

LABORATORY STUDY ON USING RECYCLED CONCRETE AGGREGATES IN NON-STRUCTURAL CONCRETE

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To investigate the suitability of using recycled concrete aggregate (RCA) as an aggregate in non-structural concrete for the bridge and highway rehabilitation projects in eastern North Carolina, Concrete slabs were selected from demolished concrete bridges in three counties in this region. The concrete bridge panels were crushed, separated from reinforcing steel, sieved, and examined in laboratory for making non-structural concrete to investigate strength related properties comparing with natural aggregate concrete (control mix). For the recycled concrete aggregate, LA Abrasion, bulk specific gravity, absorption, and alkaline-silica reaction were examined. Percentage of fine particles and impurities incorporated in the RCA generated during the crushing were also measured. Normal concrete design method was used to make concrete mixes containing 0%, 15%, 30%, 50%, and 100% RCA according to the requirements of the Standard Specifications for Class B (non-structural concrete) by the North Carolina Department Transportation (NCDOT) in terms of minimum cement content, maximum Class F fly ash content, workability, air content, 7-day and 28-day compressive strength. Rapid chloride penetration test was conducted for selected specimens. Steel slag aggregate produced in eastern North Carolina was also used with RCA to verify its contribution to strength development. The results show that the processed RCAs from demolished bridges meet NCDOT requirements for concrete aggregates; the 7-day and 28-day compressive strength surpass the minimum strength requirements for Class B concrete, and very competitive with the concrete containing natural coarse aggregates. Concrete containing RCA and steel slag aggregates has higher compressive strength that contains natural coarse aggregate and RCA.

Key Words: Eastern North Carolina, Non-structural concrete, Recycled concrete aggregate, RCA, Slag

Introduction

Recycled concrete aggregate (RCA) is a granular material manufactured by removing, crushing, and processing portland cement concrete for reuse in similar situations as virgin natural aggregate. RCA possesses different properties from natural aggregate, mainly because the resultant crushed material is composed of both original natural aggregate and reclaimed mortar, which may affect the properties and behavior of concrete produced with RCA unless specific steps are taken in the design and construction process.

Currently more than 140 million tons of RCA are produced each year in the US (CDRA 2018; Wang, et al 2018*)*. The quantity is increasing as the nation's civil infrastructures are becoming aged and being reconstructed. The North Carolina State Transportation Improvement Program (STIP) for 2016-2025 stipulates the requirements for approximate 150 bridge replacement and 700 miles of road construction projects in the 28 counties under NCDOT Divisions 1, 2 and 3. A huge amount of concrete debris will be generated, and a large quantity of new concrete will be needed including non-structural concrete. However, good quality concrete aggregate is not economically available in Eastern North Carolina. It is imperative to investigate the feasibility of RCA using as coarse aggregate in non-structural concrete construction for suitable projects in the next ten years and beyond.

In this study three typical bridge replacement projects from NCDOT Divisions 1, 2, and 3 were selected. The concrete slabs were processed to coarse aggregate to the NCDOT standards for Class B concrete, and a series of conventional and special laboratory tests for RCA, fresh and hardened concrete containing natural aggregate (granite), RCA, steel slag, were conducted. The results are promising and will benefit the bridge and road construction projects specified in STIP for 2016-2025, and the sustainable development in Eastern North Carolina - one of the fastest growing regions in the State of North Carolina.

Concrete Selection and Processing

Concrete selection

The three bridge replacement projects selected were located in Currituck County in extreme northeastern NC, Beaufort County in central NC, and Sampson County southeastern NC. Figure 1 shows the approximate locations of the bridges demolition site where the concrete slabs were selected, marked, removed, and transported to concrete crushing plant. Figure 2 shows the concrete was saw-cut and slab was removed from the project site near 5786 Slatestone Road, Washington in Beaufort County and panels removed from bridge from demolition site in Salemburg in Sampson County.

The demolished concrete bridges were built in 1950-60’s, and are in their 60-70 years of age. All are the type of T-girder with flat slab bridges. It was assumed that the concrete properties from the three projects are similar, which were proved later in a series of laboratory testing.

The removed slabs were paint marked and piled at the jobsites and later were transported to concrete crushing plant for further processing.

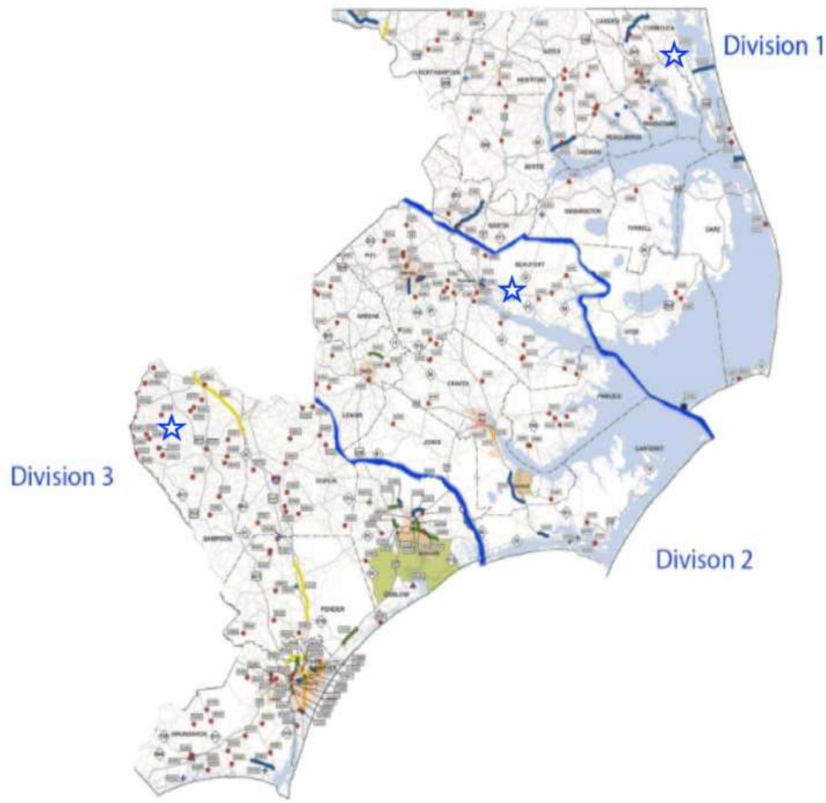

Figure 1: The approximate locations where the concrete slabs selected from old bridge demolition in eastern North Carolina.

Figure 2: Concrete slabs removed - bridge where panels were removed in Beaufort County (left); panels removed from bridge in Sampson County, NC (right).

Processing of RCA and sampling

The selected concrete panels were firstly crushed using a concrete pulverizer (Figure 3) to remove the reinforcing steel and bring the slabs down to smaller sizes that will fit the crushing machine. Figure 4 presents the concrete debris can be crushed, screened into two adjustable sizes, and undergo magnetic separation at the same time within a single machine, and the reinforcing steel removed after the initial pulverizing.

Although the traditional method and same basic equipment to process virgin aggregates can be used to crush, size, and stockpile RCA, the selection of crushing process can affect the amount of mortar that clings to the RCA particles and, therefore, the properties of the RCA. Jaw crushers generally are more effective at producing higher quantities of RCA, but generally result in relatively high amounts of reclaimed mortar in RCA particles. Impact crushers can be lower productivity, but more effective to remove mortar from RCA, therefore the coarse RCA is more similar to virgin aggregate (Snyder 2016*)*. For this study, Terex Finlay J-1170 compact and tracked jaw crusher for crushing, screening, and magnetic separation was used. Figure 5 shows the three-in-one processing machine and 1.5-inch screener used for the concrete aggregate screening. The production of RCA is almost completed on site by this integrated equipment. Figure 6 shows the RCA after crushing and screening using 1.5-inch sieve for sampling. RCA materials were sampled and transported to lab for blending (Figure 6).

Figure 3: Concrete pulverizer used to size and remove concrete reinforcing steels – operation (left); jaw of the pulverizer (right).

Figure 4: After pulverizing – most of reinforcing steel was removed (left); sized concrete for crushing and screening (right).

Figure 5: Concrete slabs removed - Terex Finlay J-1170 compact and tracked jaw crusher for RCA processing; (left); 1.5-inch screener for RCA used in the concrete (right).

Figure 6: Crushed RCA (left); Sampling of RCA (right).

Materials and Properties

The materials used for concrete specimens include the recycled concrete aggregates from three locations, natural stone (granite), sand, Type I cement, Class F fly ash, steel slag, water reducer, air-entraining agent. The properties of RCA and steel slag were examined for mix designs and concrete making.

Properties of RCA

The RCA from three divisions were examined in laboratory for sieve analysis, gradation, impurities, specific gravity, absorption, L.A. abrasion test, and alkaline-silica reaction test.

Sieve Analysis and Gradation
RCA samples were blended and sieved using #4 sieve and 1.5-inch sieve to remove fine particles and those larger than 1.5-inch. Then the RCAs were blended thoroughly for concrete making. From Table 1 it can be seen that the crushed RCA contain approximate 43.4% fine particles, which conform to the data from other reports (Topçu and Şengel 2004). Impurities in the subject RCA samples are within 0.3% which meets the required value by the specification. Table 2 presents the gradation of the RCA samples that marginally meets the 57 stone gradation.

Table 1

Summary of RCA Particle Sizes and Impurities

Samples	Fines (less than #4) (%)	Larger than 1.5 inch (%)	Impurities (%)	RCA for testing (%)
DIV 1	39.0	0.24	0.28	60.3
DIV 2	49.6	0.13	0.23	50.3
DIV 3	41.6	0.16	0.26	58.2
Average	43.4	0.18	0.26	56.2

Table 2

Gradation of the RCA Samples

Sieve Size	Percentage Passing (%)			57 Stone Gradation by NCDOT
	Division 1	Division 2	Division 3	
1.5”	100	100	100	100
1.0”	89.5	86.5	83.7	95-100
0.5”	40.2	50.5	42.0	25-60
#4	2.6	2.9	2.7	0-10

Specific Gravity and Absorption Value

RCA has a number of unique characteristics and properties that must be considered during the mix design and construction stages. These properties include lower specific gravity, which decreases with increasing amount of reclaimed mortar; higher absorption, which increases with increasing amount of reclaimed mortar; greater angularity; increased abrasion loss, which increases with increasing amount of reclaimed mortar; presence of unhydrated cement, which may alter its behavior and complicate stockpiling, especially the fines (passing No. 4 sieve); the fines produced during the crushing operation are angular, which may make RCA concrete mixtures very harsh and difficult to work. Table 3 includes the results of the bulk specific gravity and absorption. The values of the three subject RCA samples are very close with the average of specific gravity of 2.27 and absorption value of 5.11%.

Table 3

Specific Gravity and Absorption Value of the RCAs

RCA from	Bulk Specific Gravity	Absorption (%)	Note
DIV 1	2.27	4.97	Average of two parallel samples for each material
DIV 2	2.25	5.33	
DIV 3	2.29	5.02	

Alkali-Silica Reactivity

Not all RCA is appropriate for use in concrete. For example, RCA made from concrete exhibiting materials-related distress such as alkali-silica reactivity (ASR) or D-cracking may not be used in concrete unless certain mitigation methods are employed. Additionally, RCA may have high chloride contents due to extended exposure to deicing chemicals, which may make it unsuitable for use in reinforced concrete. Although it had made clear that the old bridges did not suffer ASR and D-cracking during the selecting candidate concrete bridges, the three RCA samples were examined for susceptibility of ASR. Test results from the Potential Alkali Reactivity of Aggregate (Mortar Bar Method, ASTM C1260) show that the RCA samples from three locations are 0.02%, 0.03, and 0.05% at 14-days.

L.A. Abrasion Test

L.A. Abrasion Test was conducted according to ASTM C 131 Standard Test Method for Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine. The results indicate (i) the abrasion values of the three RCA samples are close; and (ii) the abrasion of value, with average of 35.6% (Table 4) which is within the range of L.A. Abrasion values of RCA reported by literature, i.e., 30% - 50%(*4*).

Table 4

L.A. Abrasion Test Results

Materials	DIV 1	DIV 2	DIV 3	Average
L.A. Abrasion value	35.4%	35.7%	35.8%	35.6%

Expansive Properties of Steel Slag Aggregate

1. The advantages of steel slag as aggregates are well known (Arribas 2015; Fronek 2012; Wang 2010; 2016) in providing strength and durability. To investigate the effect of steel slag aggregate on the strength of concrete, 19-mm electric arc furnace slag sampled from Nucor Steel Plant in Cofield, NC was used. The volumetric stability of slag sample was tested under steaming in pressure cooker for three hours, and disruption ratio was calculated. Figure 7 is the slag particles after three hours treatment. The disruption ratio is zero.

Figure 7: Steel slag aggregate after treatment.

Mix Designs

Mix Design of New Concrete containing Recycled Concrete Aggregate

Five concrete mixes containing RCA samples, namely, 0%, 15%, 30%, 50%, and 100%, and three concrete mixes containing steel slag and RCA samples, namely, 20% steel slag+ 80% RCA, and 50% steel salg+50% RCA, were prepared which presented in Tables 5 and 6. Darex II air entraining agent and Mira 85 water reducer were used for all of the mixes. The steel slag, or electric arc furnace (EAF) slag, is produced at Nucor Steel Hertford and the aggregates are processed by Harsco Metals in Cofield, NC. The content of cement and fly ash and water cement ratio (W/C) were kept the same as those of the control mix to examine the changes of fresh concrete properties and compressive strength. The same design procedure was used in this study.

Table 5

Mix Designs for the Concrete Containing RCA

Mixes	Materials (in lb per cubic yard)						Fresh concrete properties		
	RCA	67 Stone	Cement	Fly Ash	Sand	W/C	Slump (in.)	Unit weight (pcf)	Air content (%)
1-0%	0	1750	436	131	1192	0.47	3.5	147.7	3.5
2-15%	227	1488	436	131	1192	0.47	3.5	140.9	5.5
3-30%	453	1225	436	131	1192	0.47	1.5	143.5	4.5
4-50%	755	875	436	131	1192	0.47	4.5	138.3	5.5
5-100%	1510	0	436	131	1192	0.47	3.5	134.8	5.5

Table 6

Mix Designs for the Concrete Containing EAF Slag and RCA

Mixes	Materials (in lb per cubic yard)						Fresh concrete properties		
	EAF Slag	RCA	Cement	Fly Ash	Sand	W/C	Slump (in.)	Unit weight (pcf)	Air content (%)
1-20%+80%	473	1078	436	131	1192	0.47	5.8	137.3	5.3
2-50%+50%	1101	776	436	131	1192	0.47	6.0	143.3	4.3

The RCA and steel slag aggregates were soaked one day before the mixing to maintain in saturated surface dry condition when the mixes were made. This is consistent with the current ready mixed concrete production practices. In principle, the mix design of the concrete containing recycled concrete and steel slag aggregates is not different from that of conventional concrete and the same mix design procedures was used. In practice, depending on the purposes of the designs, slight modifications may be required. These include:

To keep the same strength, when coarse RCA is used with natural sand, it may be assumed at the design stage that the W/C ratio required for a certain compressive strength may be the same for RCA concrete as for conventional concrete. If trial mixes show that the compressive strength is lower than required, an adjustment of the W/C should be made which would be up to 5%. In some cases, if free water content of a RCA concrete is increased, the cement content may also need to be higher to maintain the same W/C ratio.

Literature suggests that the unit weights of concrete made using RCA are within 90% to 100% of the control concrete mixture. Air contents of RCA concrete are up to 5% higher. The optimum ratio of fine-to-coarse aggregate is the same for RCA as it is for concrete made from virgin materials (Fronek 2012*)*. It is believed that the reduction in the residual mortar, when the concrete is recycled more than one time, makes the recycled RCA concrete perform better than the RCA concrete (ACI 2001).

It is the practice that the use of coarse RCA (up to 50%) is normally recommended but the addition of superplasticizer is necessary for achieving the required workability of new concrete (Fronek 2013*)*. Higher than 50% RCA may cause higher shrinkage of concrete (Parekh and Modhera 2011).

Results

Properties of Concrete containing Recycled Concrete Aggregate

Workability

RCA concrete workability is strongly affected by the shape and texture of the coarse recycled aggregates surface. By using the same W/C ratio, slightly increasing water reducing agent is needed to keep the required workability. However, for the mixes containing 15% to 100% RCA, the same amount water reducer (45.4 ml for two cubic feet batch) was used, the slump values are generally in the same level, i.e. 3.5 to 4.5 inch slump, except for Mix 3-30%.

Strength

The study has confirmed that the use of RCA in substitution of virgin aggregates from 15%, 30%, 50% to 100% leads to concretes meeting NCDOT Class B concrete (2,500 psi) and slightly lower strengths. Concrete made with 100% coarse RCA reached 2500 psi at 7-day age. The strength differences between 0% RCA and 100% RCA are in 24% for 28-day strength and 18% for 7-day strength. In between, 0% to 100% RCA, the trend follows straight line declining. Figure 8 presents the strength decline trends based on the averaged compressive strength value for both 7-day and 28-day.

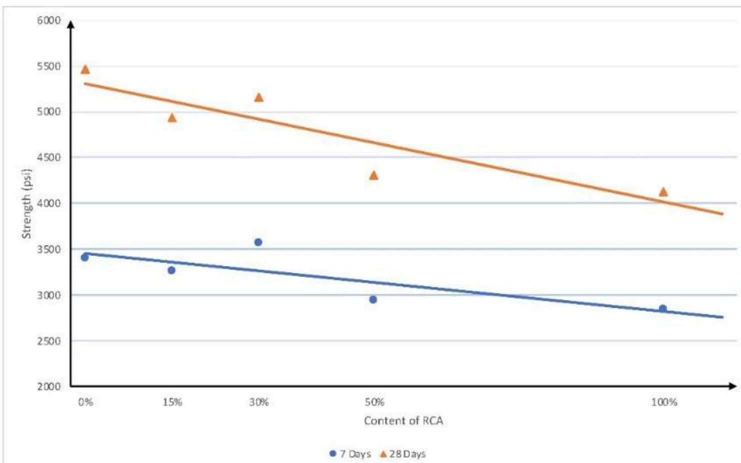

Figure 8: Compressive strength trend from zero to 100% of RCA.

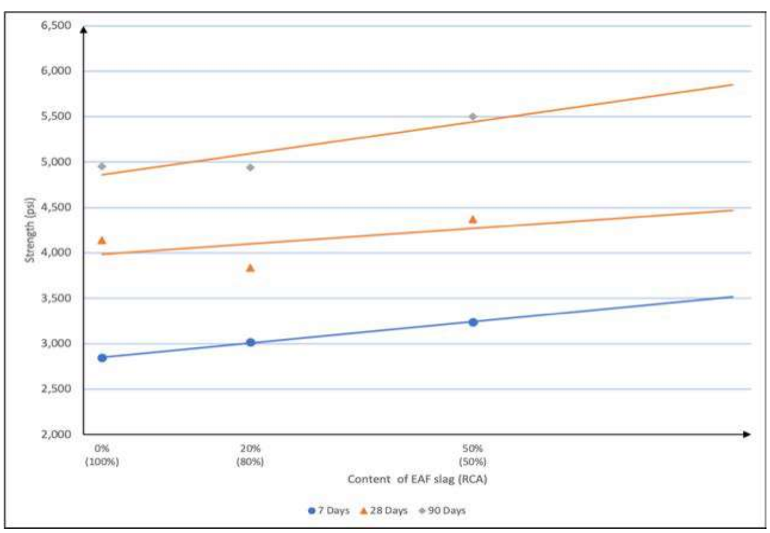

Figure 9: Compressive strength trend with EAF slag addtions.

Conclusions

The practicality of the coarse RCA use in Class B, i.e. 2,500 psi non-structural concrete and the competitive performance of RCA concrete has been proved in laboratory study. The processed RCA from three counties (NCDOT Divisions) process good qualities that meet concrete aggregate requirements by the NCDOT Specifications for non-structural concrete. The RCA from three location perform similar physical and mechanical properties. The study shows that the RCA samples possess good abrasion resistance, and no alkaline-silica reaction susceptibility. Conventional mix designs can be used with slightly adjustment of water reducing agent which can ensure the similar workability (slump) of the fresh concrete without change W/C ratio. The compressive strength results show that both 7-day and 28-day strengths are above 2,500 psi, the minimum requirement for Class B concrete. With the increase of RCA content, strength is slightly declined. The results also show that 100% of RCA addition is practicable to make Class B concrete. With addition of steel slag concrete produced locally in eastern North Carolina, the concrete containing coarse steel slag aggregate and RCA show strength gaining than RCA and natural aggregate. The unit weight of concrete containing steel slag and RCA is lighter than that of RCA and natural aggregate. Therefore blending use of RCA and steel slag can utilize the advantages of strength from steel slag and lighter weight from RCA to make user-friendly end concrete product.

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