RECLAMATION

Managing Water in the West

Recycled Concrete Aggregate for Use in Reclamation Structures – Scoping Study

Research and Development Office
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Mission Statements

Protecting America's Great Outdoors and Powering Our Future

The Department of the Interior protects and manages the Nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its trust responsibilities or special commitments to American Indians, Alaska Natives, and affiliated island communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

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Recycled Concrete Aggregate for Use in Reclamation Structures

CATHERINE LUCERO

Digitally signed by CATHERINE LUCERO
Date: 2017.08.28 08:15:25 -06'00'

Prepared by: Catherine Lucero, MSCE, EIT
Civil Engineer, Concrete, Geotechnical, and Structural Laboratory, 86-68530

JEFFERY KEIM

Digitally signed by JEFFERY KEIM
Date: 2017.08.28 08:35:35 -06'00'

Peer Review: J. Scott Keim, P.E.
Civil Engineer, Concrete, Geotechnical, and Structural Laboratory, 86-68530

Acronyms and Abbreviations

ACI	American Concrete Institute
ACPA	American Concrete Pavement Association
CLSM	Controlled Low Strength Material
DOT	Controlled Low Strength Material
f'_c	design compressive strength
FHWA	Federal Highway Administration
HMA	Hot Mix Asphalt
IDOT	Illinois Department of Transportation
ITZ	Interfacial Transition Zone
MDOT	Michigan Department of Transportation
MnDOT	Minnesota Department of Transportation
NRMCA	National Ready Mixed Concrete Association
ODOT	Ohio Department of Transportation
PCC	Portland cement concrete
RCA	Recycled concrete aggregate
TxDOT	Texas Department of Transportation
w/c	water to cement ratio

Executive Summary

Recycled concrete aggregate (RCA) has been used for decades in the transportation industry as road base or as an aggregate in rigid pavements. With proper proportioning, use of admixtures, and quality control measures, RCA can be used in several applications outside of transportation infrastructure. This scoping study summarized recent research in mechanical and durability properties of concrete containing RCA. Overall, mechanical properties are not greatly diminished with a partial replacement of coarse aggregate. Some other properties (such as shrinkage) are potentially greater in concrete using RCA.

Reclamation does not currently allow the use of recycled aggregate in new concrete. RCA can be used in a wide range of construction from low-strength fill to normal-strength applications. The next steps would be to consider allowing the use of recycled aggregates for an appropriate application and developing a standard specification or a special provision.

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Introduction

Recycled concrete aggregate (RCA) is produced by crushing demolished concrete to use in new construction. It is most commonly used as a base course in new pavement construction, but it can also be used as a coarse aggregate in new concrete. This practice has been researched and used in the pavement industry since the 1970's [1]–[3]. Most commonly, concrete containing RCA is used in lower-strength applications such as sidewalks, curbs and gutters. Due to a shift in the concrete industry's commitment to sustainability, researchers have focused on producing strong, durable concrete to be used in a wide variety of structural applications. ACI 555R-01 from the American Concrete Institute's Manual of Concrete Practice describes the process of producing aggregate from demolished concrete. It also lists a summary of properties of concrete with RCA versus virgin aggregate, but the data is from the 1970s and 80s and is outdated.

The use of RCA has the following advantages:

- Provide aggregate where high quality aggregate is no longer economically available
- Eliminate the need for locations to landfill the large amount of concrete rubble
- Conserve the present aggregate sources.
- Reduce the need for disrupting land for quarrying purposes
- Save fuel and energy by reducing aggregate transportation
- Reduce damage to haul roads near projects
- Achieve a monetary savings while constructing high quality structures or roadways

Literature Review

RCA is produced by breaking, removing and crushing hardened concrete that has been deemed acceptable for re-use. Records for strength and durability of the original concrete are reviewed to determine if the resulting RCA will be suitable for a given application. The demolished concrete is then transported to a processing facility where embedded steel is removed prior to crushing. The crushing, sizing, and stockpiling operations are similar to those used for virgin aggregate [4]. The resulting aggregate consists of the original aggregate surrounded by mortar (hydrated cement paste and original sand) as shown in Figure 1 below. The additional mortar is porous which increases the absorption of the RCA. The RCA also includes the interfacial transition zone (ITZ) which is a weak zone between the aggregate and paste.

Figure 1. 2" to 4" recycled concrete aggregate used for road base

Typically, a portion of the coarse aggregate is replaced with RCA, but some researchers have investigated using fine RCA as well. The literature presented in this report focuses on research performed in the past 15 years (since 2002).

Many State DOTs use recycled concrete aggregates either as base course or as an aggregate in new pavement. Some have experience using RCA in new rigid pavement construction.

Replacement of Coarse Aggregate

Basic mechanical properties of concrete containing various replacements of coarse aggregate have been thoroughly documented. In general, the performance of normal-strength concrete (i.e. *w/c* between 0.45 and 0.50 and f'_c of 4500 psi) concrete containing recycled concrete aggregate did not significantly decrease given that the new concrete employs quality recycled aggregate [5], [6]. Lower values of absorption in RCA generally results in a higher quality concrete. A summary of compressive strengths from various studies is shown in Figure 1 [7]–[15]. The mechanical properties of the old concrete prior to crushing for use as aggregate influence the properties of the new concrete using RCA. For example, aggregates crushed from a low strength concrete with high porosity will result in a lower-strength concrete than one using aggregate crushed from steam-cured precast concrete panels. Unfortunately, it is not always possible to know the exact source of the recycled material.

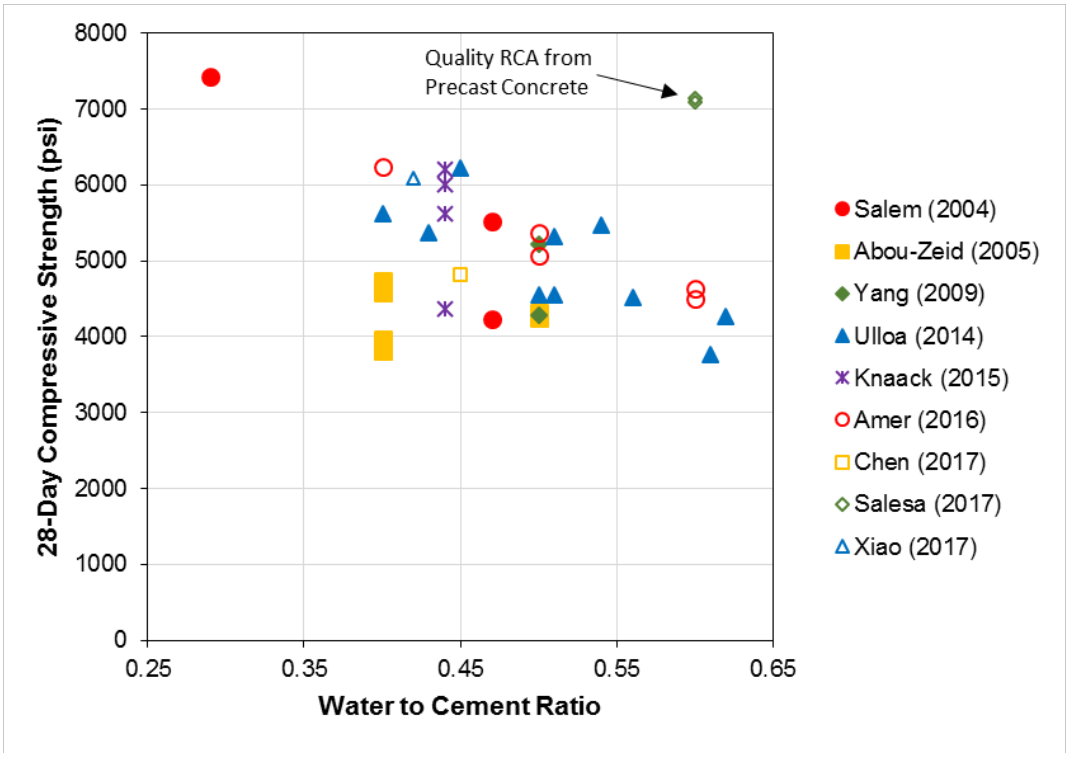

Figure 2. Compressive strength of concrete with 100% recycled coarse aggregate.

Since RCA generally has higher absorption, there is a higher water requirement to achieve the same slump as the same concrete using virgin aggregates. Mixtures containing RCA are sometimes described as harsh or stiff with low slumps (1 ½" to 2") compared to the same mixtures containing virgin aggregates [8]. The workability issues can be overcome with the use of superplasticizers [16], [17].

The durability of RCA has also been investigated by several researchers. There have been mixed findings for freeze-thaw durability. Some researchers found that concrete with RCA performed just as well as traditional concrete when properly air entrained [7], [18], [19]. Others [Nishibayashi] found that freeze-thaw durability was poor despite using an air entraining admixture. Again, the quality of the RCA used (particularly the porosity/absorption) will influence the new concrete's resistance to freeze-thaw damage. Through proper air-entrainment, durable concrete containing recycled aggregates can be produced. Both mechanical and durability properties can be improved with the addition of silica fume, however, the rate of carbonation and chloride ingress remains inferior to concrete made with virgin aggregate [27].

Creep and shrinkage behavior have been measured and modeled by several researchers. The behavior is highly influenced by the percent of aggregate replaced with RCA due to the old mortar still being attached to the stone particles. Many researchers have found an increase in creep and shrinkage with the replacement of recycled aggregate [9], [20], [21]. Fathifazl determined that if proportioned correctly (using the Equivalent Mortar Method), concrete containing recycled concrete aggregate experiences comparable or even lower creep and shrinkage compared to conventional concrete [22], [23].

Structural performance of concrete containing RCA has also been evaluated. If the concrete is proportioned correctly (i.e. using the Equivalent Mortar Volume method), current code provisions for flexural design are applicable to RCA-concrete beams [24]. Studies have shown that the overall seismic behavior of precast and cast in place recycled aggregate concrete frames have no significant discrepancy compared to precast or cast in place normal aggregate concrete structures [25], [26].

Replacement of Fine Aggregate

Recycled fine aggregate is typically not used in new construction. In general, workability decreases and water demand increases with the addition of fine RCA since the particles include a large quantity of hydrated cement paste compared to coarse RCA. Researchers have investigated the durability of concrete at various replacement volumes (25 to 100%) of fine aggregate. Typically, if the fine RCA is very absorptive, it will influence the amount of water in the paste surrounding the aggregate and will decrease durability (i.e. shrinkage and permeability) [29]. There are limited studies on performance of concrete with fine recycled aggregate.

Guidelines for Quality RCA

In order to produce high quality concrete for the new application, FHWA suggests RCA aggregate should:

(1) Be free of harmful components such as soil, asphalt, and steel. More than 90% of the material should be cement paste and aggregate. Asphalt content should be less than 1 percent;
(2) Be free of harmful components such as chlorides and reactive materials unless mitigation measures are taken to prevent recurrence of materials related distress in the new concrete; and
(3) Have an absorption of less than 10 percent.

In general, the recycled materials used for concrete projects must meet the same quality requirements normally used for virgin aggregate (ASTM C33). The Los Angeles Abrasion Test (ASTM C 131) is used to determine an aggregate's resistance to breakdown during handling and mixing.

There are several strategies to control the quality of concrete containing RCA. Laboratory and field trials of the concrete mixture must be conducted to insure that the properties of the mixture containing RCA meet job requirements.

Table 1. Summary of specifications and guidelines for quality concrete containing recycled aggregates

Topic	MnDOT	IDOT	ODOT	MDOT
Document Type	*Specification*	*Specification*	*Specification*	*Specification*
Limitation of RCA content	Coarse aggregate only. Proportions determined by Engineer	Coarse aggregate only	Coarse aggregate only. Use combined RCA and virgin aggregate to obtain a well graded mix.	None
Preparation and handling guidelines	Handled and stockpiled in such a manner that it will not become contaminated with foreign matter.	Stockpile pads shall be provided and haul roads/plant area properly maintained to assure that acceptable material is not contaminated prior to use.	Do not intermingle dissimilar materials into stockpile. Maintain moisture above SSD	Must maintain separate stockpiles to avoid non MDOT source material
Limitation of source material	Original source must be known	IDOT-specified concrete	ODOT concrete	MDOT concrete
Allowable applications		Specified by special provision for appropriate projects	Pavement, walks, curb ramps and steps, curbing, medians and traffic islands, concrete barriers	Curb and gutter, valley gutter, barriers, driveways, temporary pavements, ramps with commercial ADT 250, shoulders
Characterization requirements		Freeze-Thaw, ASR and Chloride content	Identify material related distress such as Alkali Silica Reaction (ASR) or D-Cracking	Project by project freeze-thaw characterization

Topic	TXDOT	FHWA	NRMCA	ACPA
Document Type	*Specification*	*Guideline*	*Guideline*	*Guideline*
Limitation of RCA content	Recycled fine aggregate limited to 20%	Recycled fine aggregate limited to 10-20%	10% for general source RCA, 30% for returned materials > 21 MPa	10-20% limit on recycled fine aggregate
Preparation and handling guidelines	None	Sprinkle stockpiles to keep aggregate saturated; store separately from other materials	Separate incoming material according to quality; maintain SSD conditions with sprinklers	None
Limitation of source material	None	None	Higher quality returned material	None
Allowable applications	Inlets, manholes, gutters, retards, sidewalks, driveways, backup walls, anchors, riprap, small signs, pavements	Pavements	Structural elements should contain less than 10%; non-structural applications up to 30%	Pavements
Characterization requirements	None	Check for deleterious materials such as chlorides and sulfates	Weekly verification of absorption and specific gravity	Perform freeze-thaw evaluation on materials exhibiting D-cracking or containing fly ash

Availability and Pricing

RCA is available in the Western states. As shown in a 2004 survey by FHWA (Figure 3) the primary application is for road base course, so recycled concrete is typically crushed to state DOT base specifications. Less states use RCA for Portland cement concrete (PCC), however more states have adopted specifications for RCA in concrete since the survey. California, Massachusetts, and Oklahoma currently have specifications for RCA in PCC.

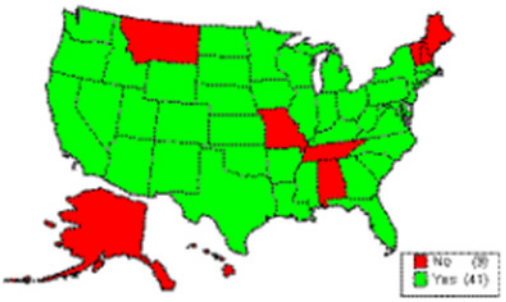

Figure 1 Recycling concrete as aggregate

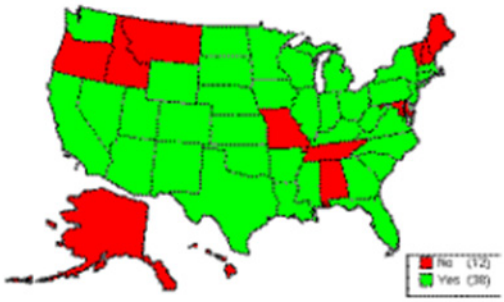

Figure 2 Base Aggregate

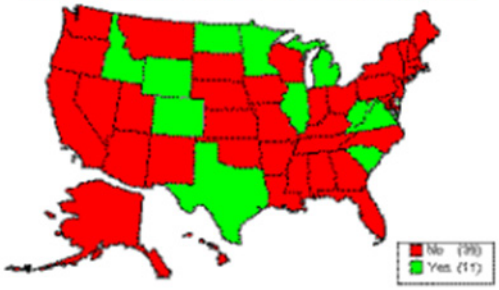

Figure 3 PCC aggregate

Figure 3. Use of recycled concrete aggregate by state DOTs [30].

RCA is generally similarly priced to virgin aggregates in the Western US. This is due to relatively high crushing costs and the process of removing harmful particles from crushed concrete [8]. In some instances, it may be more cost effective to use a recycled aggregate if a suitable virgin aggregate is not locally available.

Applications within Reclamation

RCA can potentially be used in a variety of new concrete construction for Reclamation. It has been used in non-structural applications (i.e. sidewalks, gutters, driveways) for decades but can also be used in structural applications as long as a quality RCA is used and trial batches are tested prior to construction.

RCA has also been used in controlled low-strength materials (CLSM). Serpell et al. noted that CLSM mixtures benefited from the higher powder content and lower particle density of recycled fine aggregates [31].

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