10 and 15 percent). Nano-silica and ceramic powder were replaced part of the cement. The details of these mixtures are given in Table 9.

Also, six high strength concrete mixes contained 5, 10 and 15 percent metakaolin and different proportions of ceramic powder (5, 10 and 15 percent) were made. Metakaolin and ceramic powder were replaced part of the cement. The details of these mixtures are given in Table 9. In all mix design W/C was constant (0.37) and to acquire a consistency denned by slump values of between 3 and 6 cm a super plasticizer was used.

The concrete mixtures were mixed in accordance with ASTM C 192 in a 120 liter drum mixer. The workability of the fresh concrete was measured with a standard slump cone using the slump test according to ASTM C 143. The coarse and fine aggregate were mixed first, followed by the addition of the cement, pozzolan and water containing the required amount of Superplastiziser. One fifth of the Superplasticizer was always retained to be added during the last one minute of the mixing period. To distribute uniformly nano-silica and metakaolin, in phase B, particles were stirred in water for one minute at 120 RPM, and then they were added to the mixture.

The test specimens were cast in steel cubic moulds (100×100×100mm) and compacted on a vibrating table. After approximately 24 hours, the specimens were removed from the moulds. The concrete specimens were cured in lime-saturated water at 21 ºC in cure tanks until the time of testing. Casting, compaction, and curing were accomplished according to ASTM C 192 -81.

For each mix, cubic samples were tested to determine the compressive strengths at 7, 28, 56 and 90 days of curing. The compressive strength for each mixture was obtained from an average of three cubic specimens. A 2000-kN capacity uniaxial compressive testing machine was used to test the specimens. The water absorption test according to ASTM C 642 was conducted at the end of the 90th day.

Table 9 - Concrete mixture proportions - Phase B (kg/m3)

Mixture name	C	S.C	G.C	Nano-silica	MK	CA	FA	W
C5N0.5	538.7	-	28.5	2.8	-	724	836	211
C5N0.8	536.9	-	28.5	4.6	-	724	836	211
C10N0.5	510.2	-	57	2.8	-	724	836	211
C10N0.8	508.4	-	57	4.6	-	724	836	211
C15N0.5	481.7	-	85.5	2.8	-	724	836	211
C15N0.8	479.9	-	85.5	4.6	-	724	836	211
CS5N0.5	538.7	28.5	-	2.8	-	724	836	211
CS5N0.8	536.9	28.5	-	4.6	-	724	836	211
CS10N0.5	510.2	57	-	2.8	-	724	836	211
CS10N0.8	508.4	57	-	4.6	-	724	836	211
CS15N0.5	481.7	85.5	-	2.8	-	724	836	211
CS15N0.8	479.9	85.5	-	4.6	-	724	836	211
C5M5	513	-	28.5	-	28.5	724	836	211
C5M10	484.5	-	28.5	-	57	724	836	211
C10M5	484.5	-	57	-	28.5	724	836	211
C10M10	456	-	57	-	57	724	836	211
C15M5	456	-	85.5	-	28.5	724	836	211
C15M10	427.5	-	85.5	-	57	724	836	211
CS5M5	513	28.5	-	-	28.5	724	836	211
CS5M10	484.5	28.5	-	-	57	724	836	211
CS10M5	484.5	57	-	-	28.5	724	836	211
CS10M10	456	57	-	-	57	724	836	211
CS15M5	456	85.5	-	-	28.5	724	836	211
CS15M10	427.5	85.5	-	-	57	724	836	211

C: cement, SC: sanitary ceramic ware, GC: ground tile ceramic, CA: coarse aggregate, FA: fine aggregate, W: water

3. Results & Discussion

Part A: The average results obtained from the strength compressive tests at 7, 28, 56 and 90 days are shown in Fig. 3. This figure illustrates the compressive strength development for all of the concrete mixtures used in part A. The difference in the strength development of the samples can be attributed to the pozzolanic reaction. All samples had a plastic consistency.

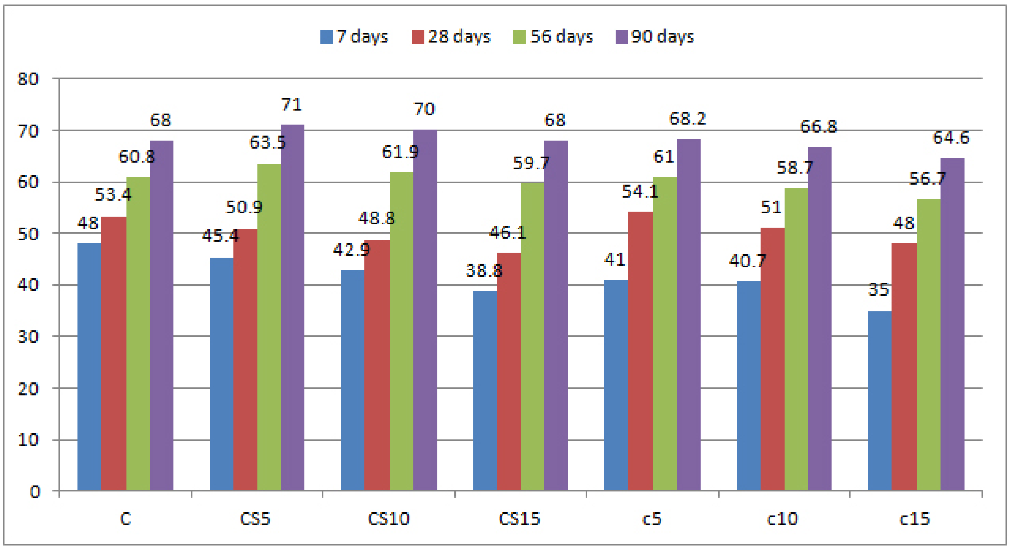

Fig. 3 - Compressive strength (Mpa), (part A)

The results indicate, as expected, large differences at early curing ages and smaller differences at long curing ages. The 7th day compressive strength varied between 35 and 48 Mpa, and the 90th day strength varied between 64.6 and 71 Mpa. The compressive strength decreased as the proportion of waste ceramic in the concrete increased.

The results of concrete contain sanitary ceramic ware are most satisfactory to concrete contain ground ceramic. The concrete mixture with 5% of sanitary ceramic ware has the highest mechanical performance for all ceramic wastes which means it has the higher pozzolanic reactivity.

As it was observed, increasing the strength in the samples containing pozzolan (ceramic powder) started after 28 days of curing. It shows that pozzolanic activity was begun appropriately at this curing age. Similar previous studies confirm these results (Heidari & Tavakoli, 2013; Pacheco-Torgal & Jalali, 2011). At early curing ages, pozzolan only acts as filler and does not undergo the pozzolanic reaction.

The reduction in the early compressive strength is mainly due to the immature pozzolanic reaction in the concrete and the preventive growth of C–S–H gel affected by components in ceramic powder.

Eventually, there was a 4.4 percent increase in the compressive strength in the sample containing 5 percent sanitary ceramic ware powder (CS5) (maximum strength). Furthermore, in C15 with 15 percent floor ceramic powder, the compressive strengths were reduced by 4.93 percent (minimum strength).

The water absorption test was performed on all mixtures at part A; the results on the 90th day of curing are shown in Fig. 4.

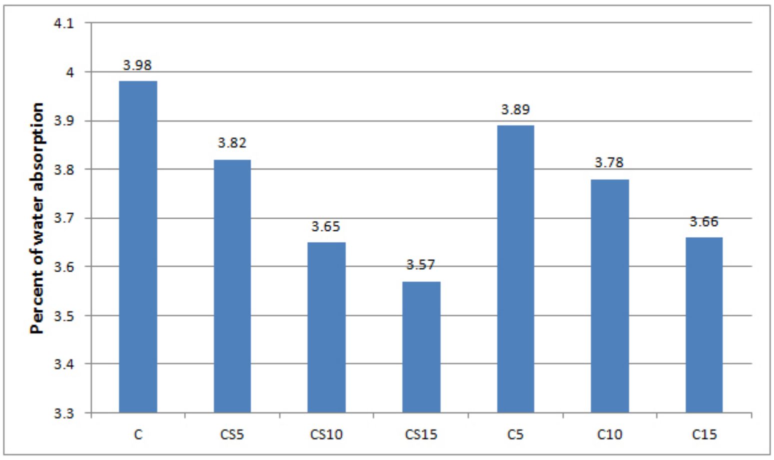

Fig. 4 - Percent of water absorption

Fig. 4 shows that pozzolanic concrete possesses a lower water absorption capacity compared to the control concrete. The efficiency of sanitary ceramic ware powder on decrease of water absorption is better than ground ceramic. This figure also shows that by increasing the amount of ceramic powder from 5 to 15 percent, a dramatic decrease occurred in water absorption.

The water absorption for C5, C10, C15, CS5, CS10 and CS15 at 90 days decreased respectively by approximately 2.26, 5.15, 8.04, 4.02, 8.29 and 10.3 percent compared to the control concrete. It shows that the pozzolanic reaction, which occurs in pozzolanic concrete, has an effect that leads to a lower water absorption capacity of the concrete. This behavior must be related to the denser microstructure provided by the pozzolanic reaction between ceramic powder and calcium hydroxide, generating secondary C–S–H and micro filler effect of ceramic powder. This results show that ceramic powder can improve durability properties of concrete.

Part B: The results of compressive strength for samples contain nano-silica and contain metakaolin (part B) are presented in Fig. 5 and fig 6 respectively.

In general, the compressive strength of the concrete specimens decreased as increasing amounts of ceramic powder was added. As more cement was replaced by ceramic powder, lower compressive strengths were observed. Furthermore, the addition of nano-silica and metakaolin are helpful for the improvement of the compressive strength in the concrete specimens. The compressive strength developed in concretes containing nano-silica and metakaolin particles were higher than that of the control sample in each case. As mentioned above, nano-silica and metakaolin are thought to be more eff ective in the pozzolanic reaction than ceramic powder. The pozzolanic activity of nano-silica on the compressive strength was more effective at early curing ages, but, for the samples that contained metakaolin, it was found at older age.

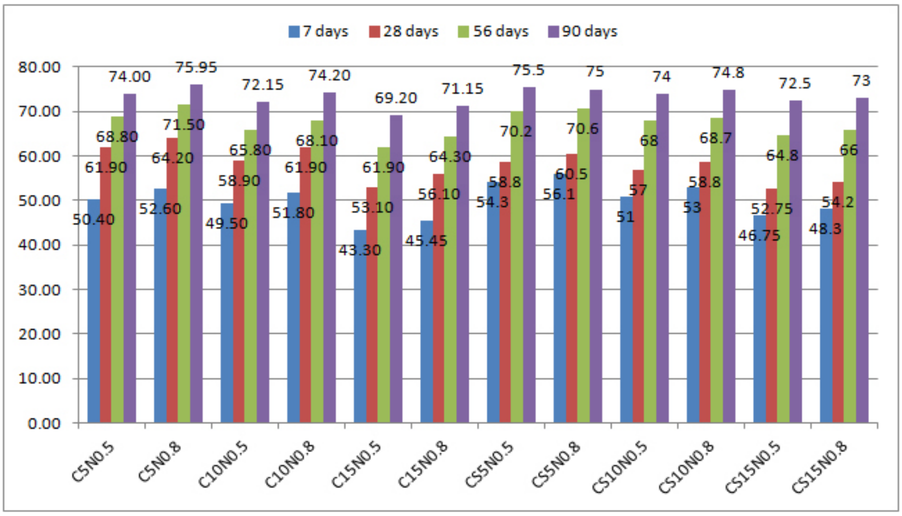

Fig. 5 - Compressive strength, (Mpa), part B

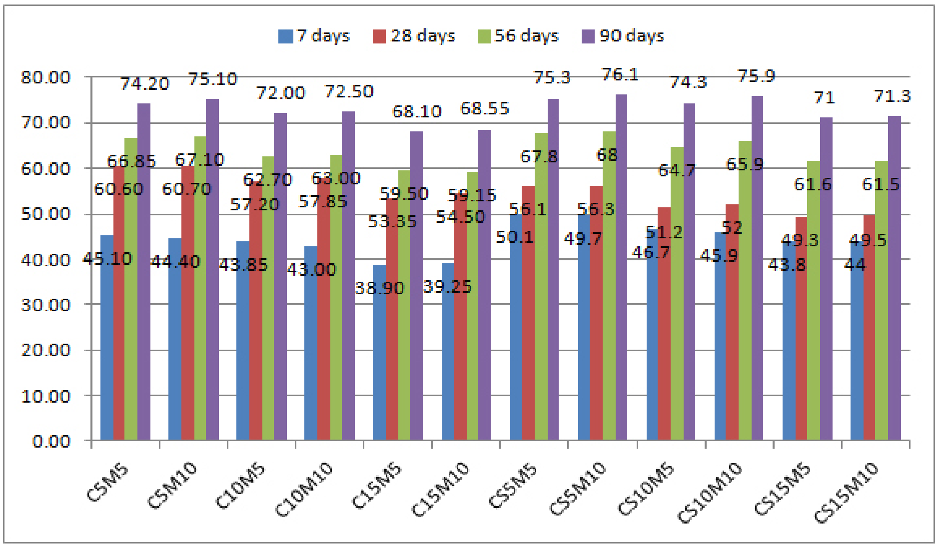

Fig. 6 - Compressive strength, (Mpa), part B

The maximum compressive strength in samples containing nano material was obtained in the sample containing 0.8 percent nano-silica and 5 percent floor ceramic powder (C5N0.8). In addition, by using 0.5 percent of nano-silica and 15 percent of ceramic powder, the lowest compressive strength was determined (C15N0.5). The maximum compressive strength in samples containing metakaolin was observed in CS5M10. There is not much difference between ground ceramic and sanitary ceramic ware in simultaneously effect of ceramic powder and nano SiO2 or metakaolin.

According to Fig. 5, for the sample C10N0.5, which contains 10 percent ceramic powder (same as C10) and 0.5 percent nano-silica, it was found that the compressive strength after 7 days of curing was higher than C10, and it was even higher than the compressive strength of the control sample (C0). This surprising increase was due to the effect of the nano-silica reaction at an early age. The nano scale particles, such as nano-silica, have a high surface energy, and atoms at the surface have a high activity, which leads the atoms to react with outer ones easily. As a result, the pozzolanic activity of nano-silica at early ages is higher than that of normal size material such as silica fume (Heidari & Tavakoli, 2013).

The strength of the concrete samples was found to increase as the nano-silica content increased from 0.5% to 0.8%. However, the compressive strength of samples with 0.5 and 0.8 percent nano-silica was obtained nearly the same. It should be noted that using a higher content of nano-silica should be accompanied by adjustments to the water or superplasticizer dosage in the mix to ensure that specimens do not su ffer excessive decrease and cracking. Otherwise, using this much nano-silica could actually lower the strength of composites instead of improving it, although this was not observed in this study.

As a result, nano-silica can increase the hydrate reaction of cement and produce more hydration crystals.

Metakaolin is an artificial pozzolan obtained from the calcination of kaolinitic clays at temperatures around 700–850 °C. Due to its high pozzolanic activity, the inclusion of metakaolin improves the mechanical properties and durability of concrete (Siddique & Klaus, 2009). The main component of metakaolin amorphous silica and also amorphous alumina that in presence of water, react with calcium hydroxide (CH), mainly producing calcium aluminate hydrates and aluminum silicate hydrates (CAH and CASH, respectively) (Khatib & Clay, 2004).

Figure 7 and figure 8 show the water absorption values for all of the concrete mixtures used in this part.

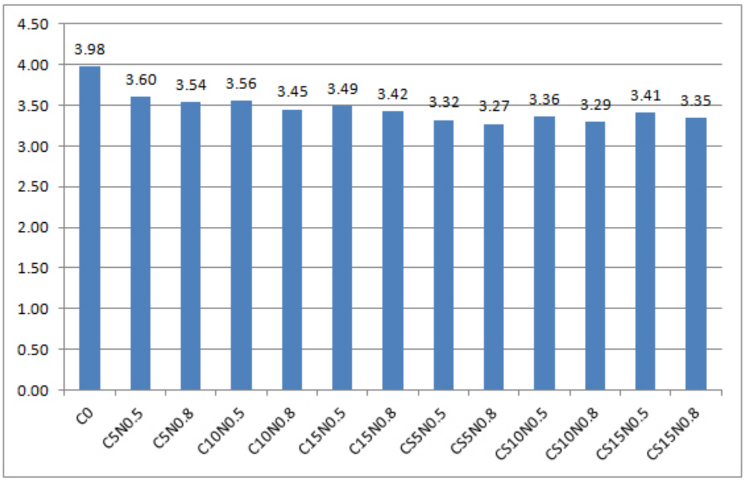

Fig. 7 - Percent of water absorption (Part B)

Fig. 7 illustrates that adding nano-silica to concrete leads to much lower water absorption compared to control sample, and it was also lower than the water absorption in the pozzolanic concrete in part A. The first cause of the decrease in the water absorption is the packing effect of small nano-silica, acting as a filler to fill the interstitial spaces inside the skeleton of the hardened microstructure of concrete to increase its density. The second cause is the pozzolanic effect, which combines glass-like silicon elements in nano-silica with the lime elements of calcium oxide and hydroxide in cement to increase the bonding strength and solid volume, resulting in a higher compressive strength and lower water absorption capacity of the concrete.

Water absorption values show a decreasing trend for all samples. At 90 days in part B. The simultaneous usage of nano-silica and ceramic powder intensified the reduction of water absorption, and thus, as expected, the maximum reduction in water absorption occurred in CS5N0.8, which contains 5 percent sanitary ceramic ware powder and 0.8 percent nano-silica.

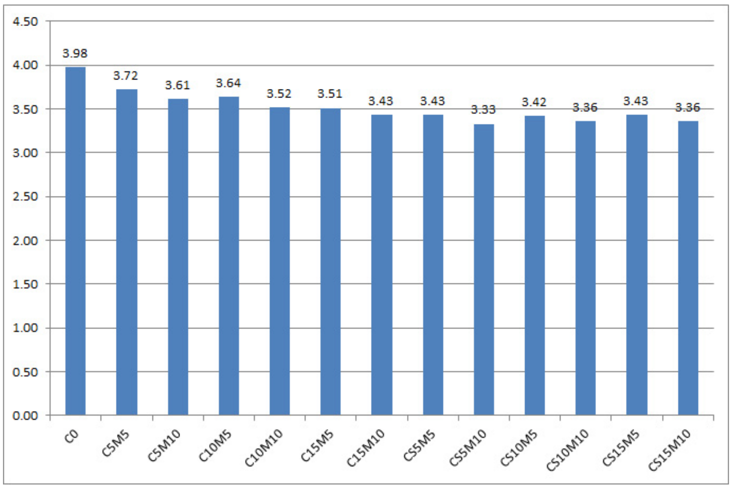

Fig. 8 - Percent of water absorption (Part B)

Fig. 8 illustrates that adding metakaolin to concrete leads to much lower water absorption compared to control concrete, and it was also lower than the water absorption in the pozzolanic concrete in part A.

Most of the work that has been done on the replacement of cement by metakaolin shows that the use of this pozzolanic material leads to improvements in the behavior of mortar and concrete. The calcium silicate hydrates (C-S-H) are formed as a gel that penetrates pores, promoting porosity refinement due to the decrease in average pore size. This effect is also observed in the interfacial transition zone (ITZ) between the binder and aggregate, resulting in densification. The refinement of pores and densification of ITZ can justify improvements in the mechanical strength and reduction of capillary water absorption, improved chemical resistance and increased durability (Lagier & Kurtis, 2007; Kou & Poon, 2013).

The water absorption of samples with 5 percent metakaolin was greater than that of the samples containing 10 percent metakaolin. The maximum reduction in water absorption occurred in CS5MK10. By increasing the amount of pozzolan from 5 to 15 percent, the reduction in water absorption was greater in the samples with 10 percent Metakaolin compared to 5 percent.

4. Conclusion

The possibility of using waste ceramic powder (sanitary and ground ceramic) and the combination of ceramic wastes powder with nano-silica and metakaolin as a replacement for cement has been investigated in this study. The waste ceramic powder was used in quantities of 0 up to 15 percent, nano-silica was 0.5 and 0.8 percent, and metakaolin was 5 and 10 percent of the cement. The following conclusions can be drawn from the present study:

The compressive strengths of samples decrease with increasing ceramic powder content, especially at early ages. However, the results show that concrete with ground ceramic waste powder ultimately demonstrates only minor strength loss, and in samples containing sanitary ceramic ware, increase in strength was illustrated compare to the reference sample. These results show that pozzolanic activity of sanitary ceramic ware better than ground ceramic. This is may be because of quality of manufacturing or chemical composition of sanitary ceramic ware. However, ceramic waste powder exhibits very good pozzolanic activity and can be used as a cement replacement.

The water absorption capacity of concrete was decreased by using ceramic powder as a pozzolan. This decrease can leads to durable concrete.

Nano-silica improves the mechanical properties of pozzolanic samples. The greatest impact of adding nano-silica on compressive strength was observed at early curing ages. Because of the reduction of the compressive strength of concrete due to the use of ceramic powder that was determined at an early stage, the addition of nano-silica could effectively compensate for it. A very slight difference in the mechanical properties of concrete with the use of 0.5 or 0.8 percent of nano-silica was observed.

Using nano-silica caused decreasing water absorption in all samples. The use of both floor ceramic powder and nano-silica resulted in a dramatic decrease in the concrete water absorption capacity and increased the compressive strength of concrete.

Metakaolin improves the mechanical properties of pozzolanic samples. The greatest impact of adding metakaolin on compressive strength was observed at older curing ages. It was found that the strength of the concretes increase as the metakaolin content increased from 5% to 10%. However, the compressive strength of samples with 5 and 10 percent metakaolin was obtained close together. Moreover, using metakaolin led to water absorption decrease in all samples. .

Because of the slight decrease in compressive strength and considerable reduction in water absorption capacity with the usage of waste ceramic powder (particularly up to 15 %), ceramic powder would be a useful material for incorporation into concrete structures (such as concrete dams).

Using construction industry waste (specifically ceramic wastes) to make concrete, it can convert the wastes into an environmentally friendly material. Because it reduces massive volume of the waste, energy consumption and resulting in environmental pollution. It can be said that using waste ceramics can be an impressive attempt in sustainable development.

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