Construction and Building Materials 79 (2015) 83–89

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

# Initial moisture and mixing effects on higher quality recycled coarse aggregate concrete

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## HIGHLIGHTS

- RCA performs best in concrete when in a partially-saturated moisture condition.
- Two-stage mixing could improve the concrete strength properties.
- Shrinkage of concrete with RCA was not affected by the mixing method.

## ARTICLE INFO

*Article history:*
Received 5 September 2014
Received in revised form 2 January 2015
Accepted 5 January 2015
Available online 21 January 2015

*Keywords:*
Recycled concrete aggregate
Two-stage mixing approach
Aggregate moisture condition
Recycled aggregate concrete
Strength
Shrinkage

## ABSTRACT

Higher quality recycled concrete aggregates (RCA) were used as coarse aggregates in a concrete mixture. The initial aggregate moisture condition (oven dry, partially saturated, fully saturated) and mixing method (normal, two-stage) were assessed in order to limit the differences between concrete containing RCA and virgin aggregates. Concrete with partially-saturated RCA using two-stage mixing was beneficial for improving the compressive and split tensile strengths. For this material, the mixing method did not affect the concrete free drying shrinkage at any age. Overall, the two-stage mixing method increased the concrete workability and could potentially improve the concrete strength properties, particularly when the RCA is partially saturated.

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## 1. Introduction

Under modern airport renovation plans, agencies are faced with disposing significant amounts of concrete waste because of reconfiguration and reconstruction of the airfield. Concrete pavement waste can be crushed into an aggregate and placed as granular base or subbase layer for asphalt or concrete pavements, which has been done extensively over the years. The concrete waste can also be used as an aggregate in new concrete materials to replace virgin aggregates, as has been under investigation for the several decades, primarily for highway rigid pavements [1–3]. There have been fewer studies of using RCA for airfield rigid pavements, either as a support material [4,5], which has been the most common, or as a replacement of virgin aggregate in concrete [6–8]. In order to minimize adverse impact to aircraft operation and performance, one primary requirement of utilizing RCA in new airfield concrete is that it would not significantly affect the concrete strength, shrinkage, and surface properties.

The moisture condition of the RCA has been found to affect the workability and strength of the concrete [9], mainly because of the higher absorption capacity of the RCA relative to virgin aggregate. Researchers have published studies on RCA concrete with the initial moisture state of RCA in the oven dry [10], air dry [11], prewetted (soaked for 10 min) [12–14], partially saturated [15,16], fully saturated [17,18], or otherwise described as "presoaked" conditions without further details [19–21]. Etxeberria et al. [15] cautioned that fully saturated RCA may result in the failure of the new interfacial transition zone (ITZ) between the new cement paste and the RCA. Poon et al. [22] explicitly studied the effects of three RCA moisture conditions (oven dry, air dry, and saturated surface dry) and found that the oven dry condition had the greatest initial slump but also had the fastest slump loss while the air dry condition (50% of the maximum absorption capacity) resulted in the greatest compressive strength. Barra de Oliveira and Vazquez

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http://dx.doi.org/10.1016/j.conbuildmat.2015.01.047
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[23] also considered the effects of three RCA moisture conditions (oven dry, partially saturated at 88–90% absorption capacity, and saturated surface dry) and found that the partially saturated RCA had slightly greater strengths and better freeze/thaw resistance than the other two moisture states. A RILEM report [24] stated that pre-soaking the RCA is beneficial to prevent rapid loss of workability but there is not a significant difference in compressive strength between air dry and saturated surface dry RCA.

The thickness of the ITZ in concrete is on the order of 20–40 μm, which corresponds to approximately 20–40% of the total volume of the matrix between aggregates [25]. For many low slump concretes, the ITZ is the controlling factor for the concrete strength because of two main factors: (1) the interface between the aggregate and the ITZ, i.e., the bond, and (2) the larger porosity present in the ITZ [26]. Compared to virgin aggregate, the ITZ with RCA can be morphologically different because of its higher porosity and absorption capacity [27]. One study found that the strength of the old ITZ between the aggregate and mortar in the RCA can affect the strength of the new concrete [28]. Another study found that the microhardness of the old ITZ is affected by its quality and not the quantity of the adhered mortar [29]. In an attempt to improve the ITZ between the new cement paste and the RCA, two similar approaches have been proposed: the two-stage mixing approach (TSMA) by Tam et al. [30] and the double mixing (DM) method by Ryu [31]. In later studies, Tam et al. [32,35] modified the TSMA to examine the effects of how the concrete is affected by different mixing times and mixture components. In TSMA method, the RCA is coated with a "cement slurry" in an attempt to fill the cracks and pores in the RCA with hydrating cement. Subsequently, variations of TSMA/DM have been utilized by other researchers [7,8,21,33,34,36–40]. Compared to conventional concrete mixing approaches, TSMA/DM with RCA has been found to increase the compressive [30–33,35,37–39], split tensile [31,35,38], flexural strengths [33,35]; increase the modulus of elasticity [32,33,35,38]; potentially improve the ITZ [30–37,39] while reducing ITZ thickness [31]; reduce the chloride ion penetrability [31,37] (more notably at later ages [34] or earlier ages [38]); generally reduce the water permeability [34]; and shrinkage [34,38] and creep strains [34]. Overall, the literature has shown that there is a beneficial effect of TSMA on mean RCA concrete properties without explicitly demonstrating the statistical improvement.

A recent study on airport RCA materials showed that 100% volume replacement of the virgin coarse aggregate with RCA did not statistically reduce its strength but did produce rapid loss in workability [7]. The initial RCA moisture condition at batching appeared to be the main factor in the loss in workability, as noted by previous researchers [22]. The objectives of this study were to determine the statistical significance in terms of workability, strength, and shrinkage of replacing the virgin aggregate type with high quality RCA given different mixing approaches (normal mixing method versus TSMA) and initial coarse aggregate moisture contents (oven dry, partially-saturated, and saturated surface dry). While another study has specifically examined the effects of these three moisture conditions on RCA concrete mechanical and durability properties [23], this research will verify if there is a statistical improvement in the concrete strength and shrinkage properties of 100% high-quality coarse RCA relative to virgin aggregate concrete with the TSMA compared to the normal mixing procedure (NMP).

## 2. Materials and methods

### *2.1. Cementitious materials*

All concrete mixtures in this study contained a total cementitious content of 517 lb/yd$^3$ (307 kg/m$^3$), which was composed of 80% Type I portland cement and 20% Class C fly ash. This total cementitious content was selected based on the minimizing total cementitious content in the paving mix for the airport.

### *2.2. Aggregate properties*

The RCA in this study was sourced from a single stockpile of crushed concrete at the O'Hare International Airport [41]. This RCA in particular is of higher quality and less variability relative to conventional RCA or construction and demolition waste, as there are stricter protocols as to what can and cannot be used in concrete for airfield rigid pavements. From X-ray diffraction the RCA was found to contain dolomite, quartz, and remnant hydrated cement phases.

Two virgin coarse aggregates were blended (i.e., sieved and recombined) in this study, which were classified, according to the Illinois Department of Transportation [42], as CA-7 and CA-16 (see Table 1). The RCA was sieved and recombined to match the blended virgin aggregate gradation. The same fine aggregate was used in all mixes, which was a natural sand classified as FA-02. The specific gravity (saturated surface dry) and absorption capacity of the aggregates are also shown in Table 1. As expected, the RCA was found to have a lower specific gravity and higher absorption capacity relative to virgin aggregates.

The RCA was evaluated for the residual mortar content (RMC) using a method outlined by Abbas et al. [43] in which the RCA was immersed in sodium sulfate solution while undergoing freezing and thawing cycles. This method found that the particles retained on the #4 (4.75 mm) sieve had an RMC of about 26% while particles larger than 25 mm had an RMC of about 13%.

### *2.3. Aggregate moisture conditions*

The three initial aggregate moisture conditions used in this study were oven dry (OD), saturated surface dry (SSD), and partially-saturated (approximately 80–85% SSD). The OD condition was met by drying the aggregates in a 105 °C oven for at least 24 h prior to batching. The SSD condition was obtained by soaking the aggregates in water for at least 24 h prior to batching and then removing the excess surface moisture off of the aggregates until the SSD condition was reached. In order to

**Table 1**
Aggregate gradations and properties.

| Gradation (percent cumulative passing) | | | | | |
|---|---|---|---|---|---|
| Sieve | | Virgin coarse 1 | Virgin coarse 2 | Combined grading of CA-7 and CA-16 for RCA | Natural sand fine aggregate |
| U.S. | mm | CA-16 | CA-7 | | FA-02 |
| 3/4 in | 19 | 100% | 83% | 93% | 100% |
| 1/2 in | 12.5 | 100% | 20% | 66% | 100% |
| 3/8 in | 9.5 | 95% | 6% | 59% | 100% |
| #4 | 4.75 | 41% | 1% | 47% | 92% |
| #8 | 2.36 | 6% | 0% | 31% | 68% |
| #16 | 1.18 | 2% | 0% | 19% | 42% |
| #30 | 0.6 | 1% | 0% | 10% | 21% |
| #50 | 0.3 | 1% | 0% | 1% | 2% |
| #100 | 0.15 | 1% | 0% | 0% | 0% |
| #200 | 0.075 | – | – | – | 0% |
| *Aggregate properties* | | | | | |
| Specific gravity | | 2.68 | 2.67 | 2.41 | 2.57 |
| Absorption capacity | | 2.73% | 1.90% | 5.51% | 2.43% |

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