PROPERTIES OF RCA CONCRETES MIXED WITH CEMENT PASTE DISSOCIATION AGENT

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Abstract

Due to environmental regulations, difficulty in quality control, and decrease in strength properties, the use of recycled concrete aggregate (RCA) has been limited to nonstructural application, despite its economical and eco-friendly benefits. The attached residual mortar (RM) in the RCA unfavorably affects basic aggregate material properties such as density, absorption, porosity, etc. Meanwhile, a cement paste dissolution agent (CPDA) in concrete mix is known to help dissolving the RM within limits and enhance the mechanical properties of RCA concrete. Thus, our study aims at assessing the effect of the CPDA on mechanical strength and drying shrinkage properties of RCA concrete. Two experimental series were carried out. For a first series, a total of three mixes were prepared for typical paving concrete with 100% replacement of the natural coarse aggregate with the RCA. The CPDA ranging from 0-5% by mass of cement has been utilized in the RCA mixes. Test results showed that the addition of 2.5% of CPDA as chemical admixtures in the RCA concrete mixes helps improvement of compressive strength, flexural strength, and elastic modulus properties. Next, a total of nine mixes were proportioned by th the conventional ACI volume mix design and the EMV mix design for typical PC culvert. In the second test series, spray coating the RCAs with CPDA solution for two days before mixing helps decreae of drying shrinkage.

Keywords:

Recycled concrete aggregate**;** Cement paste dissolution agent; Mechanical strength, Drying shrinkage

1 INTRODUCTION

It has been reported that recycled concrete aggregate (RCA) is more heterogeneous, porous and less dense than natural aggregate. The attached residual mortar (RM) unfavorably affects the RCA concrete properties. It was also reported that the RM in the RCA concretes results in a decrease of the compressive strength by 42 % and the modulus of elasticity by 45% [Fathifazl 2008]. FHWA data shows that the RCA concrete leads to an increase in the coefficient of thermal expansion by 30% and permeability by 500% [Snyder 2010].

So far many researchers have carried out various experimental studies on the use of RCA, such as using RCA source manufactured from precast concretes, the two-lift paving method, modification of mixing processes, new mix design approaches, and strengthening of residual mortar (RM). High quality RCA can be obtained from precast concretes [Thomas 2016] or concrete sleepers. The main advantage of retaining RCA from the precast products is the possibility of producing reliable RCAs and reducing sorting costs. Two-lift concrete pavements have been successfully constructed in the west Europe countries and USA, applying low quality RCA concrete in the bottom layer. It was pointed out that two-lift construction using recycled materials in the bottom layer could have the highest positive impacts from a social and environmental perspective [Shi 2018]. After introducing a two stage mixing approach (TSMA) [Tam 2007], a triple mixing procedure was suggested to manufacture strong and durable RCA concrete [Sicakova 2018]. The triple mixing process divides the mixing process into three parts: coating coarse aggregates by application of additive and a certain amount of water, adding cement with fine aggregate, and mixing with the remaining water and plasticizer. It was reported that the density, water absorption capacity, and strength properties were improved. New modified mix proportioning methods for producing RCA concrete have been proposed by a few researchers [Fathifazl 2009; Yang 2017; Gupta 2016]. Gupta et al. proposed the equivalent coarse aggregate mass method. The main concept is that the attached mortar is treated as part of the sand. The equivalent mortar volume (EMV) method was proposed by Fathifazl et al. [Fathifazl 2009]. It was assumed that the RM was considered as that of the total mortar. Many researchers reported to have an equivalent mechanical strength properties and drying shrinkage using the EMV mixes, compared to the companion natural aggregate concrete.

Researchers have investigated the strengthening of RM. Numerous materials were used to improve the RCA quality by filling the pores and ITZs [Wu 2018]: PVA solution [Kou 2010], siloxane and silane polymer solutions [Spaeth 2013], pozzolanic material slurry [Kong 2010]. Overall, the above mentioned surface treated materials contributed to a reduction in water absorption of RCA. In recent years, the bio-deposition method was introduced to improve the quality of RCA. This method uses bacteria to produce calcium carbonate on the surface of cells near pores or ITZs in the presence of adequate calcium sources [Wang 2017]. The compressive strength as well as water absorption was improved by this method.

In this study was adopted a cement paste dissolution agent (CPDA) which is known to help dissolving the RM within limits and enhance the mechanical properties of RCA concrete. Our study aims at assessing the effect of the CPDA on mechanical strength and drying shrinkage properties of RCA concrete. Two experimental mix series were carried out. In the first mix series, a total of three mixes were prepared with 100% replacement of the natural coarse aggregate with the RCA, proportioned by the conventional ACI volume mix design. The CPDA was used as a chemical admixture. Next, a total of nine mixes were prepared for typical PC culvert concrete using the conventional ACI volume method and EMV method. A CPDA solution was sprayed on the surface of RCAs and cured for two days then incorporated in mixing.

2 EXPERIMENTAL PROGRAM

2.1 Aggregates

This experimental study used recycled aggregates produced from two different sources. RCA1 is a maximum size of 25 mm and was crushed from the old runway concrete pavement at 00 air base reconstruction site in S. Korea. RCA2 is a maximum size of 20 mm and was crushed from the PC culverts with 30 MPa grade .

The specific gravity and absorption ratio of RCAs, NCA and sand are shown in Tab. 1. In addition, residual mortar content (RMC) of RCA is provided in Tab. 1. The RMC value of RCA2 was determined by the thermal treatment [Juan 2009]. The RMC samples were prepared and dried in a muffle furnace at 500 °C for two hours. The sampe was then immersed in cold water. Extra mortar that still remained may be removed by the sudden cooling. The RMC was evaluated by using the following equation :

$$RMC\ (\%) = (W_{RCA} - W_{OVA})/W_{RCA} \quad (1)$$

where W_{RCA} is the first oven-dried RCA sample weight and W_{OVA} is the final oven-dried OVA weight after removal of the residual mortar (RM).

Tab. 1: Basic aggregates properties.

tests	RCA1	RCA2	N C A	sand1	sand2
Specific gravity	2.54	2.60	2.69	2.58	2.60
Absorption ratio(%)	4.81	2.62	0.54	0.52	0.95
RMC	-	20.0	-	-	-

Crushed granite was used as natural coarse aggregate (NCA). This NCA is the same source of coarse aggregate from which the previous PC culverts were made. Natural river sands were incorporated as fine aggregates.

2.2 CPDA

A cement paste dissolution agent (CPDA) adopted in this study is a commercial product, which is composed of SiO_2, CaO, NaCl, $NaNO_3$, Na_2SO_4, and K_2CO_3. The following equations illustrate the additional hydration reaction of CPDA with calcium hydroxide from cement [Rusinoff 1998].

$$3Ca(OH)_2+6NaCl+30H_2O+[3CaOAl_2O_3] \Rightarrow 3[CaOAl_2O_3CaCl_210H_2O]+6NaOH \quad (2)$$

$$3Ca(OH)_2+6NaNO_3+32H_2O+Ca_3(AlO_3)_2 \Rightarrow 3Ca_3(AlO_3)_23Ca(NO_3)_232H_2O+6NaOH \quad (3)$$

$$3Ca(OH)_2+3Na_2SO_4+31H_2O+Ca_3(AlO_3)_2 \Rightarrow 3(CaOAl_2O_3)_2CaSO_431H_2O+6NaOH \quad (4)$$

For the first mix series, the CPDA amounts of 0, 2.5, 5% by mass of cement was used as a chemical admixture. Meanwhile in the second mix series, a 300g of CPDA powder was dissolved into 1 liter of water and sprayed on the surface of RCAs (Fig. 1). Then, the coated RCAs was covered in a pan with plastics for two days and the coated RCAs were incorporated into RCA concrete mixing.

Fig. 1: Spray Coating RCAs.

2.3 Mix Design

Two series of mixes were designed and summarized in Tab. 2. First series of mixes were designed for a typical structural concrete while the second series of mixes were designed for the PC culverts.

The mix design identification in Tab. 2 can be explained as follows. There are four different sets of terms. The first numers such as 25, 50, 100 denote replacemenf of RCA percentage. The second term *C* designates the conventional mix method, while *E* is the EMV mix method. The third term indicatees the type of coarse aggregates; *RA* implies recycled coarse aggregate, while *NA* as natural coarse aggregate. The last digit numbers in the first series denotes CPDA contents as a percentage of cement amounts. The term *S* in the second series designates surface coating with CPDA for 2 days.

The first series of mixes were designed to find out whether adding CPDA as chemical admixture leads to improvement of mechanical strength properties. The first series of mixes consist of three different mixes with 0, 2.5, and 5% of CPDA. The second series of mixes were then designed to investigatge whether coating the RCAs with CPDA solution is a possible way to improve strength and drying shrinkage properties.

Tab. 2: Concrete mixture designs and material quantities.

Test series	Mix[a)]	W/C	S/a	RCA wt %	Mix Proportions (kg/m³) W	C	S	F/A	NCA	RCA	CPDA (kg)	Admixture (kg)
1	100CRA-0	0.37	38.9	100	138	370	695	-	-	1093	0	0.93
1	100CRA-2.5	0.37	38.9	100	138	370	695	-	-	1093	9.25	0.93
1	100CRA-5	0.37	38.9	100	138	370	695	-	-	1093	18.5	0.93
2	CNA	0.36	39.1	0	158	396	675	44.0	1051	0	-	2.56
2	25CRA	0.36	40.4	25	158	396	694	44.0	767	256	-	2.49
2	50CRA	0.36	41.7	50	158	396	712	44.0	499	498	-	2.49
2	25CRA-S	0.36	40.4	25	158	396	694	44.0	767	256	-	2.49
2	50CRA-S	0.36	41.7	50	158	396	712	44.0	499	498	-	2.49
2	25ERA	0.36	37.0	25	152	380	648	42.3	830	276	-	2.60
2	50ERA	0.36	34.6	50	145	363	619	40.3	584	583	-	2.61
2	25ERA-S	0.36	37.0	25	152	380	648	42.3	830	276	-	2.74
2	50ERA-S	0.36	34.6	50	145	363	619	40.3	584	583	-	2.62

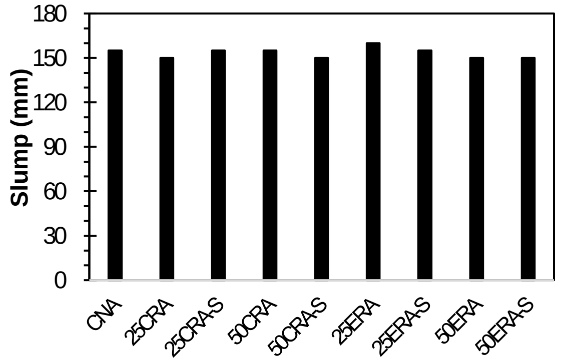
a) First numbers denote percent replacement of RCAs, then, C and E in the mix identification denote conventional and EMV mix design, respectively. RA implies recycled coarse aggregate and NA as natural coarse aggregate. Lastly, 0, 2.5, 5 are percentage of CPDA by mass of cement in first mix series and S denotes spray coating RCAs in second mix series. Test series 1 and 2 used RCA1 and RCA2, respectively, as RA.

The second series of mixes are composed of 9 mixes; one as control mix with natural coarse aggregate, four conventional ACI volume mix method with and without RCA coating with CPDA, and four EMV mix method with and without RCA coated with CPDA.

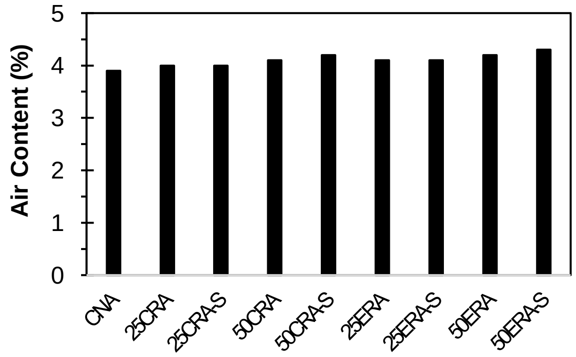
3 TEST RESULTS

3.1 Slump, Air Content and Density

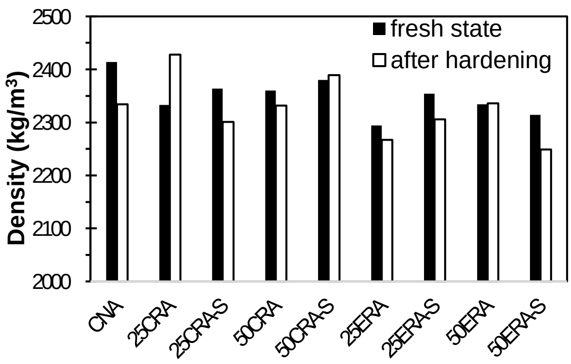
Fig. 2 shows test results of slump, air content, and sensity of the second mix series. The mixtures slumpes ranged between 150-160mm. The air contents values of the mixtures ranged between 3.9-4.3%.



(a) Slump



(b) Air content



(c) Density

Fig. 2 : Effect of different mixes in second series.

3.2 Compressive and Flexural Strength

Fig. 3 shows compressive strength test results of the first mix series at the age of 7 days and 28 days. Compared to 100CRA-0 as control specimen, the compressive strengths increased by 32% and 24% at 7 days and 28days, respectively in the 100CRA-2.5 mix. Whileas in the 100CRA-5 mix, the compressive strengths decreased by 27% and 24% at 7 days and 28 days, respectively.

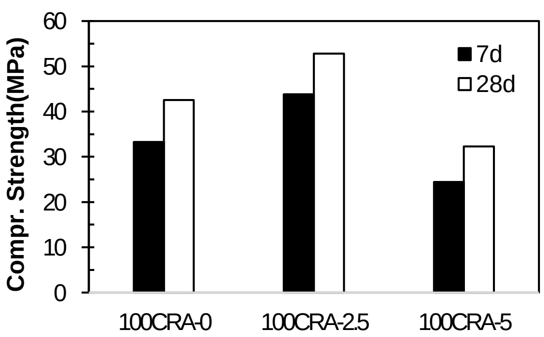


Fig. 3: Compressive strength results of first mix series.

Fig. 4 shows flexural strength test results of first mix series at the age of 7 days and 28 days. In a similar manner to the compressive strength results, the flexual strengths increased by 56% and 18% at 7 days and 28days, respectively in the 100CRA-2.5 mix, compared to the control mix. Whileas in the 100CRA-5 mix, the flexural strengths decreased by 21% and 3% at 7 days and 28 days, respectively.

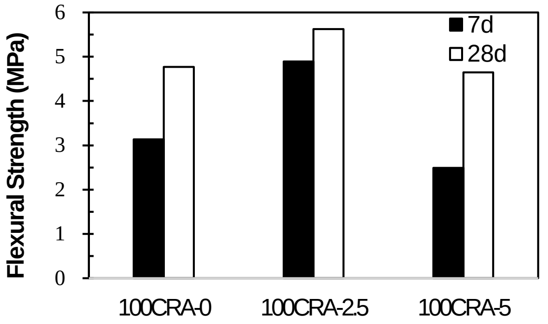


Fig. 4: Flexural strength results of first mix series.

Fig. 5 shows Compressive strength test results of second mix series at the age of 28 days. Except for the 25ERA and 50ERA-S, the compressive strengths remained almost same to be ranged from 30.1-32.2 MPa. In second mix series, compressive strength from the EMV based mixes were expected to be higher than the conventional volume mixes. However, due to excellent RCA properties such as speicific gravity of 2.60 and absorption ratio of 2.62%, on the contray the CRA mixes resulted in better strength results. Unlike the compressive strength results in first mixes, coating RCAs with CPDA for 2 days does not result in compressive strength gains.

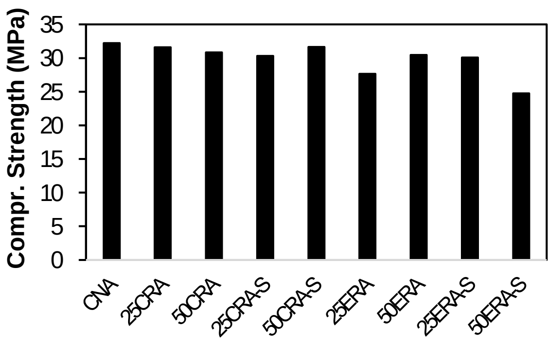


Fig. 5: Compressive strength results of second mix series.

3.3 Elastic Modulus

Fig. 6 shows the average Young's modulus of the first mix series at the age of 28 days. Similar to the compressive strength trend in first mix series, the elastic modulus increased by 3% in the 100CRA-2.5 mix, while as in the 100CRA-5 mix, the elastic modulus decreased by 9%.

Fig. 7 shows the average Young's modulus of concrete samples at 28 days with the conventional ACI volume mixtures and the EMV mixtures. All the elastic modulus values ranged from 26.3-27.7GPa within 5% difference.

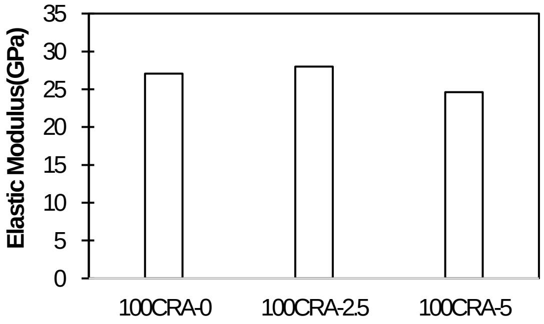


Fig. 6: Elastic modulus results of first mix series.

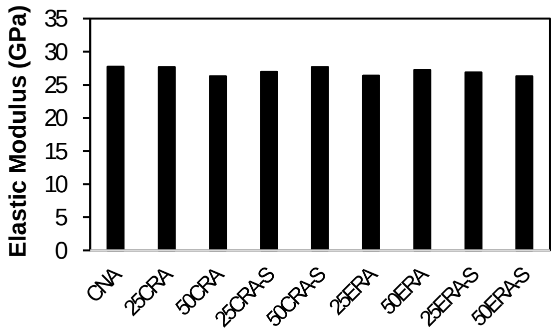
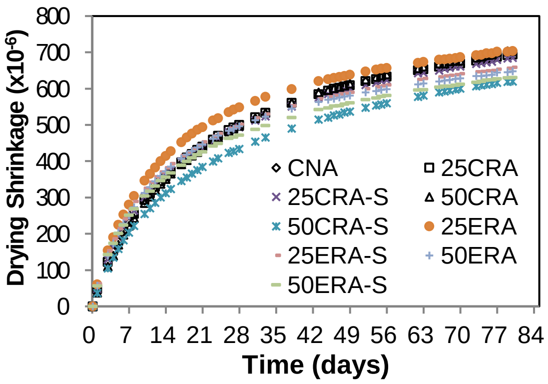


Fig. 7: Elastic modulus results of second mix series.

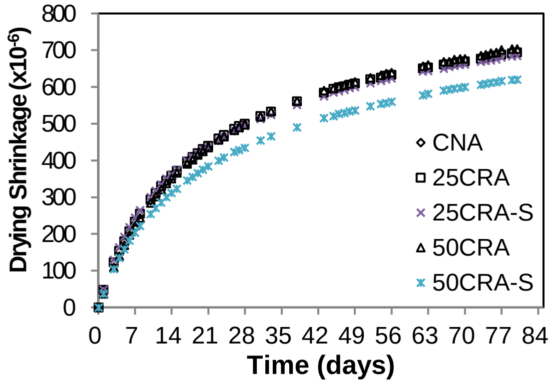
3.4 Drying Shrinkage

Test results of drying shrinkage are shown in Fig. 8. Finally, at 80 days, the shrinkage strains of the specimens are shows in Fig. 9. It should be mentioned that the wet curing period of 8 days instead of 7 days was employed for the control speimen (CNA) and CRA specimens, by the malfunction of the environmental chamber. Thus the EMV based mix specimens yielded higher drying shrinkage test results, compared to the first four mixes.

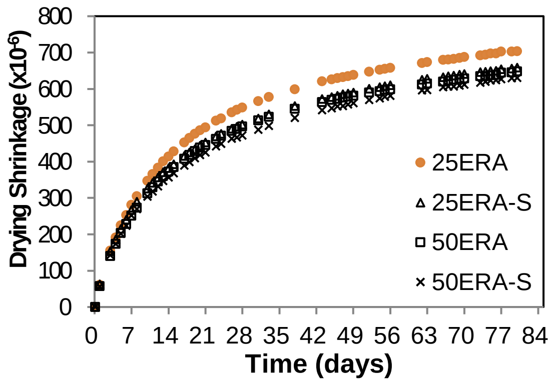
It is clearly seen in Fig. 9(b) at 80 days that the drying shrinkage of 25CRA-S and 50CRA-S mixes decreased 1% and 12%, respectively, compared to 25CRA and 50CRA mixes. Likewise in Fig. 9(c), the drying shrinkage of 25ERA-S and 50ERA-S mixes decreased 6% and 3%, respectively, compared to 25ERA and 50ERA mixes.



(a) All mixes

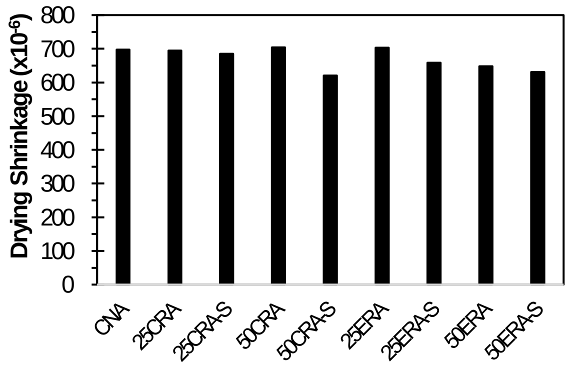


(b) *Control and conventional volume mix*

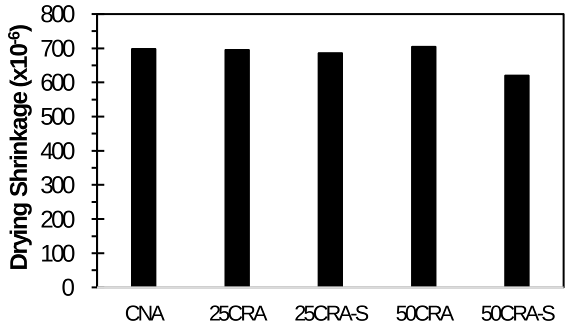


(c) *EMV mixes*

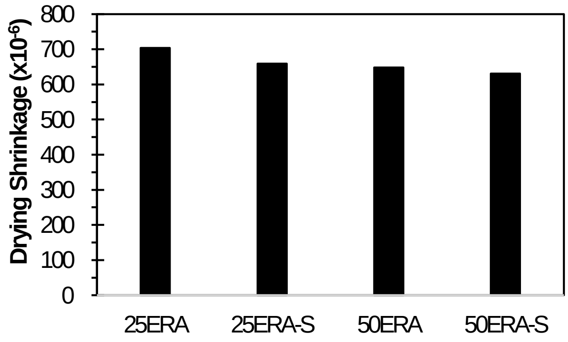
Fig. 8: Drying shrinkage results.



(a) All mixes



(b) Control and conventional volume mix



(c) *EMV mixes*

Fig. 9: Drying shrinkage at 80 days.

4 CONCLUSIONS

This study aims at assessing the effect of the CPDA on mechanical strength and drying shrinkage properties of RCA concrete. To investigate the effect of the CPDA, two experimental mix series were carried out. From this study, the following colusions are tenatively drawn.

(1)The addition of 2.5% of CPDA as chemical admixtures in the RCA concrete mixes helps improvement of compressive strength, flexural strength, and elastic modulus properties.

(2)Coating the RCAs with sprayed CPDA solution for two days before mixing helps decrease of drying shrinkage.

Further studies should be carried out whether other unknown influential factors affect cement and hydration.

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