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Self-consolidating concrete using recycled concrete aggregate and high volume of fly ash, and slag

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HIGHLIGHTS

- Using 25%, 50%, 75, and 100% RCA decreased the compressive strength of mixtures.
- Replacing NCA by RCA decreased the split tensile strength of all mixtures.
- Replacing the cement by high volume of SCMs reduces the free shrinkage strain.
- The increase in the % of RCA replacing NCA increases the total shrinkage strain.
- SCC mixtures with high content of SCMs had higher resistance to chloride diffusion.

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ABSTRACT

This paper studies the effect of using recycled concrete aggregate (RCA) on the properties of self-consolidating concrete (SCC). Twenty concrete mixtures with different mixtures of fly ash (FA), slag (S) and RCA were developed and tested. The mixtures were sorted into five categories, with constant water to cementitious materials (w/c) ratio of 0.38, based on their RCA content: 0, 25, 50, 75, and 100% of natural coarse aggregate (NCA) replaced by RCA. The results showed that as the percentage of RCA (0–100%) has increased in the mixes replacing NCA; the compressive strengths of the concrete mixes has decreased at 3, 14, and 28 days, and the tensile strengths decreased at 28 days. Moreover, the partial replacement of cement by (SCMs) had an adverse effect on the 28-days-compressive strength; however, it increased the resistance to chloride permeability. Moreover, several mixes have met the minimum Illinois Department of Transportation compressive strength requirements.

1. Introduction

Self-consolidating concrete SCC), is highly flowable concrete that doesn't segregate. The high flowability of SCC allows it to flow and consolidate into the formwork within the rebar due to its self-weight without vibration. This characteristic allows placing concrete in difficult construction conditions such as congested rebar members in seismic zones [1].

To achieve high flowability, high-range water-reducing admixture (HRWRA) is usually used in SCC mixtures. However, to maintain the consistency of the mixtures, lower water to cement ratio and viscosity-modifying admixture VMA) are used. The use of SCC is still limited especially in the United States because of its relatively high cost due to the larger amount of cement and admixtures used in SCC [2]. The adequacy of using various test methods in determining workability and recommending performance specification of concrete used in structural applications was evaluated by Huang et al. [3].

Nowadays, recycled-concrete aggregate (RCA) has been a common substitute for natural aggregate. Recycled-concrete aggregate has been used by many researchers to produce both conventional concrete and SCC and the properties of the concrete with RCA were tested [4,5,6]. The use of both coarse and fine RCA to replace natural coarse and fine aggregate has been researched. Most of the conducted research concluded the that the compressive strength of concrete made using coarse and fine RCA were lower by 15% to 40% of the strength of concrete mixes prepared using NCA [7]. Grdic et al. [6] studied the effect of replacing NCA by RCA by different percentages (0%, 50%, and 100%). The slump flow test was used

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for testing flowability and viscosity, L-box test for testing passing ability, sieve segregation test for testing the segregation resistance, and the compressive and tensile tests for testing the hardened materials. The research indicated that the mixtures with coarse RCA showed only slight differences compared to those made with NCA. The density of the mixtures containing RCA had lower densities, and lower compressive and tensile strengths compared to the control mixture. However, those mixtures had higher water absorption compared to the control mixture.

Kou and Poon [5], studied the use of fine RCA FRCA) as a replacement of river sand in SCC. The researchers concluded that the compressive and tensile strength decreases with the increase in FRCA. Moreover, the maximum compressive and tensile splitting strength were obtained by using 25–50% FRCA replacement. The carbonation, permeability, and freeze-thaw resistance were the same or even better than concrete prepared with regular aggregate [5,8]. Although, the drying shrinkage increased with an increase in the FRCA content, reducing the water to cement ratio can mitigate it. Zoran et al. [8] suggested that the quantity of water should be increased when using RCA to prepare SCC. Measuring the water absorption of RCA in the first 30 min will provide an indication on whether an additional amount of water needs to be added. Another approach to compensate for the water absorbed by RCA is to saturate through prior immersion until the required consistency of the mix is achieved. Safiuddin et al. [9] studied the fresh properties such as filling ability, passing ability, and segregation resistance of SCC using RCA substituting 0–100% NCA by weight. The research concluded that SCC with up to 50% replacement of NCA has acceptable passing and filling properties and adequate resistance to segregation.

2. Objectives and tasks

The objective of this research is to study the use of RCA in replacement of NCA (0–100%) and the replacement of Portland cement with SCMs with different proportions, on the fresh, hardened, and durability characteristics of SCC. This research focuses on the study of SCC with a wide range of RCA (0–100%) and high volume of SCMs (50% FA and 50%S), which will provide significant results about the use of SCC with different combinations of RCA and different binding materials. Additionally, this research includes studying the fresh and hardened, properties and durability characteristics of SCC using RCA and SCMs. Therefore, the following tasks were performed: 1) Twenty SCC mixes were poured; the mix matrix used in this study is shown in Table 1. The designed mixes studied the influence of using a combination of FA, S, FA and S with partial replacement of Portland cement and different percentages of RCA (0–100%), replacing the NCA, 2) laboratory testing of SCC mixes is comprised of: a) characteristics of the fresh SCC: slump flow and T50 tests, J-Ring, and segregation, b) hardened properties: compressive strength at 3, 14, and 28 days, and split tensile strength at 28 days, and c) durability characteristics: unrestrained shrinkage up to 90 days and the permeability of SCC mixtures was determined using the rapid chloride permeability test (RCPT), and 3) SCC mixtures strengths: the minimum compressive strength imposed by Illinois Department of Transportation (IDOT) for several engineering applications were adopted to determine the applicability of the use of high volume SCM's and RCA in SCC.

3. Experimental program

3.1. Materials and mix proportions

Crushed limestone with nominal maximum aggregate size of 19 mm was used in the mixtures and local sand was used as fine aggregate. The gradation of the aggregate used in this study is delineated in Table 2. NCA and fine aggregate FAG) with a specific gravity and absorption at saturated surface dry conditions of 2.68, and 1.2%, and 2.67, and 2.5% were used. The relative specific gravity and absorption at saturated surface dry SSD) condition of RCA was 2.39 and 3.03%. ASTM C 150 [10] Type I cement and SCMs such as, ground granulated blast furnace slag (S), class C fly-ash (FA) were used as binders with different percentages in all mixtures prepared. All SCMs including FA and S conform to ASTM C618 [11]; and ASTM C989 [12]. The chemical composition of Portland cement, FA and S are delineated in Table 3. High-range Water Reducer Admixture (HRWRA) having a density of 1.1 g/cm^3 was used with different amounts as shown in Table 4, in the mixtures to produce a workable concrete with low w/c ratio. This type of HRWRA contains a viscosity-modifying agent which precluded the need for adding additional VMA to the mixtures. Although the RCA was prewetted before mixing, it was left to dry before actual batching took place, therefore, RCA is considered to be in air-dry condition.

3.2. Mixing

The materials were mixed in a concrete mixer having a volume of 3 Cu.ft. The cement, sand, and gravel were first mixed together followed by the addition of water. The HRWRA was added directly during the mixing to the fresh concrete at the end of the batching cycle. Following the addition of the HRWRA, the constituents of SCC were mixed for 100 revolutions. All aggregates are considered to be in air-dry condition prior to batching.

3.3. Testing procedures

Testing includes three different categories: 1) the properties of all fresh concrete mixtures were assessed to test their flowability, restricted deformability (passing ability) and whether they have met the minimum requirements of SCC using the slump flow and T50 tests with and without the J-Ring and the segregation index (*SI*) test, 2) the properties of hardened SCC mixtures were evaluated by measuring the compressive strength of all specimens at various ages 3, 14, and 28 days), and the split tensile strength at 28 days using one cylinder of 200 × 400 mm, and 3) the durability characteristics were determined by measuring the unrestrained shrinkage up to 90 days for all concrete mixtures, and the permeability of SCC mixtures was evaluated using the rapid chloride permeability test RCPT) according to AASHTO T277 [13], and ASTM C1202 [14]].

3.3.1. Fresh properties

3.3.1.1. Slump-flow and T50. The aim of using the slump flow and T50 tests is to estimate the deformability and flowability of all SCC mixtures according to ASTM C 1611 [15]. Additionally, the T50 test was conducted to measure the rate of concrete deformability by measuring the time needed for the SCC mix to reach a 500 mm spread during the slump flow test. Table 5, shows the measured values for the slump flow and T50 tests for all mixtures.

3.3.1.2. J-Ring test. This test was used to determine the passing ability of concrete in accordance with ASTM C 1621 [16]. The passing ability of concrete can be estimated as the difference between the concrete flow in the case of the slump flow test and the J-Ring test. Table 5, shows the measured values for the slump flow with J-Ring test for all mixtures.

3.3.1.3. Segregation index (SI). Flowability in SCC has always been a concern since the addition of improper amounts of super plasticizer may result in segregation of the SCC mixture where the coarse aggregate is separated from the SCC mix. To evaluate the segregation of the concrete mixtures, a segregation index value (*SI*)

Table 1
SCC mix matrix.

Mix Type	0% RCA	25% RCA	50% RCA	75% RCA	100% RCA
100% cement	RCA0-FA0-S0	RCA25-FA0-S0	RCA50-FA0-S0	RCA75-FA0-S0	RCA100-FA0-S0
50% FA	RCA0-FA50-S0	RCA25-FA50-S0	RCA50-FA50-S0	RCA75-FA50-S0	RCA100-FA50-S0
50% S	RCA0-FA0-S50	RCA25-FA0-S50	RCA50-FA0-S50	RCA75-FA0-S50	RCA100-FA0-S50
25% FA & 25%	RCA0-FA25-S25	RCA25-FA25-S25	RCA50-FA25-S25	RCA75-FA25-S25	RCA100-FA25-S25