ASIAN JOURNAL OF CIVIL ENGINEERING (BHRC) VOL. 14, NO. 3 (2013)
PAGES 369-382

PROPERTIES OF CONCRETES PRODUCED WITH WASTE CERAMIC TILE AGGREGATE

D. Tavakoli[a], A. Heidari[*, b] and M. Karimian[b]
[a]Department of Civil Engineering, Najafabad Branch, Islamic Azad University, Najafabad, Iran
[b]Department of Civil Engineering, University of Shahrekord, Shahrekord, Iran

Received: 10 June 2012; **Accepted:** 10 October 2012

ABSTRACT

A large bulk of ceramic tiles change into wastage, these waste materials are not reusable and recyclable due to their physical and chemical structure. Given the high amount of concrete production and the possibility of wastage materials in them, using ceramic wastage could be an effective measure in maintaining the environment and improving the properties of concrete. The present experimental study deal with the investigation of possibility of using waste ceramic tile in concrete. To do so, first, the characteristics of ceramic aggregate are measured and then being grind they are used in concrete as the substitute for coarse aggregates with 0 to 40 percent of substitution and also for sand with 0 to 100 percent of substation. Besides, all other parameters are constant. Finally the slump value, compressive strength, water absorption, and the unit weight of concrete for the samples were calculated. The findings revealed that generally using waste ceramic tile lead to enhancing the properties of concrete.

Keywords: Waste ceramic tile; aggregate; concrete; compressive strength; water absorption; sustainable development

1. INTRODUCTION

Concrete, as a constructive material, has been used in construction industry for about two centuries. Approximately, the whole bulk of the concrete is used in one year is more than one ton apiece. Therefore, doing research about using modern technologies in production concrete is of great importance. Furthermore, one of the most critical problems of the world has been related to remove the wastage and reusing of it. In all countries, large amount of

[*] E-mail address of the corresponding author: heidari@eng.sku.ac.ir (A. Heidari)

wastage is produced annually. most of these wastage are not reusable or if they are, their recycling leads to wasting energy and pollution which is turn increase the risk of these materials for the environment. Moreover, a good strategy to achieve the two purposes of removing the wastage material and also obtaining the positive qualities of concrete [1-3]. Tile and constructive ceramics are among the most commonly used materials in structures. The global production of ceramic tiles in the world is about 8500 million square meters, this amount is about 400 million square in Iran, which make Iran the fifth ceramic tile producer in the world [4]. This huge amount of productions has caused them to be among the most commonly-consumed materials in the world. Usually, The wastage related to tile, ceramic and sanitary ware are created in different forms some of which are produced in companies during and after production process due to errors in either construction, human activities, and also inappropriate raw materials. Some others are produced in transportation and distribution procedures and finally, the most bulk of them are created as a result of destroying constructions. It is predicted that almost 3 to 7 percent of daily production of ceramic in Europe change into wastage and this amount reaches to millions ton per year [5]. The properties of these materials are in a way that they are unusable in other cycles of production. Therefore, they are useless in practiced and cause damages to environment. All in all, the hard physical structure of these materials and also their chemical structure make them a good and suitable choice to be used in concrete [6].

Some of previously studies have investigated the use of ceramic wastage in concrete as sand or coarse aggregate [7-11]. Lopez et al. observed that this substitution process would increase slightly the compressive strength [12]. Besides, Torgall and jalali also concluded that using ceramic wastage as sand and coarse aggregate can slightly enhance compressive strength and also durability of concrete [13]. Medina et al. also deal with the substation of ceramic as a coarse aggregate and finally reported a positive effect for the process [14]. In another study, the effect of ceramic electrical insulator as coarse aggregate in concrete was studied. In this study no negative effect was reported [15]. Furthermore, the use of these materials in non- structural concretes was performed in a study in which the only problem reported was the high water absorption of the materials [16]. Some researches were also done in which the use of the materials in concrete as a substitute or cement were investigated [13, 17-20].

However, no comprehensive study has yet done in which the use of the materials as sand and coarse aggregate in wide ranges and then determining the ideal percent of substation have not been achieved either.

Therefore, in this experimental study, first the grinded waste ceramic tile and then its grading were done in a way that the tile grading curve of the natural aggregates used in control concrete was completely in compatible with the ceramic aggregates. After that, a range of experiments including chemical analysis, unit weight, water absorption, and Los Angeles test were done on ceramic aggregates. Having been ready, in the first stage of the study, the ceramic tiles with percents of 0, 25, 50, 75, and 100 were substituted for sand and in the next stage; the ones with percent of 0, 10, 20, 30, and 40 were substituted for coarse aggregates. After that, a comparison was made between the comprehensive strength, water absorption, slump and also the unit weight of new concrete and the control samples.

2. MATERIALS AND MIX PROPORTION

2.1 Aggregates

2.1.1 Ceramic tile aggregate

The waste ground ceramic used in this study was obtained from recycled ceramic ground tile supplied by Shahrekord Arjang Tile Company in Iran. Cracked pieces of ground tiles were crushed by a jaw crusher. The ground ceramic preparation process is shown in Figure 1.

Figure 1. Ground ceramic tile preparation process

The gradation of aggregates affects both fresh and hardened concretes. The sieve analysis of this crushed aggregates have been performed according to ASTM C136. The gradations of ceramic aggregates are shown in Figure 2 and Table 1.

Ceramic aggregates were sieved in such a way that their grading are exactly compatible with the natural used aggregate in concrete, this compatibility causes that the error created by the grading differences in the properties of concrete become minimized. The diagram of grading of ceramic aggregates and natural ones should be exactly compatible.

Table 1: Gradation of aggregates used in concrete

Sieve size, mm	**Cumulative percentage passing**	
	Sand	**Coarse aggregate**
25	100	100
19	100	84.4
12.5	100	39.45
9.5	100	12.075
4.75	99.5	6.15
2.36	80.97	3.85
1.18	46.27	-
0.6	29.49	-
0.3	20.75	-
0.15	9.86	-
0.075	5.03	-

The chemical compositions of ceramic pastes were analysed, and the results obtained are reported in Table 2.

Table 2: Chemical analysis of the ceramic tile

Materials	Percent	Materials	Percent	Materials	Percent
SiO_2	68.85	Na_2O	2.01	MnO	0.078
Al_2O_3	18.53	K_2O	1.63	P_2O_5	0.034
Fe_2O_3	4.81	MgO	0.72	SO_3	0.06
CaO	1.57	TiO_2	0.737	LOI	0.48

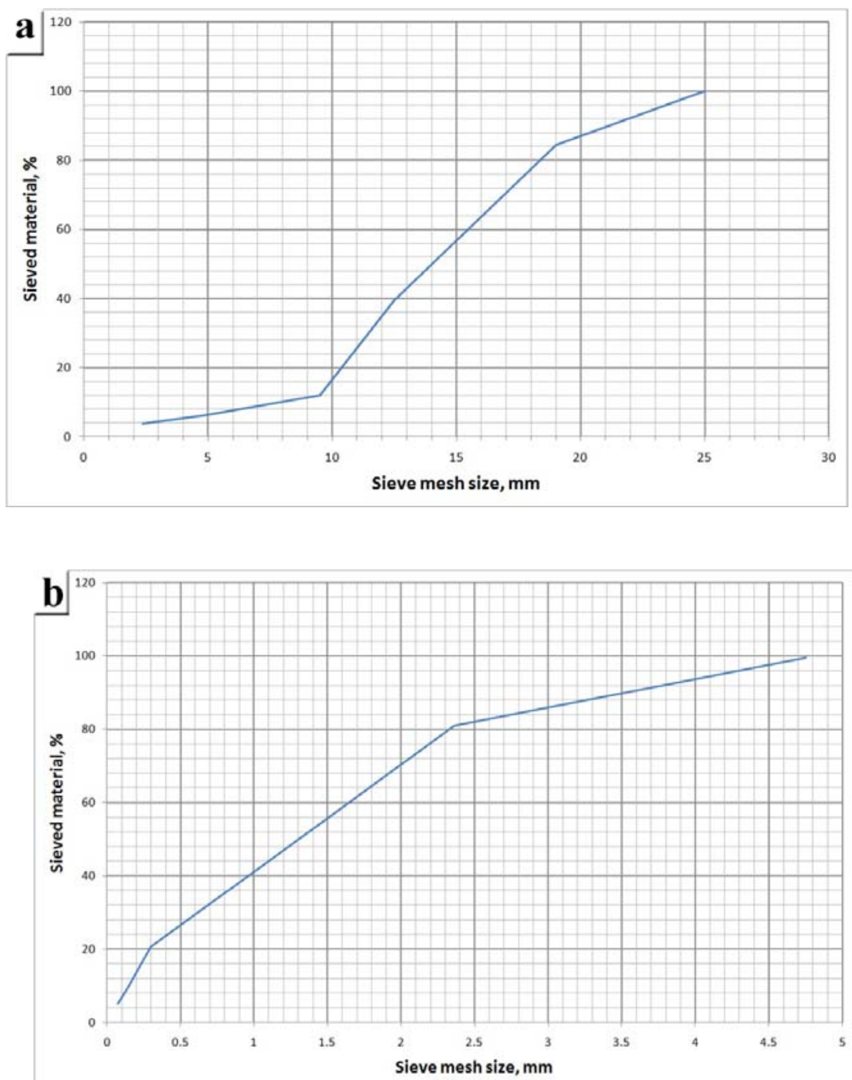

Figure 2. Gradation of both ceramic and natural aggregates: (a) coarse aggregate (b) sand

The mineralogical compounds were identified by X-ray diffraction (XRD) in a Philips diffractometer PW3040 with CuKa radiation using a secondary monochromater. Routine conditions of 40 kV and 30 mA in the range of 10º–90º, with steps of 0.05º, were used. Figure 3 shows the X-ray diffraction diagram of ground ceramic wastes.

The Los Angeles abrasion testing machine has been used to obtain the abrasion value of coarse aggregates, in accordance with ASTM C131, giving an LA value of 21.8, this value for coarse aggregate comply with those prescribed in the ASTM standard, and are therefore suitable for the concrete mixes proposed for the tests. According to ASTM C-33, the LA Abrasion value should be less than 50% for the aggregate that will be used to produce concrete.

The water absorption, particle size distribution, density and fineness modulus of the ceramic aggregates were specified following the test methods described in ASTM. Some properties of the aggregates are shown in Table 3.

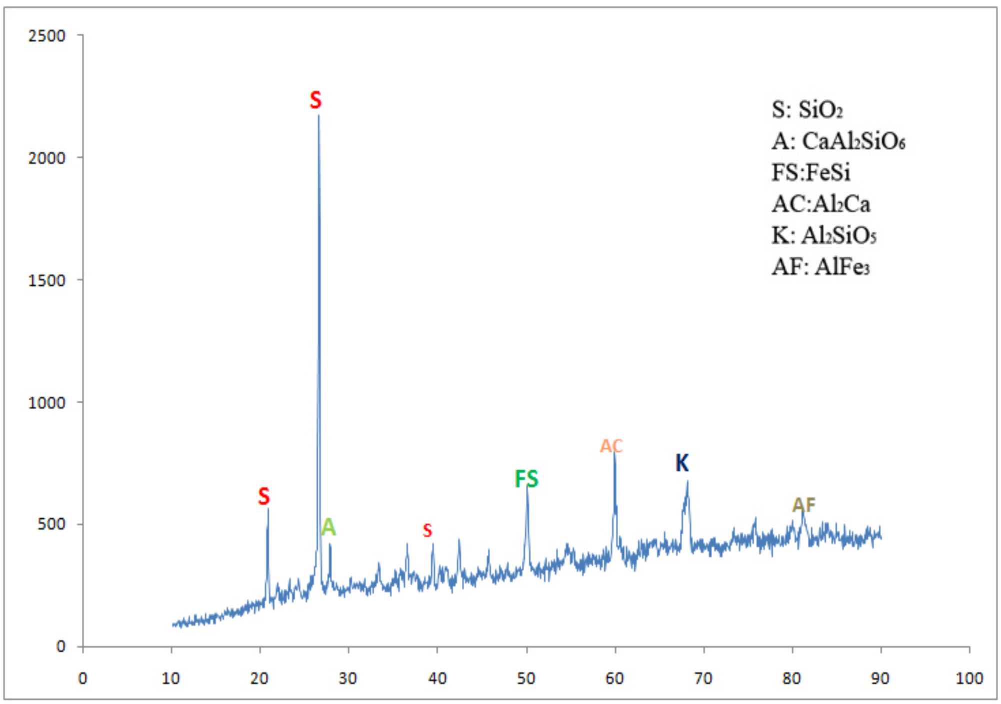

Figure 3. XRD pattern of ground ceramics

2.1.2 Natural aggregate

The natural sand and the coarse aggregate used in the concrete were crushed limestone aggregates. Physical properties of the aggregates are shown in Table 3. The gradations of aggregates are shown in Figure 2 and Table 1.

2.2 Water

The water used in the concrete was taken from the city of Shahrekord in Iran. The PH, sulphate content and chloride content of the water used in the study were 7.8, 29 mg/ lit and 40 mg/lit, respectively.

Table 3: Properties of aggregates

Property	Sand	Ceramic sand	Coarse aggregate	Ceramic Coarse aggregate
Density (g/cm^3)	2.6	2.35	2.55	2.33
Fineness modules	3.1	3.1	−	−
Water absorption (%)	2	7	0.2	4.8
Maximum size (millimetre)	−	−	25	25
Bulk density (kg/m^3)	1750	1723	1597	1584
Aggregate abrasion value, Los Angeles (%)	−	−	26.43	21.8

2.3 Cement

Locally available Portland cement (ASTM Type II) was used. The specifications of the cement are shown in Table 4.

Table 4: Properties of cement

Chemical properties	Percent	Physical properties	Value
SiO_2	21.8	Initial Setting	95 (min)
Al_2O_3	5.1	Final Setting,(min)	150 (min)
Fe_2O_3	3.9	Fineness(blain)	≥2900 (cm^2/g)
CaO	64.8	Autoclave expansion	≤0.15 (percent)
MgO	≤1.7	3 Days Compressive strength	≥190 (MPa)
CL	≤0.03	7 Days Compressive strength	≥320 (MPa)
SO_3	≤2.0	28 Days Compressive strength	≥490 (MPa)
L.O.I	≤1.3		
LnR	≤0.65		
F.CaO	≤1.1		
C_3A	≤7.5		
Total Alkali	≤0.7		

2.4 Mix proportion

The present investigation studied the partial replacement of natural aggregate by ground ceramic. The mixture is designed according to ACI-211. At the beginning of the mixture design, the binder content (320 kg/m^3) and water-cement ratio (0.5) were chosen to be constant.

In phase A, mixes were made with waste ground ceramic replacing 0, 25, 50, 75 and 100 percent by weight of the sand and In phase B, 0, 10, 10, 30 and 40 percent by weight of the coarse aggregates and with the same amount of cement and water as in the reference. The concrete mixture proportions in phase A are shown in Table 5 and in phase B are shown in Table 6.

Table 5: Concrete mixture proportions (phase A)

Properties	**Mixture name**				
	C	CS25	CS50	CS75	CS100
Cement, (kg/m^3)	320	320	320	320	320
Natural sand, (kg/m^3)	840	630	420	210	0
Ceramic sand, (kg/m^3)	0	210	420	630	840
Natural coarse aggregate, (kg/m^3)	1040	1040	1040	1040	1040
Ceramic coarse aggregate, (kg/m^3)	0	0	0	0	0
Water, (kg/m^3)	160	160	160	160	160

Table 6: Concrete mixture proportions (phase B)

Properties	**Mixture name**				
	C	CG10	CG20	CG30	CG40
Cement, (kg/m^3)	320	320	320	320	320
Natural sand, (kg/m^3)	840	840	840	840	840
Ceramic sand, (kg/m^3)	0	0	0	0	0
Natural coarse aggregate, (kg/m^3)	1040	936	832	78	624
Ceramic coarse aggregate, (kg/m^3)	0	104	208	32	416
Water, (kg/m^3)	160	160	160	160	160

3. MIX DESIGN

The concrete mixtures were mixed in accordance with ASTM C 192 in 120 litre drum mixer. The workability of the fresh concrete was measured with a standard slump cone using the slump test according to ASTM C 143. Instantly, after mixing, a slump of between 40 and 60 millimetre was obtained. The test specimens were cast in steel cubic moulds (150×150×150) 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 21ºC in cure tanks until the time of testing. Casting, compaction, and curing were accomplished according to ASTM C 192.

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

4. RESULTS AND DISCUSSION

The findings of tile substitution as sand (phase A) are show in Table 7. Figure 4 reveals the compressive strength of samples diagrammatically. As it obvious, the compressive strength of samples is very close to each other. Besides, this index is more in the samples involving tile sand. This finding is in compatible with those previously done [12]. The most compressive strength was related to the samples possessing 25 percent of tile sand in which about 7.8 percent of increase had in its strength. On the contrary, the least compressive strength related to the samples substituted with the tiles having 100 percent of tiles sand in which about 1.8 percent of increase has occurred in its strength. This increase in strength may be due to the hardness of aggregate in comparison natural aggregates or due to their being more angular in their grades which in turn lead to forming a better density. Furthermore, given the chemical tests and XRD and also the previously-done studies [13,19, 21], it can be concluded that ceramic tile may possess pozzolanic properties and therefore it can be said that tiny grades of sand can decrease the C-S-H gel slightly, and therefore a very trivial increase in the strength of it. Slump in the samples involving tile, has decreased slightly which can be because of more absorption of water by tile or the blunt forms of tile. On the whole, it can be said that the concretes having tile can be similarly use with conventional ones.

Table 7: Physical and mechanical properties of concrete mixes (phase A)

Sample	Slump (mm)	Specific weight (kg/m^3)	Water absorption (%)	Average strength (MPa)	
				7 days	28 days
C	60	2441	5.05	26.9	33.1
CS25	55	2430	4.96	28.1	35.7
CS50	50	2382	4.79	27.2	35.1
CS75	40	2341	5.10	25.8	34.6
CS100	40	2294	5.30	24.1	33.7

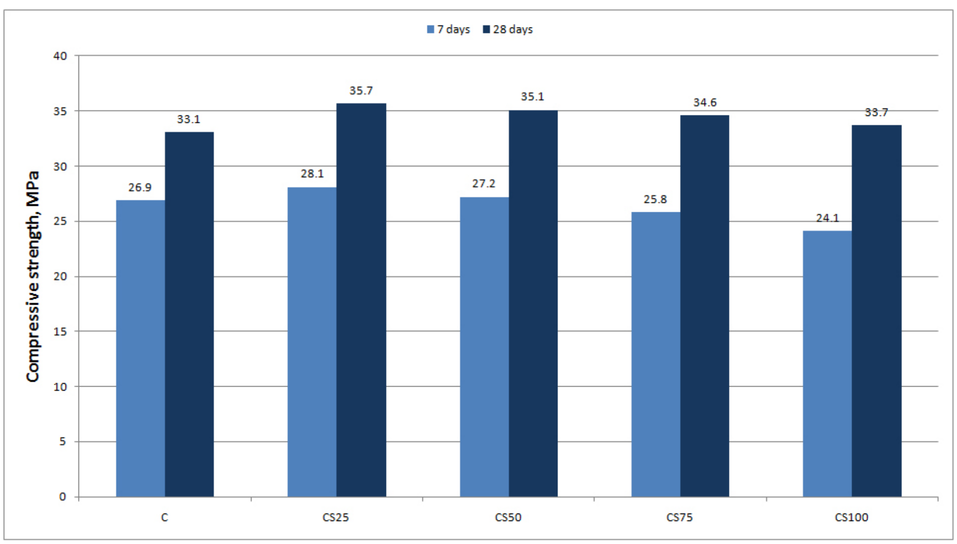

Figure 4. Compressive strength (phase A)

In Figure 5, the water absorption of samples has been reflected. The amount of water absorption decreases as the tile sand increase up to 50 percent of substitution and after that starts increasing. Then the least percent of water absorption has been observed in CS50.The study also showed that water absorption was made for CS75 and CS100 than for the control sample which can be due to the lack of cohesion in tile for concrete and therefore creating some pores in concrete in high percent.

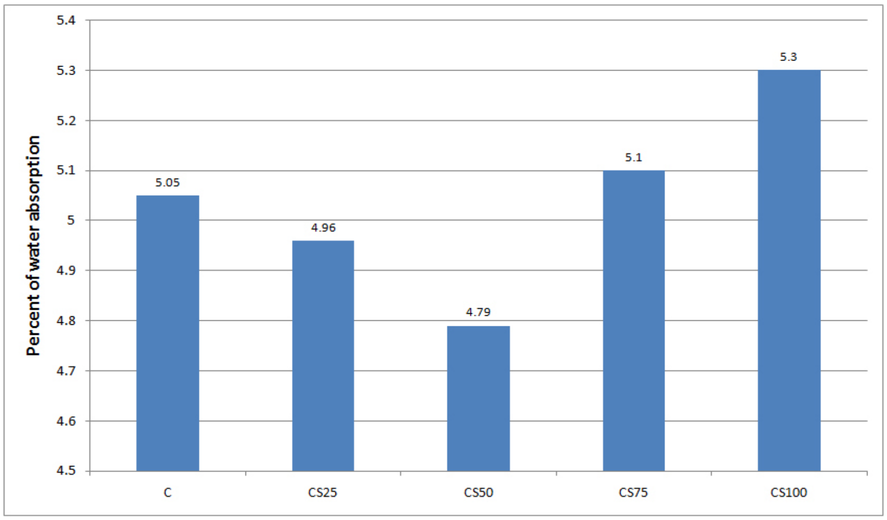

Figure 5. Water absorption (phase A)

Figure 6 shows the unit weight of samples as it is conspicuous from it, as we increase the substitution amount of tile sand, the unit weight decreases and it is due to the less unit weight of tile. That is this; this decrease has been turned out to be about 6 percent for CS100. Therefore, it can be concluded that the weight of a structure can be decreased up to 6 percent.

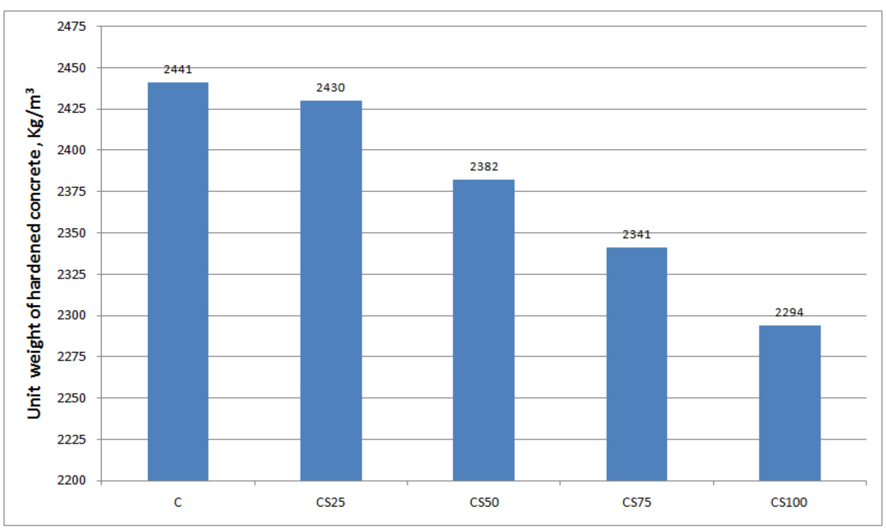

Figure 6. Unit weight of hardened concrete (phase A)

Table 8 reveals the results of substation of as a coarse aggregate (phase B). Besides, Figure 7 represents the samples compressive strength diagrammatically. It shows that using tile as a coarse aggregate not only cause no reduction in the strength of concrete, but also increase the compressive strength of it up to 30 percent and in higher percent (up to 40 percent) bear no negative impact on compressive strength. The strength of the samples which include tile has been reported to be very similar to each other. Further, the highest reported strength belonged to the sample which included 10 percent tile whose compressive strength has increased about 5.1 percent. On the contrary, the least reported strength was related to the samples including 40 percent tile whose strength was somehow similar to the control sample. One reason for decreasing the strength of samples as a result of enhancing the amount of tile may be the increase in the flaky aggregate. Given the point that tile aggregates increase especially in bigger sizes have flaky shapes, as the use of this aggregate increase in concrete the percent of flaky Aggregate in it and in turn lead to the decrease of strength. Further, another reason could be due to lack of engagement of aggregates with concrete, As a result of the smooth surface of aggregates. The other point is that the amount of slump decreases as the amount of tile as coarse aggregate increases. As it was above mentioned, this increase can be because of higher absorption of water and also being more angular of aggregates. On the whole, slump is changing in the samples and this change occurs between 40 to 60 millimeter which is considered appropriate for a concrete operation.

Table 8: Physical and mechanical properties of concrete mixes (phase B)

Sample	**Slump (mm)**	**Specific Wight (kg/m^3)**	**Water absorption (%)**	**Average strength (MPa)**	
				7 days	28 days
C	60	2441	5.05	26.9	33.1
CG10	50	2427	4.9	28.2	34.8
CG20	50	2407	5.2	27	34.3
CG30	45	2397	5.45	27.2	34.1
CG40	40	2385	5.7	25.7	33

Figure 8 represents the percent of water absorption in the samples including tile. In the samples which have 10 percent of tile, the amount of water absorption decreases slightly. In other samples, using aggregates cause an increase in water absorption. Further the flaky structure and also the existence of pores which is due to lack of cohesion along with the high amount of water absorption in tiles are among the reasons for such findings. However, water absorption was reported to be very similar to each other and this slight increase can be ignored.

Changes in the unit weight have been represented in Figure 9. The unit weight decreases as the amount of tile increases. In other work, in the samples which contain 40 percent of tile, this decrease about 2.3 percent. As a whole, it can be asserted that using tile causes a decrease in unit weight and hence it helps the load bearing capacity of structures.

Considering the obtained findings and the positive reported use of tile in concrete, it can be inferred that using tile can not only bear fruitful effects in concrete but also can have a positive effect on environment.

As it was previously mentioned, the bulk of ceramics tiles production in the world is about 8500 million square meters per year. This amount, supposing that thickness and weight are expressed in weight unit, shows that about 120 billion ton ceramic wastage is produced which can be used simply in concrete production and consequently bear positive effects both in concrete production and environment and decrease the excessive use of raw materials in concrete.

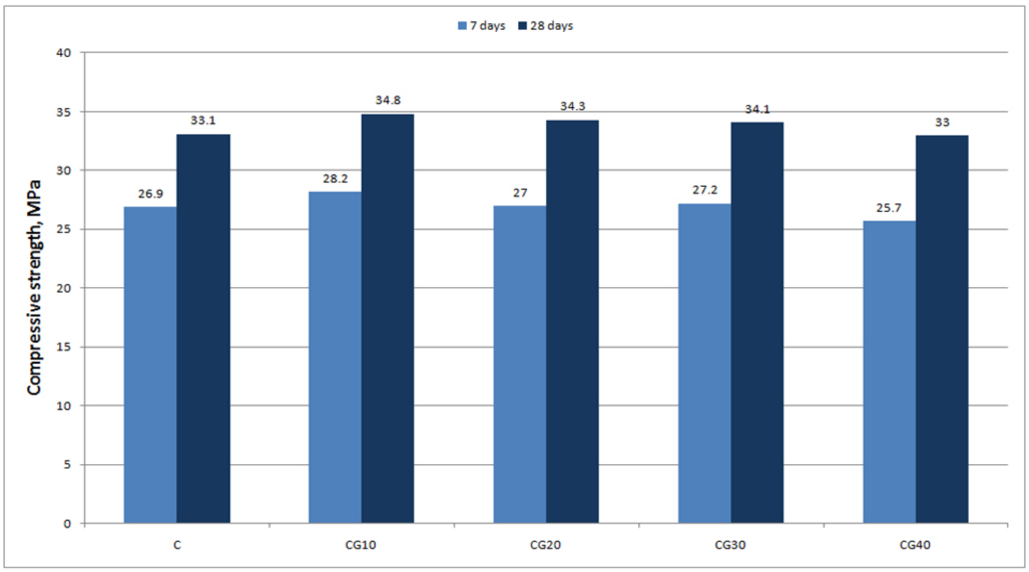

Figure 7. Compressive strength (phase B)

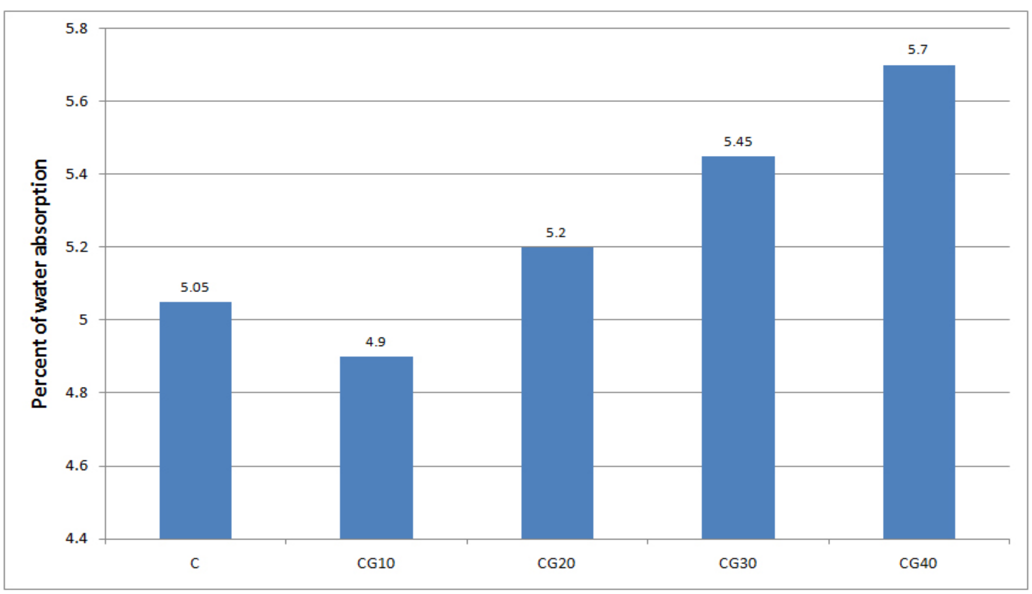

Figure 8. Water absorption (phase B)

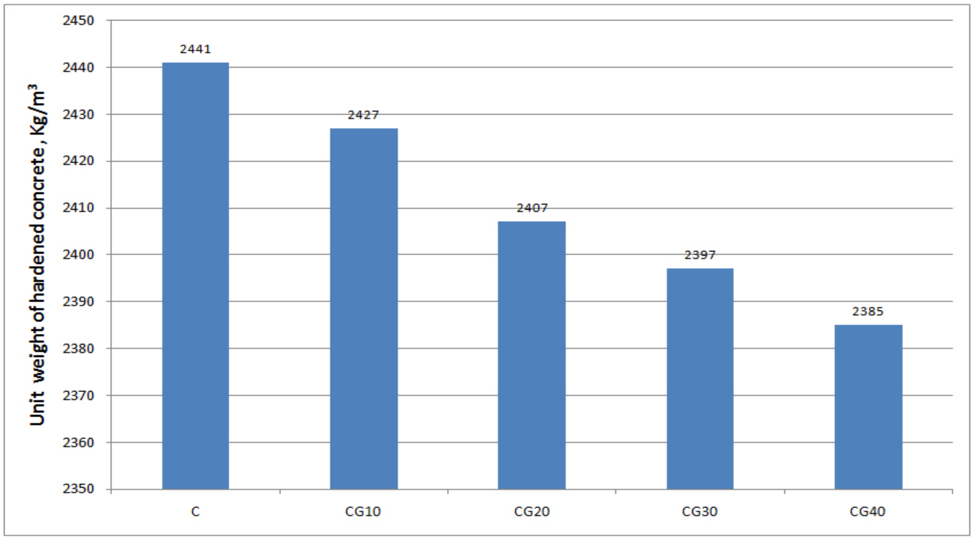

Figure 9. Unit weight of hardened concrete (phase B)

5. CONCLUSIONS

The possibility of using ceramic wastage as aggregates in concrete was investigated in the present study. Besides, the process of substituting the ceramic wastage as sand in 0 to 100 percent and in coarse aggregate in presents of 0 to 40 percent was studied and then parameters of Slump, compressive strength, water absorption, and unit weight were measured. Finally, the following results were obtained:

1. Using ceramic wastage in concrete production causes no remarkable negative effect in the properties of concrete. The optimal case of using tile wastage as sand are amounts of 25 to 50 percent, besides, the best case of their use as coarse aggregate are as amounts of 10 to 20 percent. In these measures, not only an increase happens in compressive strength, but also a decrease in unit weight and lack of remarkable negative effect on water absorption is reported.

2. Using tile wastage in concrete leads to removal of those materials from environment. Besides, decreasing the use of raw materials, using the wastage is considered positive economically.

3. Using tile wastage in concrete, with regard to reducing the costs and keeping the environment clean along with wastage management, and ameliorating the strength of structures, is an effective measure in sustainable development.

REFERENCES

1. Mehta PK. Reducing the environment impact of concrete. Concrete can be durable and environmentally friendly. *Concrete International*, **10**(2001) 61-6.

2. Jagannadha Rao K, Ahmed Khan T. Suitability of glass fibers in high strength recycled aggregate concrete-an experimental investigation. *Asian Journal of Civil Engineering (Building and Housing)*, No. 6, **10**(2009) 681-9.
3. Bhikshma V, Manipal K. Study on mechanical properties of recycled aggregate concrete containing containing steel fibers. *Asian Journal of Civil Engineering (Building and Housing)*, No. 2, **13**(2012) 154-64.
4. Tavakoli D, Heidari A, Etemadi M. Using tile as a pozzolan in concrete. *The Third National Conference on Concrete*. Tehran, Iran, 2011.
5. Meyer C. The greening of the concrete industry. *Cement and Concrete Composition*, **31**(2009) 601-5.
6. Khaloo AR. Crushed tile coarse aggregate concrete. *Cement and Concrete Aggregate*, No. 2, **17**(1995) 119-25.
7. Senthamarai RM, Devadas Manhoharan P. Concrete with ceramic waste aggregate. *Cement and Concrete Composites*, No. (9-10), **27**(2005) 910-3.
8. Correia JR, De Brito J, Pereira AS. Effects on concrete durability of using recycled ceramic aggregates. *Material and Structure*, No. 2, **39**(2006) 169-77.
9. Debieb F, Kenai S. The use of coarse and fine crushed bricks as aggregate in concrete. *Construction and Building Materials*, No. 5, **22**(2008) 886-93.
10. Guerra I, Vivar I, Llamas B, Juan A, Moran J. Eco-efficient concretes: The effects of using recycled ceramic material from sanitary installations on the mechanical properties of concrete. *Waste Management*, **29**(2009) 643-6.
11. Gomes M, De Brito J. Structural concrete with incorporation of coarse recycled concrete and ceramic aggregates: durability performance. *Materials and Structures*, No. 5, **42**(2009) 663-75.
12. Gomes M, De Brito J. Structural concrete with incorporation of coarse recycled concrete and ceramic aggregates: durability performance. *Materials and Structures*, No. 5, **42**(2009) 663-75.
13. Torgal F, Jalali S. Compressive strength and durability properties of ceramic wastes based concrete. *Construction and Building Materials*, **24**(2010) 832-8.
14. Medina C, Sánchez de Rojas MI, Frías M. Reuse of sanitary ceramic wastes as coarse aggregate in eco-efficient concretes. *Cement and Concrete Composites*, **34**(2012) 48-54.
15. Senthamarai RM, Devadas Manhoharan P, Gobinath D. Concrete made from ceramic industry waste: Durability properties. *Construction and Building Materials*, **25**(2011) 2413-9.
16. De Brito J, Pereira AS, Correia JR. Mechanical behaviour of non-structural concrete made with recycled ceramic aggregates. *Cement and Concrete Composites*, No. 4, **27**(2005) 429-33.
17. Ay N, Ünal M. The use of waste ground ceramic in cement production. *Cement and Concrete Research*, No. 3, **30**(2000) 497-9.
18. Puertas F, Garcia-Diaz I, Barba A, Gazulla M, Palacios M, Gomez M, Martínez-Ramírez S. Ceramic wastes as alternative raw materials for Portland cement clinker production. *Cement and Concrete Composites*, **30**(2008) 798-805.
19. Lavat A, Trezza M, Poggi M. Characterization of ceramic roof tile wastes as pozzolanic admixture. *Waste Management*, **29**(2009) 1666-74.

20. Naceri A, Hamina M. Use of waste brick as a partial replacement of cement in mortar. *Waste Management*, **29**(2009) 2378-84.
21. Heidari A, Tavakoli D. Performance of ceramic tile powder as a pozzolanic material in concrete. *International Journal of Advanced Materials Science*, No. 1, **3**(2012) 1-11.