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Properties of recycled concrete aggregate under different curing conditions

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Received 13 January 2015; revised 28 June 2015; accepted 15 July 2015

KEYWORDS

Concrete;
Recycling;
Curing;
Recycled aggregate

Abstract Construction and demolition wastes are produced every day around the world. Thus the idea of using recycled concrete aggregate in new concrete production appears to be an effective utilization of concrete waste. This paper presents the results of an experimental study to evaluate the effects of recycled concrete aggregate (RCA) percentages under different curing conditions. The percentages of recycled coarse aggregate to dolomite were (0:100%, 25:75%, 50:50%, 100:0%) respectively. The concrete properties which were studied were the mechanical properties (compressive and splitting strength) and mass transport properties (ISAT and sorptivity). The concrete specimens were exposed to three different curing conditions, moist (standard), open-air, and painted specimens using the substance (Curassol 1). The coarse recycled concrete aggregates were obtained by crushing a laboratory produced primary concrete at age of 28 days. The results showed that curing using paint material was the most efficient method of curing at all ages and percentages of recycling except at 100% recycling, where the maximum value of both compressive and tensile strengths was obtained using water curing. Also, in moist curing, full replacement of coarse aggregates gave the highest compressive strength at age of 28 days. In all cases of recycled aggregate ratios, curing using water caused a decrease in the concrete permeability.

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Introduction

Crushing concrete to produce coarse aggregates for the production of new concrete is one of the common methods to

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achieve an environmentally-friendly concrete. This reduces the consumption of natural resources as well as the disposal of waste concrete in landfills [1]. Thus the idea of using recycled concrete aggregate in new concrete production appears to be an effective utilization of concrete waste. However, the strength of new concrete produced using recycled concrete aggregate needs to be evaluated before their use in structures.

Many researchers studied the mechanical behavior of recycled concrete coarse aggregates [1–9]. Also, many authors have pointed to the possibility of using recycled aggregates to produce structural concrete [10–13]. On the other hand, few of

<http://dx.doi.org/10.1016/j.hbrcj.2015.07.001>

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Please cite this article in press as: A.S. Abdel-Hay, Properties of recycled concrete aggregate under different curing conditions, HBRC Journal (2015), <http://dx.doi.org/10.1016/j.hbrcj.2015.07.001>

them studied the effects of curing conditions on the mechanical properties of concrete made of recycled aggregates.

Curing is a treatment that avoids excessive drying and provides enough water content to the concrete mass in order for cement to reach the desired degree of cement hydration. The curing process of concrete tries to oppose the undesired effects of some environmental actions (sun radiation, air moisture and wind), so the effect of curing conditions on the compressive strength of recycled concrete is an interesting issue to be studied.

Two different qualities of recycled aggregates were used by Fernando et al. [14] to make concrete with 0.65 water/cement ratio. The recycled aggregates were added with their natural moisture and replaced different percentages of the coarse aggregates (0%, 20%, 50% and 100%). The concrete specimens were exposed to two different environments (standard curing and open air curing). The results showed that the 7-day strength increases with the percentage of replacement, this behavior was more evident for the standard curing environment. The 28-day compressive strengths of concretes with recycled aggregates were found similar to the ones obtained with natural aggregates regarding the standard curing condition. Fonseca, et al. [15] studied the influence of different curing conditions on the mechanical properties of recycled concrete coarse aggregate concrete. Four concrete mixes were produced using different replacement ratios, along with four different curing methods. It was concluded that compressive strength did not seem to be affected by recycled concrete coarse aggregate incorporation for a given curing condition when compared to conventional concrete. In other words, compressive strength seems to be reasonably insensitive to curing condition.

However, there is a lack of information regarding the effect of recycled aggregate concrete on mass transport of concrete such as initial surface absorption test (Isat) and sorptivity. Moreover, there is still a need to signify the impact of various curing conditions on properties of concrete made with different percentages of recycled aggregate.

In the present study the effects of different curing conditions (moist-standard curing, open air and painted) on the mass transport (ISAT sorptivity) and mechanical properties (compressive strength and splitting strength) of recycled concrete were investigated.

Experimental program

Four concrete mixes were produced using different replacement ratios of recycled coarse aggregate to dolomite (0:100%, 25:75%, 50:50%, 100:0%) respectively. The four mixes were then exposed to three different curing methods (open Air, Saturated, and Painted). After the curing period, hardened concrete tests were performed to determine the concrete properties such as mechanical properties (compressive and splitting strength) and mass transport properties (ISAT and sorptivity).

Materials and mix design

Four different concrete mixes were produced: a control concrete mix and three recycled aggregate concretes with replacement ratios of 25%, 50% and 100%. One type of cement was used in this study, Portland cement (OPC). Natural siliceous

sand with medium grade of fineness modulus of 2.73 and dolomite natural coarse aggregate with maximum nominal size of 25 mm were used in all mixes. Tap water was used for mixing and curing (saturated). Table 1 shows the mix design and slump of the concrete used in the experimental program.

The coarse recycled concrete aggregate was obtained by crushing a laboratory produced primary concrete at age of 28 days. About 250 cubes of dimension 15 * 15 * 15 cm were crushed to produce the recycled coarse aggregates using mix design No.1 (Table 1). After crushing of these cubes, the maximum nominal size of recycled coarse aggregate used in mixes 2, 3 and 4 was 25 mm. From the results of slump shown in Table 1, it is noticed that all mixes were very dry especially mix numbers 3 and 4. This means that the used mixes needed an admixture to improve the concrete workability. ADDICRETE BVF was used as an admixture with dosage 1.0% of cement weight and the resulting slump shown in Table 1.

Curing condition

After 24 h from mixing, the specimens were cured in three conditions, open-air curing in laboratory atmosphere, standard curing and painted curing for 3, 7 and 28 days respectively. Five specimens were cured in each condition. The concrete cubes were painted using Curassol 1. The paint was sprayed on the surface of concrete after casting directly, thus closing the pores and maintaining adequate moisture to interact with cement. Curassol 1 is a material that satisfies ASTM C309-81 class B type 1 with a density of 0.8 kg/liter for type 1.

Testing procedures

Compressive strength of hardened concrete was measured at the age of 3, 7 and 28 days on 150 mm cubic specimens (5 specimens in each case). 28-day splitting tensile strength was measured on five 100 × 200 mm cylindrical specimens. Sorptivity test was carried out on 100 mm concrete cubes according to the test details described in Ref. [16]. Fig. 1 shows the sorptivity test. The test was performed on three specimens at the age of 28 days, and then the average was calculated using the following equation [16]:

$$I = A + ST^{1/2}$$

where

A , is constant,

I is increase in mass in g/mm^2 ,

T is the time, measured in minutes, at which the weight is determined, and

S is the sorptivity in $\text{mm}/\text{min}^{1/2}$.

Initial surface absorption test (ISAT) was carried out on 100 mm concrete cubes. The apparatus is shown in Fig. 2 and test details are described in Ref. [17]. The test was performed on three specimens at the age of 28 days and the flow rates in $\text{ml}/\text{m}^2/\text{sec}$ were calculated using the following equation:

$$F = (60 \times D \times 0.01/t)$$

where

F : flow rate ($\text{ml}/\text{m}^2.\text{sec}$),

D : number of divisions read on tube, and

t : time (sec).

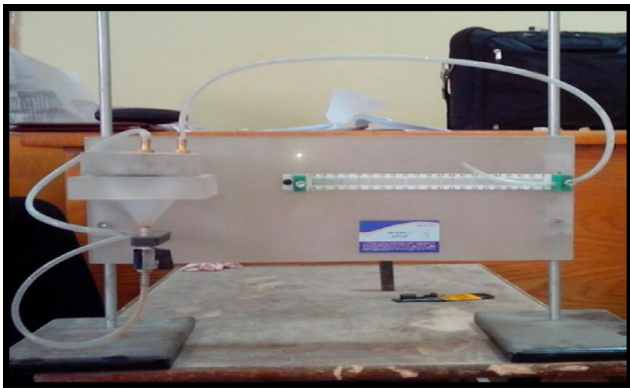
Table 1 Mix proportions used for experimental program.

Mix No.	W/C ratio	Cement (kg)	Sand (kg)	Coarse aggregates (kg)	Dolomite (%)	Recycled aggregates (%)	Slump without admixture (mm)	Slump with admixture (mm)
1	0.55	400	600	1200	100	0	60	140
2	0.55	400	600	1200	75	25	40	115
3	0.55	400	600	1200	50	50	15	100
4	0.55	400	600	1200	0	100	5	60

**Fig. 1** Sorptivity test.

Results and discussion

In this section the results of the tested specimens are presented concerning each curing condition. Then a comparison between all cases of curing in terms of their effects on the ratios of recycled aggregates in concrete mixes as well as on properties of concrete such as mechanical and mass transport properties is discussed.

**Fig. 2** ISAT device.

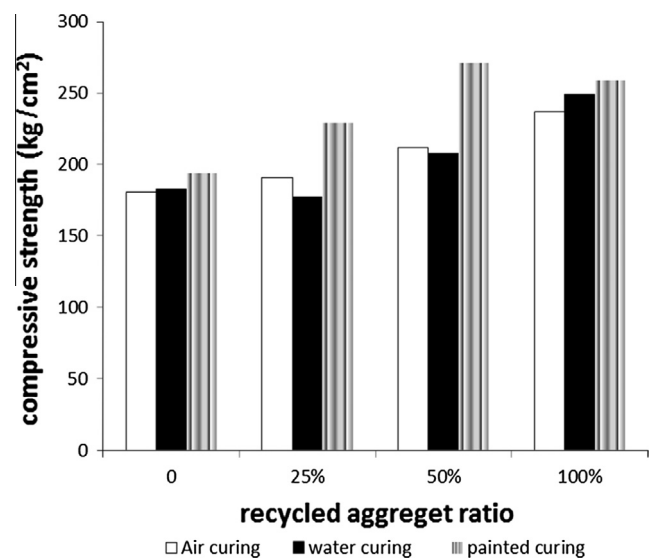
Mechanical properties

Compressive strength

In this study, tests were conducted on specimens that have been cast with different ratios of recycled aggregates while maintaining same water cement ratio (0.55). It was found that the compressive strength of concrete cured in water was higher than that which have been cured in air when the percentage of recycled aggregates were 0% and 100%. On the contrary, it was found that the specimens with recycled aggregate of 25% and 50%, which were cured in air, provided higher compressive strength than that cured in water, at ages of 3, 7 and 28 days. However the case of curing using Paint material gave values of compressive strength higher than the other curing methods, in all cases and at all ages, except in the case of (100%) recycled aggregate which provided the maximum value of the compressive strength in the case of curing with water as shown in Figs. 3–5 and Table 2.

Splitting strength

The splitting tensile strength of the tested specimens showed that the case of concrete that have been cast using 50% recycled aggregate, and cured using Paint material provided the maximum value as shown in Table 3 and Fig. 6. This result

**Fig. 3** Compressive strength for various recycled aggregate ratios at age of 3 days.

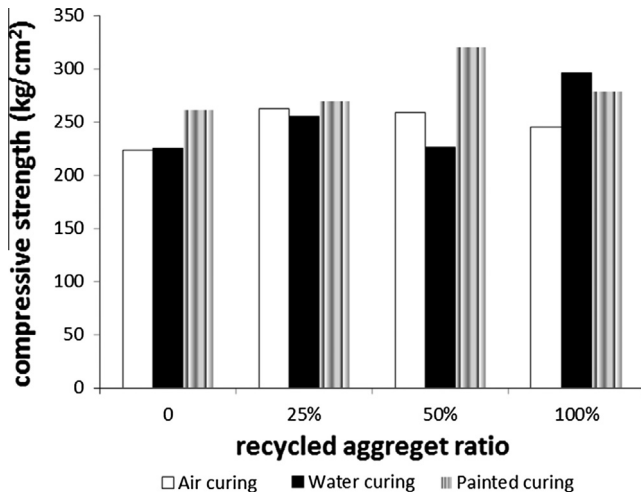


Fig. 4 Compressive strength for different recycled aggregate ratios at age of 7 days.

is in agreement with the result of compressive strength shown in Table 2.

Mass transport

Sorptivity

The test results of sorptivity on tested specimens showed that the samples that have been cured using water have lower values of sorptivity in all cases than the samples that have been cured in air, as shown in Fig. 7. This means that water curing improves the permeability of recycled concrete aggregates.

Initial Surface Absorption Test (ISAT)

When the ISAT test was performed on tested specimens, it was found that the specimens that have been cured using water have lower values of flow in all cases than those that were

Table 2 Compressive strength for different curing conditions, kg/cm².

Type	Age of specimens (day)	Air curing	Water curing	Painted curing
Control	(3 days)	181	183	194
Recycled (25%)		191	177	229
Recycled (50%)		212	208	271
Recycled (100%)		237	249	259
Control	(7 days)	223	225	261
Recycled (25%)		262	255	269
Recycled (50%)		259	226	320
Recycled (100%)		245	296	278
Control	(28 days)	264	283	350
Recycled (25%)		281	280	329
Recycled (50%)		300	242	349
Recycled (100%)		255	308	287

Table 3 Splitting strength of (10 * 20) cylinder specimens at age of 28 days, kg/cm².

Type	Specimens cured in air	Specimens cured in water	Specimens cured by painting
Control	26.5	28.1	30.3
Recycled (25%)	30.5	32.8	26
Recycled (50%)	28.9	27.6	31.1
Recycled (100%)	28.2	26.5	27.9

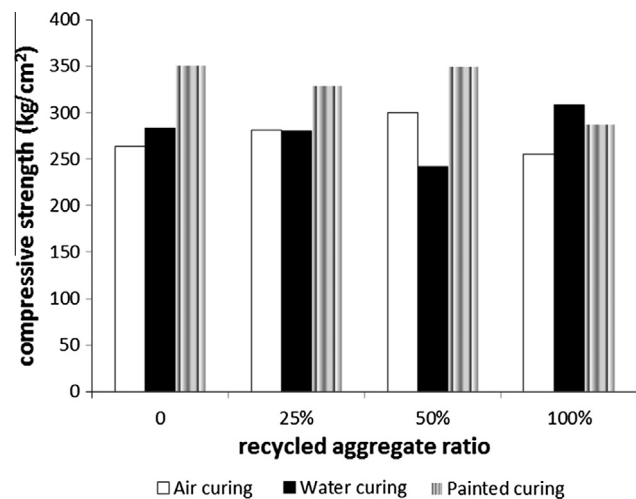


Fig. 5 Compressive strength for different recycled aggregate ratios at age of 28 days.

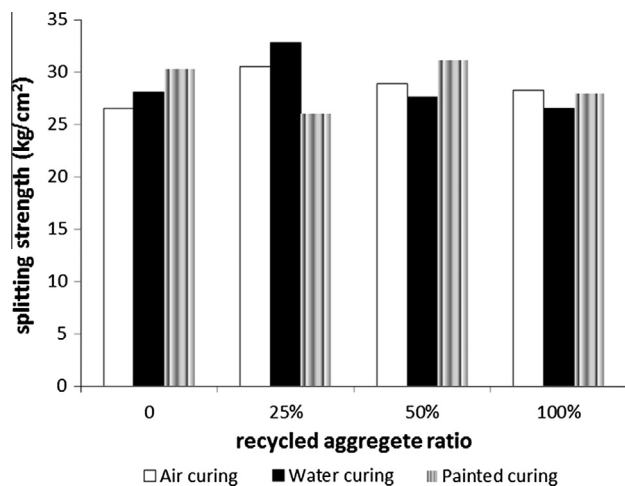


Fig. 6 Splitting strength for various recycled aggregate ratios at age of 28 days.

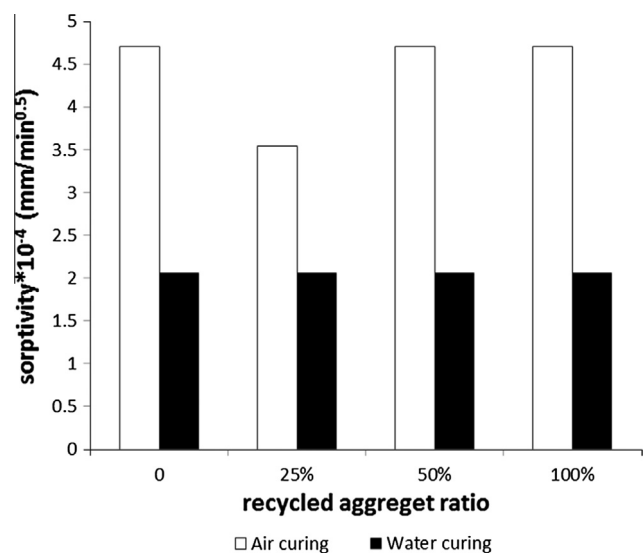


Fig. 7 Sorptivity for various recycled aggregate ratios.

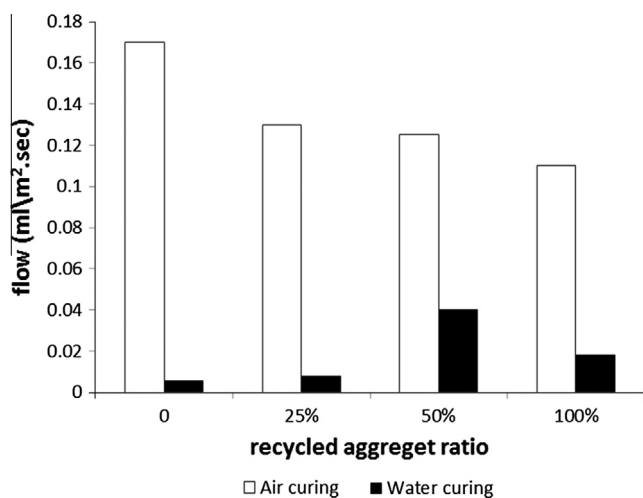


Fig. 8 (ISAT) for various recycled aggregate ratios.

cured in the air as shown in Fig. 8. This indicates that permeability increased in case of curing in air, and increasing the recycled aggregates ratio in the mixes led to decreasing the concrete permeability by ISAT in case of curing in air.

The painted specimens were not tested pertaining to, both Sorptivity and Initial Surface Absorption Test because the painted material caused the specimens to be almost impermeable.

Conclusions

According to the results that have been reached, it can be concluded that:

1. In all the studied cases of curing (air, water, paint), increasing the concrete age led to an increase in its compressive strength.
2. The best ratio of recycled aggregates to natural aggregates is the mixing ratio of 50% and that when they are cured in air or painted, the maximum value of the compressive strength and tensile strength was obtained at age of 28 days.

3. In moist curing, full replacement of coarse aggregates gave the highest compressive strength at age of 28 days.
4. Curing with Paint material is beneficial in all cases and ages than water or air curing except in the case of full replacement where the maximum value of the compressive and tensile strengths in this case, was obtained at curing using water.
5. Increasing the recycled aggregates ratio causes a decrease in the concrete permeability by ISAT in case of curing in air.
6. In all cases of recycled aggregates ratios, curing in water causes a decrease in the concrete permeability.

Conflict of interest

The author declares that there are no conflict of interests.

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