Using the Moisture Retention Property of Recycled Coarse Aggregates for Self-Curing of High Performance Concrete

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***Abstract*—The influence of using saturated surface dry recycled coarse aggregates (SSD-RCA), as replacement of normal coarse aggregates (NCA) on the properties of hardened concrete is discussed in this paper. Concrete mixes were prepared using two different mixing procedures, and by replacing normal coarse aggregates (NCA) with 10% and 30% recycled coarse aggregates. The self-curing curing of concrete due to the incorporation of RCA was evaluated by determining the compressive strength, splitting tensile strength, water absorption and percentage of voids of concrete under two different curing conditions. The compressive and the splitting tensile strength were comparable for both air and water curing mixes at 28 days with 10% and 30% replacement, indicating the influence of self- curing effect through the use of RCA. This study exploits the benefits of rather undesirable property of RCA, such as high moisture retention property, or in another word, high water absorption, as internal curing water for strength development, in order to facilitate the recycling of Construction and Demolition (C&D) waste.**

***Index Terms*—construction and demolition waste, curing, normal coarse aggregate, saturated surface dry, strength, water absorption**

I. Introduction

Construction and Demolition waste has been considered as a major cause of total solid waste production in the world [1]. There is a major increase in construction and demolition waste quantities in Kuwait, partly due to deterioration of old buildings, and mainly due to urban expansion and the need to free lands for development of new constructions. Statistics show that the total volume of construction waste produced in Kuwait in 2017, received by the landfill and recycling sites was approximately 16 million tons [2]. There are several sources of Recycled aggregates such as from demolished buildings, airport runways, bridge supports, and even concrete roadbeds [3]. The recycling of such aggregate in concrete can be useful from environmental and economic aspects, as the construction industry suffers shortages in aggregates supplies [4]. Treatment and reusing such waste as a coarse aggregate in concrete can be considered as a welcomed form of waste management in construction.

The possible use of supplementary cementitious materials as a replacement of cement and the use of recycled coarse aggregates (RCA) as a replacement for normal coarse aggregates, have been reported in several studies [5, 6]. The studies reported the negative effect of the high water absorption of RCA on the strength and durability properties of concrete.

The investigation in this paper is focused on exploring the possibility of using the water saturated RCA as an internal water self-curing material to promote concrete strength development, due to its high water retention and absorption abilities. The material preferably with a water absorption capacity of more than 5% is generally considered as a self-curing agent [7]. It has been reported that the performance of RCA as a self-curing agent depends on the amount of RCA as well as its saturation level [8,9]. The water absorption of locally available RCA was determined according to ASTM C127 in Construction and Building Materials Laboratory, for which the value varies from 4%-8% compared to approximately 0.5%–1% for normal aggregates. This paper reports the possibility of using saturated surface dry recycled coarse aggregates (SSD-RCA), as replacement of normal coarse aggregates (NCA) at different percentage increments of 10-30 %. The effect of replacement on the self-curing was evaluated through properties of hardened concrete.

II. Experimental Study

A. Materials

The properties of raw materials including ordinary Portland cement (OPC), fine aggregates, normal coarse aggregates (NCA) and recycled coarse aggregates (RCA) were determined according to ASTM standards and specifications. The physical properties of SSD-RCA of 20 mm (3/4”), 12 mm (1/2”), and 10 mm (3/8”) were tested and compared with the properties of natural coarse aggregates (NCA).

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B. Concrete Mix Preparation

The control mix was prepared for a w/c ratio of 0.4 and a designed strength of 45 MPa. Concrete mixes were prepared by replacing normal coarse aggregates (NCA) at different percentage increments with saturated surface dry recycled coarse aggregates (SSD-RCA). RCA was conditioned and saturated to ensure water fills the aggregates' pores, according to ASTM C127. The RCAs were pre-soaked in water for 24 h, then surface dried with a cloth to get saturated surface-dried (SSD) condition, before using in the concrete mixes. NCA was replaced with 10-30% SSD-RCA based on the mix proportions, and a two-step mixing procedure was carried out [10,11].

C. Mixing Procedures

In this study, two mixing procedures were performed to understand the influence of mixing procedure on self-curing of concrete due to the use of RCA. In Procedure 1, all materials excluding the natural coarse aggregates (NCA), were loaded in the mixing pan in the first stage of mixing for 180 sec. SSD-RCA, ½ amount of cement and ½ amount of water were loaded and mixed for 60 sec, then the rest of cement, the sand, and the rest of water were added for 120 sec, so the total mixing time of first stage was 180 sec. The NCA, and the SP, were added in the second stage of the mixing to complete the process in 120 sec. In Procedure 2, all materials excluding the natural coarse aggregates (NCA) and SP, were loaded in the mixing pan in the first stage of mixing for 60 sec. Then SSD RCA was added, and mixing was continued for 180 sec. The NCA, and SP, were added in the second stage of the mixing to complete the process in 120 sec. The total mixing time for the whole procedure was 5-6 minutes in both procedures.

D. Sample Preparation and Curing Conditions

Samples were prepared from both mixing procedures to determine the various properties such as Compressive strength (ASTM C39), splitting tensile strength (ASTM C496-17), water absorption (ASTM C642), rapid chloride permeability test (RCPT) according to ASTM C1202, after required period of curing. Curing of concrete test specimens were done in two ways; water curing, and air curing, in order to assure the benefit of water retention specific to RCA, on strength development and other physical & mechanical properties.

E. Results and Discussions

Water absorption of RCA is the critical property that influences the self-curing property of the concrete. The average value of water absorption of NCA was 0.9% and that of RCA was 7%. The bulk density of NCA was recorded as 1520 kg/m^3 and that of RCA as 1365 kg/m^3.

1) Compressive strength

The effect of replacing NCA with RCA on self-curing was evaluated using two different mixing methods by determining the compressive strength at 7 and 28 days. It was observed that the mixes prepared with Procedure 1 had shown higher compressive strength at 7 and 28 days than the mixes prepared with Procedure 2 in most cases. This may be due to the reaction of cement with the absorbed retained water within the RCA pores, alongside the formation of the cement paste cover on the surface of RCA during mixing Procedure 1. The designed strength of 45 MPa was achieved at 28 days in both curing methods as well as with both mixing procedures up to 30% replacement with RCA.

The results showed that control mixes, and mixes with 10% and 30% RCA had shown higher strength in air curing than water curing at 7 days in both mixing methods. However, it is clear that the highest percentage reduction in compressive strength was for the sample with 10% SSD-RCA substitution at 7 days curing age, and the strength reduction was approximately 23% when compared with the control specimen (Refer Table 1). While comparing with the control sample, the compressive strength reduction was about 39% for the7 days air curing (Procedure 2) samples with both 10% and 30% SSD-RCA substitution. As expected, it is clear from Table I and Fig. 1 that the compressive strength enhanced significantly as the curing age increased from 7 to 28 days. The higher strength reduction observed at 7 days could not be observed at 28 days in air curing signifying the influence of self-curing with age of curing due to the incorporation of 10% and 30% RCA. Also, in the case of mixing procedure 1, the strength reduction is higher in water curing than air curing for both 10% and 30% replacements after 28 days curing. This clearly explains the effect of internal curing for continuing the hydration process in air curing due to the use of SSD- RCA, and further development of strength with age.

Also, while comparing the water curing and air curing methods, it was observed that in the case of control mixes, water curing method was giving more strength compared to air curing method at 28 days, whereas in the case of 10% and 30% replacement with RCA in Procedure 1, it was observed that the strength in air curing and water curing at 28 days were comparable, which indicates the influence of internal self- curing through the use of RCA. Therefore, when the general notion considered the high water absorption of RCA to be a negative influence on the mechanical properties of concrete, this study showed that such property could be utilized in a positive manner to understand its contribution to internal self-curing of concrete.

TABLE I. COMPRESSIVE STRENGTH OF CONCRETE UNDER DIFFERENT CURING CONDITIONS

SSD - RCA Content %	7 Days (MPa)	28 Days (MPa)	7 Days- Strength Reduction (%)	28 Days- Strength Reduction (%)
Air Curing Specimens Procedure 1				
Control	52.7	48.79	0	0
10%	42.82	48.23	23.06	1.16
30%	43.81	47.83	20.28	2.01
Water Curing Specimens Procedure 1				
Control	43.53	50.68	0	0
10%	43.29	50.03	0.55	1.3
30%	40.26	46.96	8.12	7.92

Air Curing Specimens Procedure 2				
Control	52.7	48.79	0	0
10%	37.69	44.00	39.81	19.44
30%	37.81	46.49	39.35	4.94
Water Curing Specimens Procedure 2.				
Control	43.53	50.68	0	0
10%	41.86	47.11	3.99	7.57
30%	37.27	49.11	16.79	3.19

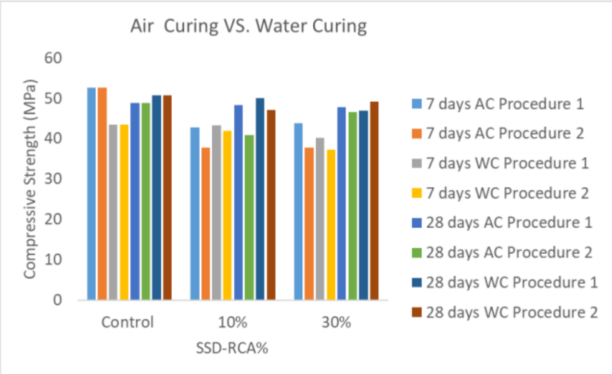

Figure 1. Compressive strength of concrete mixes under air and water curing

F. *Splitting Tensile Strength*

The splitting tensile strength of concrete mixes was determined on 12 cylinders of diameter 100 mm and height 200 mm after 28 days of air curing and water curing methods. The splitting tensile strength of three cylinders was measured in each case and the average value was taken. Based on the results in Table II and Fig. 2, it can be observed that as in the case of compressive strength, the splitting tensile strength for mixes prepared with Procedure 1 had shown higher strength for air cured samples at 28 days than the mixes prepared with Procedure 2. The results showed that there is a clear increase in the strength at 28 days with 10% SSD-RCA substitution in air curing in procedure 1 due to the internal self-curing effect contributed by the RCA. The strength increase was approximately 9% when compared with the control specimen, and also a comparable strength could be observed for 30% replacement. However, the same performance could not be observed in the case of Procedure 2. While comparing with the control sample, the splitting tensile strength had reduced to around 19% and 13 % after 28 days' air curing for 10% and 30% SSD-RCA respectively in this case. When comparing the water curing and air curing methods, it can be observed that strength in air curing and water curing at 28 days are comparable in both procedures, which shows the effect of internal curing due to the use of RCA in the development of strength.

TABLE II. SPLITTING TENSILE STRENGTH RESULTS FOR DIFFERENT PROCEDURES AND CURING METHODS

SSD - RCA Content %	**28 Days (MPa)**	**28 Days- Strength Reduction (%)**
Control	3.11	0.0
10%	3.436	+9.4
30%	3.11	0.3
Control	3.02	0.0
10%	3.098	+2.5
30%	3.06	+1.2
Control	3.11	0.0
10%	2.607	19.3
30%	2.73	13.8
Control	3.02	0.0
10%	3.159	+4.4
30%	3.06	+1.3

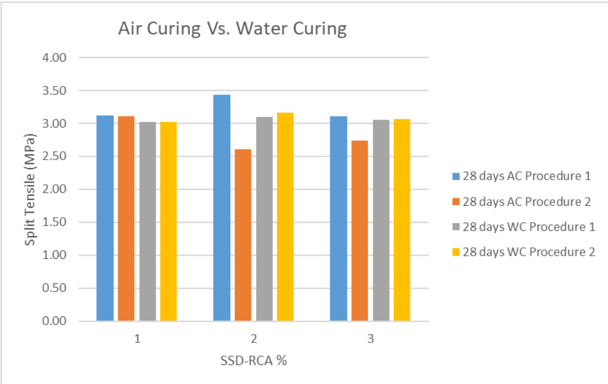

Figure 2. Splitting tensile strength of concrete mixes under air and water curing

G. *Water Absorption and Percentage of Voids*

The water absorption was determined according to ASTM C642 on cylinders of size 100 mm diameter and 200 mm height. The water absorption results obtained for concrete mixes with NCA were compared with10% and 30% SSD-RCA replacement under air and water curing after 28 days (Refer Fig. 3). It was noted that the results for the control as well as test mixes prepared using procedure 1 and 2 were quite comparable for control and 10% replacement. However, with increase in RCA replacement to 30%, the mixing procedure showed an effect on water absorption such that the water absorption for procedure 1 was 5.88%, and it dropped to 4.35% for procedure 2 under air curing. Also, it was observed that water curing had shown lower water absorption compared to air curing in both procedures due to more densification of matrix in water curing.

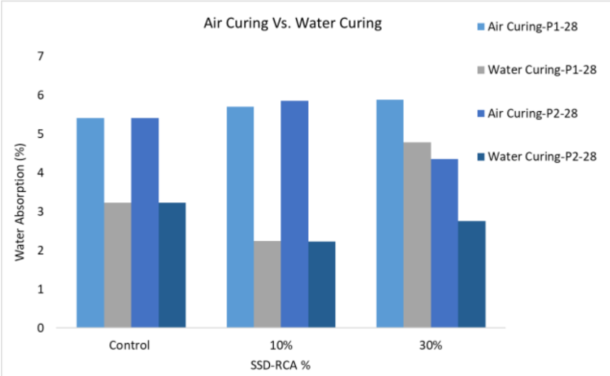

Figure 3. Water absorption of concrete mixes under different curing conditions

Table III gives the details of the percentage of voids of different concrete mixes which affect both the strength and water absorption. It can be observed from the results that the percentage of voids is higher in air curing than water curing, which is in line with the higher water absorption observed for air cured specimens. Under both curing methods and mixing procedures, the percentage of voids increases with increased percentage of RCA, may be due to the porous nature of the mortar on the recycled aggregate's surface.

TABLE III. VOLUMES OF VOIDS OF CONCRETE MIXES UNDER DIFFERENT CURING CONDITIONS

SSD-RCA Content %	Volume of Voids at 28 Days (%)
Air Curing - Procedure 1	
Control	12.42
10%	12.94
30%	13.32
Water Curing - Procedure 1	
Control	7.52
10%	5.28
30%	10.89
Air Curing - Procedure 2	
Control	12.42
10%	13.33
30%	9.98
Water Curing - Procedure 2	
Control	7.52
10%	5.28
30%	6.38

III. CONCLUSION

The concluding results of this investigation have proven that RCA can be utilized economically for development of normal and high performance concrete (HPC), as it contributes to concrete strength maturity and its mechanical properties, without the impact of the adverse effects of the high water absorption. The internal self-curing of concrete contributed by the incorporation of RCA was evaluated by determining the properties of HPC under two curing conditions. The study confirmed that the higher water absorption capacity of RCA could be utilized positively for the development of strength. The designed strength could be obtained up to 30% replacement of NCA with RCA, and the internal self-curing effect due to RCA was more significant with age of curing. In addition, it was detected that the mixing procedure has a predominant effect on strength development while using RCA as an internal self-curing material. It is recommended to conduct further studies to understand the effect of replacing NCA with higher percentages RCA as well as at later age curing of 90 days. It is also important to study the microstructural analysis, and preform durability tests as it is an important factor to identify the sustainability of concrete structure.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

AUTHOR CONTRIBUTIONS

All authors had involved in the experimental work including the preparation of specimens, testing, analysis and contributed to the Preparation of the paper.

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