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Influence of milled waste glass as partial cement replacement on durability of recycled aggregate concrete in sulfate environment

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ABSTRACT: Recycling of demolished concrete is a rational and practical solution for construction waste issue. Milled waste glass has been widely examined as secondary substitute material towards production of concrete with improved strength and durability attributes. In this study, the durability of concrete specimens made with natural and recycled coarse aggregates (RCA) containing various amounts of milled waste glass (MWG) as partial cement replacement (0% and 30%) is investigated. Half of the specimens were submerged in magnesium sulfate solution to investigate their durability. The specimens were tested in different ages and 4 specimens had been made for each test. The specimens were tested for water absorption, mass changes (mass losses), and size changes. Furthermore, volume of permeable pore spaces (voids) was investigated. The results indicate that using milled waste glass in recycled aggregate concrete has a considerable influence on durability of concrete in sulfate environment.

1 INTRODUCTION

Increasing rate of demolished concrete due to the destruction of concrete structures through natural and human disasters like earthquake and war; and also renewing old structures is one of the most concerning environmental issues. Recycling of concrete has attracted lots of attention in both economic and environmental terms due to the limitation of natural resources like gravel and sand and also environmental problems of raw materials transportation in long distances. Destroying of lands due to the concrete waste bury, implies the necessity of recycling of concrete as well (Mostofinejad & Eftekhar, 2005).

Properties of concrete containing recycled coarse and fine aggregates have been investigated by different researchers such as Corinaldesi (2010), Etxeberria et al. (2007), Rahal (2007) and Sagoe-Crentsil (2001). Accomplished studies showed that adhered mortar to recycled aggregate surface is responsible for low resistance towards mechanical and chemical actions of recycled aggregate concrete. The increase in concrete porosity and the presence of weak interfacial bonding between aggregate and binder matrix are the main reasons attributed to this situation, (Kwan et al., 2012). Most of studies carried out on recycled concrete dealt with strength characteristics; though there is few data focuses on durability properties (Kwan et al., 2012).

Some researchers have used glass in concrete as replacement of aggregate (Maier and Durham, 2012) or as replacement of cement (Cassar and Camilleri, 2012). It is reported that crushed glass used as aggregate replacement results in poor bond; therefore, concrete exhibits alkali–silica reaction (ASR). However, reduction of crushed glass to finer particles and its using as cement replacement produced good quality concrete that did not exhibit ASR (Cassar & Camilleri,

2012). Nassar & Soroushian (2012) have emphasized the novel concept of affirmative using milled waste glass to overcome the limitations of recycled aggregate and consequently recycled aggregate concrete. When milled waste glass is used in recycled aggregate concrete as partial replacement of cement, it interacts with calcium hydroxide available in the attached mortar/paste clinging to aggregate surface to form calcium silicate hydrate (C–S–H) which is the key binder among cement hydrates. This reaction can enhance the quality of the remnant cement paste on recycled aggregates, thus benefiting the strength, durability and dimensional stability of recycled aggregate concrete. Authors demonstrated that during the 30 years life of parent concrete, it had not shown any signs of durability related problems. Also it seems because of low relative humidity, demolished and crushed concrete have not already carbonated; therefore, calcium hydroxide can be potentially active for some reactions.
In this study, the influence of using two recycled materials including milled waste glass (MWG) as partial cement replacement and recycled coarse aggregate (RCA) on durability properties of concrete in sulfate environment is investigated.

2 EXPERIMENTAL PROGRAM AND RESULTS

2.1 Materials

Moderate sulfate resistant cement (Type 2) was used in recycled concrete. Furthermore, crushed windowpane was utilized to obtain waste glass. In order to gain MWG, windowpane particles were crushed by a jaw crusher (shown in figure 1) to averagely 3 mm grains and then powdered by Los Angeles machine (shown in figure 2) for several cycles. This powder was sieved to gain particles finer than 75 µm. Figure 3 shows waste glass powder. Recycled aggregate was obtained by crushing of available cubic specimens in concrete laboratory by the same jaw crusher and sieving these grains to obtain 4.75-9.5 mm RCA. Table 1 shows physical properties of the virgin and recycled coarse aggregates as well as that of sand. The particle size distribution of recycled coarse aggregates and sand are demonstrated in Tables 2 and 3, respectively.

Table 1. Physical properties of aggregates

Aggregate type	Dry density (kg/m^3)	Bulk specific gravity	Bulk specific gravity (SSD)	Absorption (%)	Moisture content (%)
Virgin	1460	-	2.73	0.60	0.90
Recycled	-	-	-	0.72	0.00
Sand	2.88 (F.M.)	2.65	-	0.70	0.00

Table 2. Particle size distribution of recycled aggregates

Sieve opening (mm)	25.0	19.0	12.5	9.5	4.75	Plate
Residual value (%)	-	-	1.75	22.09	76.16	0.00

Table 3. Particle size distribution of sand

Sieve number	4	8	16	30	50	100	Plate
Residual value (%)	1.24	21.58	19.63	13.42	17.63	18.71	7.79

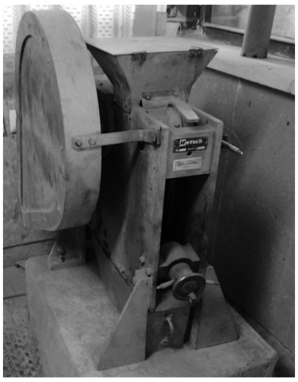
Figure 1. Jaw crusher.

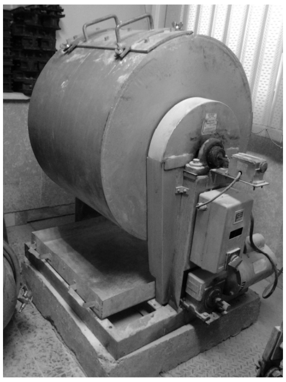
Figure 2. Los angeles.


Figure 3. Milled waste glass powder.

2.2 *Test specimens and testing procedures*

2.2.1 Mix design

Concrete mixes incorporating two percentages of RCA (0%, 30%) and MWG (0%, 30%) was produced. According to these contents, 4 different mix designs were provided according to ACI - 211 to investigate the influence of MWG as cement replacement on durability of recycled aggregate concrete in sulfate environment. Since the amount of MWG is related to cement weight, high cement content was used in order to have considerable amount of MWG to get more reliable results from each mix design and the mix designs comparisons. 48 cubic specimens of 70 mm dimension, including control specimens and specimens in sulfate environment, were tested in ages of 28-day, 56 days and 74 days, with 4 repeat for similar conditions. Table 4 shows the various concrete mix designs involving different percentages of two recycled materials. After casting and 28 days curing of the specimens, half of them were moved to 14.7% concentration magnesium sulfate solution (saturated concentration) to measure the mass changes and volume changes over time.

Table 4. Mix designs of concrete mixes

	D1[a]	D2[b]	D3[c]	D4[d]
Virgin coarse aggregate (kg/m^3)	657.0	459.9	657.0	459.9
RCA (kg/m^3)	0.0	197.1	0.0	197.1
Sand (kg/m^3)	875.4	875.4	875.4	875.4
w/c ratio	0.42	0.42	0.42	0.42
Cement content (kg/m^3)	542.857	542.857	380.0	380.0
Water content (kg/m^3)	232.16	232.16	232.16	232.16
MWG (kg/m^3)	0	0	162.857	162.857

[a] Control specimens (without recycled materials)
[b] Contains 30% RCA
[c] Contains 30% MWG as cement replacement
[d] Contains 30% RCA and 30% MWG as cement replacement

2.2.2 Density, absorption and voids

Required measurements were done to calculate density, water absorption and voids of hardened concrete, according to ASTM C 642. Table 5 shows the results of the absorption after immersion, absorption after immersion and boiling, apparent density and volume of permeable pore space (voids). The values of dry bulk density, bulk density after immersion, and bulk density after immersion and boiling are also shown in Table 5 for hardened concrete. Each value in this table is the average of 3 tests. The weight of each specimen in water was measured by the buoyancy balance machine which is shown in Figure 4. Partial replacement of cement with MWG is observed to decrease the dry bulk density, bulk density after immersion and bulk density after immersion and boiling. It decreases the apparent density of concrete as well.

Figure 4. Buoyancy balance machine.

Table 5. Properties of hardened concrete

	Absorption after immersion (%)	Absorption after immersion & boiling (%)	Bulk density dry (Kg/m^3)	Bulk density after immersion (Kg/m^3)	Bulk density after immersion & boiling (Kg/m^3)	Apparent density (Kg/m^3)	Volume of permeable pore space (voids), (%)
D1	7.09	7.53	2261.22	2421.48	2432.91	2725.64	17.02
D2	7.65	8.27	2235.48	2406.52	2413.33	2742.73	18.49
D3	8.20	8.72	2160.74	2337.92	2354.00	2662.50	18.84
D4	7.34	7.84	2224.40	2387.49	2384.20	2694.15	17.43

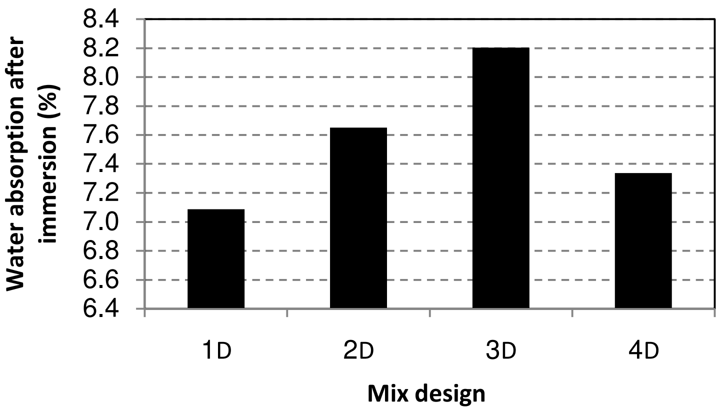

Figure 5. Water absorption at 63 days of age.

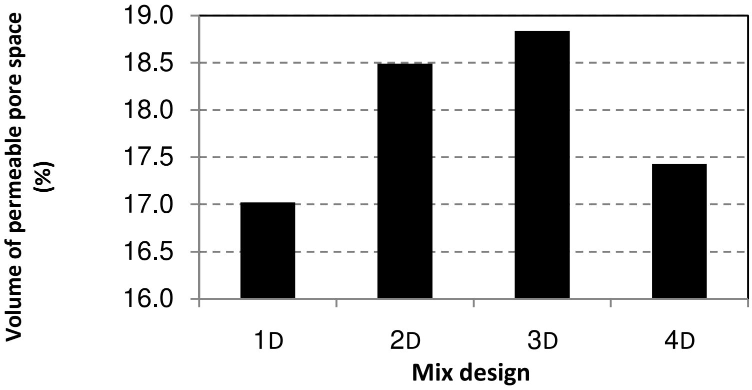

Figure 6. Volume of permeable pores at 74 days of age.

Figure 5 shows that using either MWG or RCA in concrete increases the water absorption but using MWG in recycled aggregate concrete moderates this influence. Furthermore, it is concluded from Figure 6 that using MWG or RCA in concrete increases the volume of permeable pores but using MWG in recycled aggregate concrete moderates this influence. A proportion is observed between water absorption and permeable pores of the specimens; the higher permeable pores, higher the absorption.

2.2.3 Mass changes

Specimen masses were measured at 28, 56 and 74 days of age. Figure 7 shows the mass changes percentage at age of 56 and 74 days, respect to 28 days measurements. Figure 7 demonstrates that all 4 mix designs caused a decrease in mass and this reduction has been increased over time. D2 mix design (recycled aggregate concrete) is observed to have the lowest mass reduction among mix designs. Besides, results show that using MWG in recycled aggregate concrete increases the mass reduction.

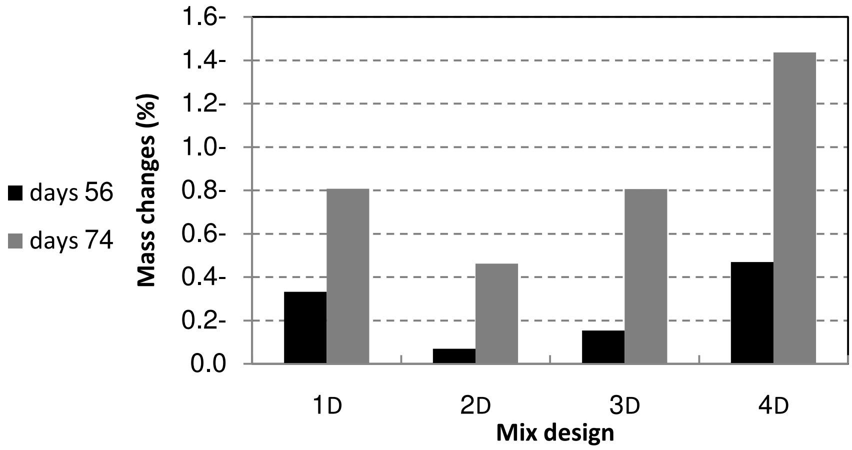

Figure 7. Mass changes percentage of 56 and 74 days specimens in sulfate solution.

2.2.4 Volume changes

Specimen sizes were measured at 28, 56 and 74 days of age. Figure 8 shows the volume changes percentage at age of 56 and 74 days, respect to 28 days measurements. Figure 8 demonstrates that all 4 mix designs caused a decrease in volume at 56 days of age, though the specimens were expanded at 74 days of age. In addition, results show that using MWG and RCA decreases expansion of concrete

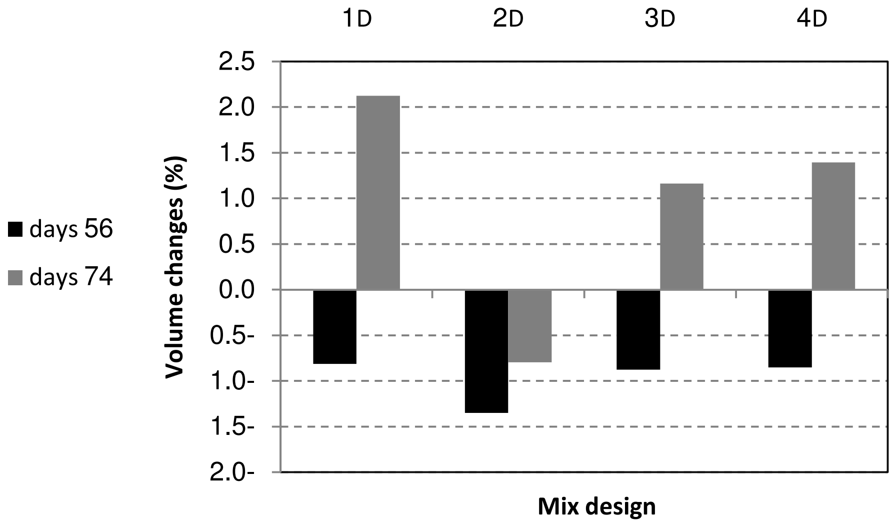

Figure 8. Volume changes percentage of 56 and 74 days specimens in sulfate solution.

3 CONCLUSIONS

48 cubic specimens of 70 mm side dimension were cast and tested in this study to investigate the effect of milled waste glass on durability of recycled aggregate concrete. Mass changes and volume changes of the specimens exposed to sulfate environment for 28, 56 and 74 days were measured. Besides, density, water absorption and volume of permeable pores (voids) were determined. Experimental results showed that using MWG as partial cement replacement has considerable influences on durability properties of concrete exposed to sulfate environment. Based on the results of the present study, the conclusions can be summarized as follows

1. Using MWG in recycled aggregate concrete reduces water absorption and permeable pores volume. It seems that some reactions have enhanced the quality of the remnant cement paste on recycled aggregates.

2. There is a direct relation between water absorption and permeable pores volume of the specimens; the higher permeable pores, the higher the absorption.

3. Using MWG as cement replacement in recycled aggregate concrete has a negative effect on mass changes of specimens in sulfate environment; i.e. it increases mass reduction of concrete specimens exposed to sulfate environment.

4. Using RCA and MWG as cement replacement reduces expansion of concrete specimens exposed to sulfate environment.

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