A Technology Deployment Plan for the Use of Recycled Concrete Aggregates in Concrete Paving Mixtures

National Concrete Pavement Technology Center

Tech Center

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About the National CP Tech Center

The mission of the National Concrete Pavement Technology Center is to unite key transportation stakeholders around the central goal of advancing concrete pavement technology through research, tech transfer, and technology implementation.

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16. Abstract

The Every Day Counts (EDC) initiative is an FHWA effort that acknowledges the need for sustainable practices. According to the FHWA Administrator, the initiative is “designed to identify and deploy innovation aimed at shortening project delivery, enhancing the safety of our roadways, and protecting the environment”. The use of recycled concrete aggregates (RCA) in new concrete paving mixtures is an example of innovation that aligns well the goals of the EDC initiative.

RCA used in new concrete paving mixtures can expedite construction schedules, reduce waste and associated hauling cost, conserve resources of virgin aggregates, and potentially reduce project costs. The Technology Deployment Plan presented herein is aimed at addressing the barriers that limit the use of RCA in new concrete paving mixtures. The Plan recognizes barriers grouped into three primary categories: compliance, quality, and production. In order to overcome these barriers, the Plan includes the creation of a Technical Working Group (TWG) and four programs: Outreach and Communication, Training, Technical Support, and Demonstration Projects. Through coordinated efforts by the TWG, the tasks developed and carried out under each program will mark forward progress towards achieving a future where RCA is used as a commonly accepted alternative to virgin aggregates for new concrete paving mixtures.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

EXECUTIVE SUMMARY

The Every Day Counts (EDC) initiative is an FHWA effort that acknowledges the need for sustainable practices. According to the FHWA Administrator, the initiative is “designed to identify and deploy innovation aimed at shortening project delivery, enhancing the safety of our roadways, and protecting the environment”. The use of recycled concrete aggregates (RCA) in new concrete paving mixtures is an example of innovation that aligns well the goals of the EDC initiative.

RCA used in new concrete paving mixtures can expedite construction schedules, reduce waste and associated hauling cost, conserve resources of virgin aggregates, and potentially reduce project costs. The Technology Deployment Plan presented herein is aimed at addressing the barriers that limit the use of RCA in new concrete paving mixtures. The Plan recognizes barriers grouped into three primary categories: compliance, quality, and production. In order to overcome these barriers, the Plan includes the creation of a Technical Working Group (TWG) and four programs: Outreach and Communication, Training, Technical Support, and Demonstration Projects. Through coordinated efforts by the TWG, the tasks developed and carried out under each program will mark forward progress towards achieving a future where RCA is used as a commonly accepted alternative to virgin aggregates for new concrete paving mixtures.

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CHAPTER 1: INTRODUCTION

BACKGROUND

Sustainability, as defined by the United Nations Report on the World Commission on Environment and Development in 1987, is "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." Over the past few years, the pavement industry has been hard at work developing a more focused meaning of what sustainability is with regard to design, construction, and maintenance.

The Federal Highway Administration (FHWA) is making a conscientious effort to acknowledge the need for sustainable practices. The Every Day Counts (EDC) initiative is an FHWA effort that recognizes an urgent need for highway infrastructure sustainability. EDC is designed to identify and deploy innovation aimed at shortening project delivery, enhancing the safety of our roadways, and protecting the environment."

It has been reported that concrete can be almost 100 percent recyclable and can be processed into aggregate for use in new construction [1,2]. According to the 2009 Concrete Pavement Road Map briefing document, *Building Sustainable Pavements with Concrete*, the use of recycled concrete aggregates (RCA) in new pavement construction applications is a sustainable practice [3].

The use of RCA can save money, save time, and reduce the environmental impact of concrete paving. Its use can potentially shorten project delivery as a result of expedited construction schedules due to reduced haul times. The potential for increased material transportation savings is even greater when there is no locally available aggregate and aggregate has to be trucked in from farther away. Expedited construction schedules result in fewer lane closures, which improve public safety. Public safety is also improved if processing of the aggregate is in close proximity to the project and there are fewer commercial vehicle-miles required for transport. Using RCA in new construction benefits the environment because it reduces the amount of material typically disposed of in landfills and conserves resources related to mining virgin aggregates.

RCA is produced from existing concrete structures and is currently used in a number of new construction applications. In this report, RCA differs from crushed concrete aggregate (CCA) in accordance with a definition published by the National Ready Mixed Concrete Association (NRMCA). The NRMCA refers to CCA as aggregate processed from concrete that was never in service. Therefore, CCA is a type of RCA [4].

According to a FHWA survey published in 2004, 41 states recycle concrete for use as aggregate in new construction, primarily in base applications [5]. Of these states, however, only 11 are reported as using RCA in new portland cement concrete (PCC). By not incorporating RCA into new concrete mixtures, the industry may be missing an opportunity to take advantage of a viable material for the construction of new pavements and concrete overlays.

Commonly cited reasons for limiting the use of RCA in new concrete paving mixtures include agency restrictions, an inability to meet specifications, and lack of consistent quality. Some of these limitations seem to reflect a general lack of knowledge. For example, a common owner-agency concern is the use of RCA from concrete previously exhibiting materials related distress (e.g., ASR or D-cracking). There have been studies, however, that demonstrate how proper mitigation efforts can make RCA from such concrete sources a viable option. Contractors are also concerned that RCA will result in inconsistent quality, which in turn can compromise workability and the ability to meet specifications. Because of concerns about quality, contractors increase the costs for using RCA, making it a less attractive option for new concrete paving mixtures. Educating contractors and owner-agencies about methods for effectively incorporated RCA into new concrete mixtures could help the industry overcome this limitation. Such an education would require understanding the characteristics of RCA, revising specifications for aggregate as necessary, understanding the impact of the use of RCA on fresh and hardened concrete properties and on the durability of pavements, and making appropriate adjustments in the development of mixture proportions and production methods. This education would show contractors and owner-agencies that RCA can be a cost-effective material that will not compromise the quality of concrete paving mixtures. Ultimately, a successful education program would result inan industry-wide change in perception about the use of RCA.

Due to the realization that there is a gap in education about RCA and the recognition that such a plan could have many potential benefits for the concrete paving industry, the research team developed a deployment plan aimed at educating the industry on the use of RCA in new concrete paving mixtures. That technology deployment plan is described in this report.

OBJECTIVE

The objective of this project is to develop a technology deployment plan for educating and training State DOT and industry personnel on the use of RCA in new concrete paving mixtures.

SCOPE

In order for a technology deployment plan to be effective, it must be clear and focused. The plan must include relevant methods for teaching to address deficiencies in current thinking.

To support the technology deployment plan for RCA, a literature search was conducted to identify relevant educational material already in existence. A survey was also conducted to benchmark current use of RCA in new concrete paving mixtures. Based on the information gathered from these sources, a robust technology deployment plan was developed.

CHAPTER 2: LITERATURE SEARCH

As a key component of this effort, a literature search was conducted. The purpose was to identify relevant resources that could be used as references, and to assimilate an electronic library of relevant references. The library is categorized to identify potential obstacles that may limit the use of RCA in new concrete paving mixtures. A complete list of references (with brief summaries) and a bibliography is provided at the end of this report. The following sections present information gathered during the literature search.

RCA APPLICATIONS

According to the literature reviewed, the most common application for RCA in the U.S. is as aggregate in base and subbase layers. The FHWA (2004) reports that five states believe RCA performs better than virgin aggregate in base and subbase applications [5]. The report further suggests that this belief may be based on the ability of RCA to exhibit cementitious behavior. Other applications for RCA include cement-treated base (CTB), backfill, embankment stabilization, erosion control (riprap), and landscaping [6]. It has also been reported that some RCA has been incorporated into new concrete paving mixtures since as early as the 1940s [6]. Using large amounts of RCA in new concrete paving mixtures, however, is not a common or accepted practice throughout the U.S. [5].

However, there are some case studies where RCA has been used in new concrete mixtures. A concrete pavement section constructed according to the European method for two-lift construction that incorporated RCA in the concrete paving mixture designed for the bottom lift was constructed in Florida during the 1970s [7]. More recently, similar sections (two-lift construction) were built in Kansas. In addition to use in two-lift construction, sections of concrete pavement constructed by typical methods that include RCA exist in Colorado, Connecticut, Illinois, Iowa, Kansas, Michigan, Minnesota, North Dakota, Oklahoma, Wisconsin, and Wyoming [8]. Work by Cuttell et al. summarizes pavement performance over time on a few of these sections and provides recommendations for optimizing mix designs [9,10].

In other countries, typical applications for RCA in new concrete pavements include aggregates for base and subbase layers [1,11]. The use of RCA in new concrete paving mixtures has been reported, and research for making RCA a more viable option for new concrete paving mixture applications has been performed.

For example, in Finland, 10 percent of all RCA applications are bound applications implying new concrete mixtures or cement-treated bases (CTBs) [12]. In Austria, RCA is used as aggregate in concrete mixtures designed for the lower layer in two-lift construction [6]. Research has shown that RCA can be used successfully as both coarse and fine aggregate in such applications. In Australia, RCA is allowed as a coarse aggregate in new concrete mixtures for curbs and sidewalks. There are two classifications the material must meet, depending on the quality required for the application: Class 1A (higher quality) and Class 1B [13].

In Japan, RCA is recognized as an alternative to virgin aggregate in new concrete mixtures; however, a methodology to assess quality has been an issue for the implementation of this application. Recent research, however, has resulted in a method for indexing quality that may help encourage more RCA in new concrete mixtures [14].

Research in New Zealand, Spain, and the UK has also concluded that there is potential for RCA as an alternative to virgin aggregates for use in new concrete mixture designs [15,16,17].

A study in Belgium reports RCA can be used successfully in roller-compacted concrete (RCC) [18].

ENCOURAGING THE USE OF RCA

Based on the literature reviewed, countries with successful recycling programs have a well-organized approach that involves government directives and/or joint efforts between the government, industry, and public stakeholders [1]. In Denmark, for example, the government works to influence the market towards recycling while public-private partnerships are responsible for processing RCA. The result has been the production of a higher quality material [1,11].

Where virgin material is becoming limited and expensive (because of taxes and the cost of hauling), standards for typical pavement applications and the production of high quality material have been essential in making RCA a viable alternative. In the Netherlands, RCA is considered a product rather than a waste material, and industry is involved in the processing procedures. There are standards and policies for using RCA that improve quality and make it a more attractive alternative [1].

In countries where the cost to produce RCA may be greater than the cost of acquiring virgin aggregates (e.g., Germany and Sweden), government incentives and efforts to educate the public on the environmental benefits associated with the use of RCA are key to promoting increased and alternative applications [1].

Many European countries prohibit discarding material in landfills that can otherwise be recycled. Taxes on material sent to the landfill and/or taxes on the mining of virgin aggregate also help promote alternative uses for RCA [1].

The Environmental Protection Agency (EPA) reports that several states in the U.S. tax landfill operations. Historically, however, the problem with this approach in the U.S. is that it only works to divert the use of one landfill where taxes exist to another where taxes do not exist [19].

In the U.S., there is not yet a common, clearly defined, and accepted set of guidelines for the use of RCA. FHWA has provided some general guidance, as have other documents cited herein. However, these documents are more educational tools than guidelines. A provisional specification for coarse RCA is currently in review by the American Association of State Highway and Transportation Officials (AASHTO) and a few states, like Texas, have developed specifications for the use of RCA in various applications, including new concrete paving mixtures. These specifications have gone a long way in incentivizing RCA in those states.

For the most part, in the U.S., the use of RCA in new pavement projects is at the contractor’s discretion, as long as job specifications permit RCA as an approved material. Its use in new concrete paving mixtures depends largely on the reduction of overall cost (or bid) on a given project. A contractor’s level of experience and how readily available the supply of RCA is, can also influence the decision making process—primarily because both affect cost. For example, if the costs associated with the use of RCA in new concrete paving mixtures are greater than the costs associated with using RCA in another application on the same job, then it is more likely the

RCA will not be used in the new concrete paving mixture. This is particularly true if there is not enough RCA for both applications and there are no cost incentives.

RCA PRODUCTION

RCA Sources

Contractors looking to use RCA for a project can both acquire and produce it themselves or they can purchase it from a producer. There are a number of sources from which concrete can be recycled. The demolition of a structure, reconstruction of a roadway, or waste concrete at a batch plant or precast yard are examples of sources for acquiring old concrete to process into RCA [4,6].

Acquisition

Acquisition of concrete for producing RCA requires reclaiming it from a source, removing any contaminants, and transporting it to a processing plant. Depending on the source, there are different methods and equipment used for removal. Both the ACI Committee 555 report and ACPA 2009 Engineering Bulletin identify methods and equipment for removal of concrete and debris from existing structures [6,20].

Before acquisition, however, it is recommended that properties of the hardened concrete be determined [20]. Research has shown that the properties of the concrete from which the RCA was produced will affect the characteristics of the new concrete produced with that RCA. Specifically, the strength, air content, durability of the original virgin aggregate (e.g., ASR and D-cracking susceptibility), and amount of chloride ingress into the matrix are important. Some of this information can be ascertained from as-built mixture designs or batch tickets if available; however, laboratory testing of core samples from the existing concrete may be required in order to obtain the necessary information. In cases where RCA is acquired from materials recycling companies, identifying concrete properties may be more difficult because concrete material may have come from a variety of sources. This means that the strength, air content, and durability as a whole can vary greatly.

Contamination of RCA includes reinforcing steel, asphalt, wood, masonry, and any other material that is not concrete. These contaminants must be removed before the material can be processed as RCA. These contaminants can affect the properties of the RCA and thus the performance of new concrete paving mixtures. From a practical perspective, it is not always possible to remove all contaminating material; therefore, tolerances are typically set that limit the amount of allowable contaminants. For example, it is reported that Austria allows up to 20 percent asphalt-bound material in new concrete mixtures designed for the lower lift of two-lift construction applications [6,11,21]. This is important because it lowers the restriction for using concrete that has been overlaid with hot-mix asphalt (HMA) or has been patched with HMA. It should also be recognized that specifications for RCA might need to have less restrictive requirements than those for virgin aggregates.

Processing

Once existing concrete has been acquired, it can be processed into RCA. Processing may include crushing the concrete into smaller pieces, removing contaminants, and storing the RCA for subsequent use. The removal of mortar and contaminants is important in achieving a quality aggregate, and affects new concrete performance. This concept is discussed further in subsequent sections under RCA Properties and RCA Concrete Properties.

Concrete is processed into aggregates typically sized to meet certain specifications for various applications. RCA can be processed into the same gradations as virgin aggregate. In the U.S., RCA is sized to meet ASTM C33 gradation requirements. ASTM C33 defines coarse aggregates as aggregate particles retained on anything greater than the #4, or 4.75 mm sieve. Fine aggregates are particles passing the #4 sieve [22]. Both are typically produced from RCA processing.

Typical processing can be done on site or at a processing plant off site. Typical crushing machines include jaw, cone, and impact machines. It is common for several crushers to be set up in a series in order to obtain certain gradations. Portable crushers can be used for in-situ processing of RCA, which may help minimize haul time and costs [23].

Wet processing is recommended by German standards for RCA because it removes some contaminants and minimizes dust on the particles, which improves workability [24]. Japan also recognizes wet processing as a method for processing high quality RCA. This process, however, can be expensive [14].

RCA PROPERTIES

RCA properties are influenced by the material properties of the concrete from which it was processed and the method and equipment used to process it. RCA is concrete crushed into smaller pieces. The smaller pieces consist of one or more virgin aggregate types from the original concrete, and the hardened mortar matrix binding that original aggregate. The method used for crushing the RCA affects the angularity, roughness, gradation, and amount of mortar left around the original aggregate.

The mortar around the original aggregate affects RCA properties. Because of the increased mortar fraction, the relative density of RCA is less than and porosity is greater than most virgin aggregates. When producing concrete with RCA, the volumetric proportioning and mixing water requirements are affected by the relative density and porosity properties.

RCA is more susceptible to mass loss, higher absorption, and freeze-thaw damage when compared to most virgin aggregates because of its increased porosity due to the mortar fraction. RCA strength is typically less than that of virgin aggregate; however, it may have greater strength than some soft virgin aggregates. The strength of RCA depends on the combined strength of the original aggregate and the transition zone between that aggregate and the mortar of the old concrete. It should be noted, however, that although there tends to be increased mass loss associated with RCA, it still commonly meets specified tolerances for LA abrasion testing [6,8,9,20,23,24].

It has been suggested in some reports that the quality of RCA is increased when there is less mortar around the aggregate. The assumption in this case is that the RCA will exhibit properties more like the original virgin aggregate used in the RCA material. Adjustments to the crushing methods used during processing can help minimize mortar content. There are some concerns, however, that too much crushing could compromise the integrity of the original aggregate and may prove not be cost effective overall.

Concrete made with RCA from material exhibiting alkali-silica reaction (ASR) does have the potential to continue to show signs of ASR [26]. RCA processed from concrete reclaimed from a freeze-thaw environment may have an increased amount of chlorides in the mortar matrix, which may increase the potential for corrosion of steel members if used as aggregate in reinforced concrete. Research has proven, however, that an engineered mixture design can overcome these durability issues. This issue is discussed further in subsequent sections.

States that allow RCA for use in new concrete paving mixtures typically require that RCA meet the same specifications as virgin aggregates. This could restrict the use of RCA, and some considerations should be made to change some requirements in specifications for virgin aggregates. For example, RCA is prone to fail the soundness requirements and limits on the quantity of fines. European standards for test methods to qualify RCA for use in new concrete mixtures recommend using a magnesium solution for testing RCA durability in freeze-thaw environments. It has been reported that absorption testing for RCA requires more time for accuracy [25,29,30]. The process for determining gradation may affect the accuracy of the results because the shaking during sieving causes mortar particles to separate from the original aggregates. Instead, it has been recommended by the Swedish National Testing and Research Institute, the Foundation of Scientific and Industrial Research at Norwegian Institute of Technology, and the Icelandic Building Research Institute to test several smaller samples [30]. The order in which gradation and abrasion testing is done with the same sample affects the results. For abrasion testing or fracture resistance, it is recommended that the sample be tested as a unit [30].

RCA CONCRETE PROPERTIES

A new concrete mixture that includes RCA must be engineered properly in order to achieve required workability, strength, and durability. Concrete designed by simply replacing virgin concrete with RCA will not necessarily perform the same.

Fresh concrete containing RCA tends to lose workability faster and is often a harsher mix [30,31]. A modest acceleration may be observed in setting time, which may be attributed to continued hydration of the old mortar fraction while the new concrete mortar is still plastic. Hardened concrete containing RCA generally has a lower modulus of elasticity, higher coefficient of thermal expansion (CTE), and experiences more drying shrinkage [6,33]. Concrete strength is often lower when compared to the same mix with virgin aggregates. New concrete may suffer ASR-related distress if RCA is from ASR distressed concrete [6,24,26,33].

The development of mixtures to minimize or offset these effects is necessary. Engineering the mix by properly proportioning RCA and virgin aggregate combinations with optimized water content and both chemical and mineral admixtures (i.e., supplementary cementitious materials or SCMs) will improve the performance of new concrete with RCA.

RCA Content

As more RCA is used in place of virgin aggregate for the same mixture design, noticeable differences in concrete properties such as strength, workability, and durability become apparent. Research has shown that, when replacing virgin aggregate with RCA, there is a limit at which, when all other mix constituents (e.g., cement, water, air content) are held constant, concrete properties such as strength and durability are affected.

In Austria, it is reported that virgin coarse aggregate can be replaced with up to 20 percent RCA [21]. In Australia, up to 30 percent of virgin coarse aggregate can be replaced by RCA, but only in new concrete mixtures for curbs and sidewalks [34].

Research in the UK supports the use of 30 percent replacement of coarse aggregate with RCA and reports that there is little to no effect on concrete properties [17]. Research in Japan concludes that up to 20 percent coarse aggregate can be replaced with RCA without affecting concrete properties and that maximum aggregate size should be limited to a range of 16-20 mm [14].

RCA as a fine aggregate is not typically used in new concrete mixtures. It has been reported that RCA fine material contains increased amounts of contaminants that adversely affect concrete properties [6,35,36]. Fine RCA may cause increased shrinkage, reduced strength, and reduced workability. Therefore, most specifications currently in existence that address the use of RCA in new concrete mixtures do not allow the use of RCA as a substitute for fine aggregate.

Water-to-Cementitious Materials Ratio (w/cm)

As is the case for new concrete mixtures with virgin aggregates, the w/cm should be optimized for placement and performance. Some research simply suggests that new concrete mixtures with RCA require additional water and cement. However, in order to achieve a workable mix that is strong and durable for paving applications, new concrete mixtures with RCA should be engineered to include chemical and mineral admixtures that minimize the need for additional water and cement [14, 31, 33].

Research in the UK resulted in a method for determining trial batch proportions based on a series of strength curves developed for a range of w/cm ratios for both RCA and virgin aggregate mixes [15].

Strength

Compressive strength of concrete with RCA is commonly reported as being lower than the strength of concrete made with only virgin aggregates. Reduced concrete strength when RCA is used in place of virgin aggregates is attributed to the mortar fraction around the original aggregate.

It has been shown that when a new concrete mixture has a higher w/cm and includes RCA with a strong transition zone between the original aggregate and the old concrete mortar fraction, the new concrete will exhibit strengths similar to that of the same mix if virgin aggregate were used. If the w/cm is low and the RCA transition zone is weak, the concrete will have lower strengths than if virgin aggregates were used in the same mix [37].

In addition to reduced compressive strengths, the relationship between compressive strength and tensile strength is not necessarily the same for concrete with RCA as it is for concrete with virgin aggregates [32,38]. Work by Tavokali and Soroushian suggest that for higher w/cm, the relationship of compressive strength to tensile strength predicts values that are too high [38].

For concrete with RCA to achieve a specific strength, the reviewed literature recommends that the RCA come from a source of equal or greater strength [31]. The catch, however (as pointed out by the Hansen 1985 report), is that even concrete from the same source may not be uniform in strength and this may cause problems in achieving specifications [31]. Minimizing the amount of mortar around an aggregate during processing will help increase strength. Mineral admixtures such as fly ash and slag can be used to improve both strength and durability. Limiting the porosity of RCA will also help the concrete achieve required strength [25].

Durability

Concrete paving mixtures that include RCA aggregate can be engineered to perform well in freeze-thaw environments. It has been shown that RCA from previously air-entrained concrete improves concrete performance in such conditions, and the use of fly ash can improve concrete with RCA performance in freeze-thaw environments [33,39].

RCA in concrete does increase the potential for more carbonation and chloride penetration because the transition zone between old mortar and original virgin aggregate is more permeable than virgin aggregate [37]. Mineral admixtures may help decrease carbonation and chloride ingress by densifying the new mortar matrix.

ASR can occur in concrete with RCA. Typical mitigation methods (e.g., reduced w/cm, addition of mineral admixtures) can work to minimize the potential damaging effects of ASR [26].

QUALITY CONTROL

Consistent workability, strength, and durability of a new concrete paving mixture that includes RCA depends on good quality control. According to the literature, there are quality control methods specific to RCA that may help to limit material variability and address moisture control. Stockpiling RCA according to the properties of the source concrete is a technique that minimizes variability [33]. Removing as much of the mortar as possible is another method, which requires optimized crushing methods as discussed previously. Pre-wetting aggregates before mixing is a moisture control method that helps combat the absorptive nature of RCA.

International efforts to regulate the quality of RCA have resulted in classifications based on the type of application for RCA. Research in Japan has resulted in a method for indexing RCA quality [14]. An equation was developed that calculates the relative absorption rate by summarizing absorption rates multiplied by respective volumes for both natural and recycled aggregates and then dividing by the total volume. This method allows RCA to be stockpiled for different applications, based on quality, and promotes control and assurance that the material will meet specifications. The Japanese Industrial Standards (JIS) identify three classes of RCA: “H” for high quality, “M” for middle quality, and “L” for low quality. A Type H RCA is required for use in concrete mixtures. The primary limits for these classifications are relative density and absorption, although the material is expected to meet additional requirements such as abrasion, shape, fine content, and chloride content for both coarse and fine Type H RCA [40].

RILEM recognizes three categories of RCA with applications for each category that are appropriate. Each category represents a different level of quality based on absorption, density, sulfate content, and various other material contents. RCA that can be classified in one of the three categories can be used in new concrete pavement mixtures as long as any additional testing for environmental durability is met [35].

BENEFITS AND BARRIERS

Based on the literature, benefits associated with the use of RCA in new concrete paving mixtures include expedited construction schedules, reduced material costs, and a reduced amount of materials discarded in landfills.

Barriers that limit the use of RCA in new concrete paving mixtures are either obstacles or misperceptions. Obstacles include the following:

- RCA does not pass the sulfate soundness test when sodium sulfate is used. In order to overcome this obstacle, the test needs to be modified. Modifications may include requiring only magnesium sulfate when testing RCA according to ASTM C88 or adjusting the acceptance limits of the test when a sulfate solution is used.
- Specifications limit the use of RCA. Modifications should be made to specifications that limit the amount of RCA that can be incorporated into a new concrete paving mixture. This will require a move away from prescriptive specifications and towards performance specifications.
- Use of RCA in new concrete paving mixtures may not be the most cost-effective application on some jobs. A general, a consistent approach for evaluating cost effectiveness of RCA in various applications needs to be developed, which will help to overcome this obstacle. In addition, cost-saving incentives for the specific application of RCA in new concrete paving mixtures may be needed.
- Quality is variable. To overcome this obstacle, methods for storing, processing, and moisture control that are specific to RCA for use in new concrete mixtures must be understood and practiced by contractors.

Misperceptions are negative assumptions based on the real obstacles. Misperceptions can be overcome through education and training. Contrary to common misperceptions, the following can be true:

- RCA can be a good quality aggregate.
- Concrete with RCA can meet strength specifications.
- RCA from concrete exhibiting ASR or D-cracking can be used as aggregate in new concrete paving mixtures.
- RCA fines can be used in new concrete mixtures.
- RCA will pass abrasion testing.
- RCA will meet gradation requirements.

A survey was developed to confirm that these real obstacles as well as the misperceptions exist as limitations to the use of RCA in new concrete mixtures and to identify any additional barriers.

CHAPTER 3: SURVEY

PURPOSE

A survey of sixteen questions was developed to benchmark the current use of RCA in new concrete paving mixtures. The survey was distributed by the National Concrete Pavement Technology Center (CP Tech Center) to members of AASHTO and the National Concrete Consortium (NC^2).

RESULTS

Twenty-six state DOTs submitted responses to the survey. A summary of their responses is provided in Appendix A. Based on the results of the survey, it can be determined that there are states interested in learning more about how to use RCA in new concrete paving mixtures. Barriers (obstacles and misperceptions) that limit the use of RCA in new concrete paving mixtures can be grouped as compliance, quality, or production related.

Compliance barriers include the inability for RCA to meet state specifications for aggregate soundness, abrasion, gradation, and strength. In addition, there was a concern expressed that ASR would be a problem. Barriers associated with quality include maintaining consistency and the perception that RCA is a waste material not worthy of use in new concrete paving mixtures. Production barriers include storage, workability, supply, removing debris, and location of processing equipment.

Conclusions cited from the literature search address a number of these barriers; thus, it is suggested that there may simply be a need for education and training when it comes to using RCA in new concrete paving mixtures.

CHAPTER 4: PROPOSED TECHNOLOGY DEPLOYMENT PLAN

VISION

The vision is to make RCA a viable option for use as an aggregate in new concrete paving mixtures within the next ten years. As such, RCA will need to be readily available and commonly accepted as an approved material. In order to work towards this vision, the barriers limiting the use of RCA in today's industry must be identified and a technology deployment plan implemented.

BARRIERS

As suggested by conclusions of the literature search, and confirmed by the survey results, there are barriers today that limit the use of RCA in new concrete paving mixtures. These barriers include obstacles and misperceptions with regard to compliance, quality, and production.

In order to develop a plan to overcome them, the barriers need to be recognized from the perspective of both the owner-agency and the contractor.

Owner-Agency

A principal concern of the owner-agency (e.g., state or local government) is meeting the performance requirements for infrastructure in a manner that is both economical and socially responsible. In addition, there is a growing awareness of sustainability that places additional pressures to consider the effects on the environment. During the project development and design stages, the owner-agency weighs the benefits of using certain material options with the risks that there will be a decrease in performance.

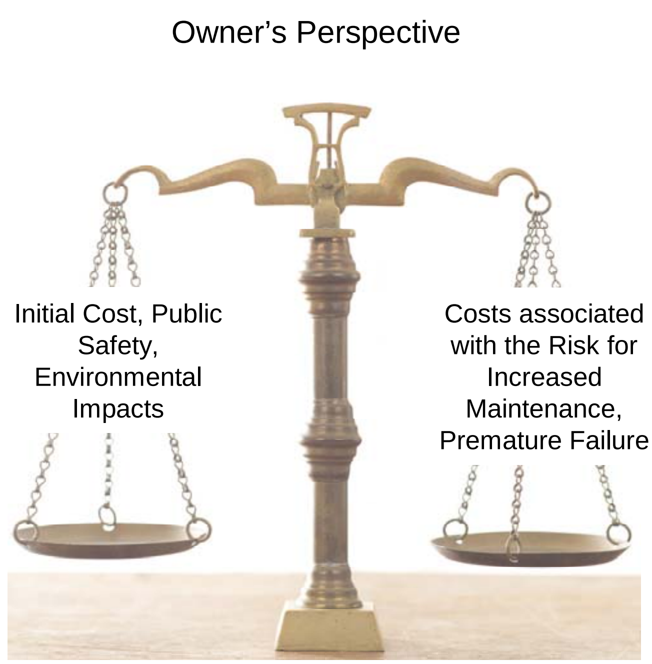

Figure 1. Owner-agency perspective when considering RCA

The benefits to the owner-agency when using RCA include reduced impact on the environment, reduced cost, and increased public safety. Risks include potential adverse impacts to long-term performance and structural durability. These risks are issues the owner-agency faces when considering RCA in new concrete pavement mixtures. Specifications developed to address these issues can minimize owner-agency risk but often impart limitations on the use of RCA in new concrete paving mixtures.

Owner-agencies often require RCA to meet the same specifications as virgin aggregates. This provides the owner-agency with some level of comfort and assurance that the pavement will meet its design life. However, it has been suggested that the specifications are too strict, particularly since research has shown that properly engineered mixtures that contain RCA can be durable in freeze-thaw environments even though specimens do not pass the sulfate soundness test when a sulfate solution is used. Specifications and testing of RCA should be geared toward what is achievable with these materials for assurance of adequate performance.

A technology deployment plan must recognize the shortcomings in current specifications and testing procedures. The plan should address the issue by providing sources for education and collaborative forums for identifying future research needs in order to achieve the vision. In addition, the plan should consider means for owner-agencies to encourage the use of RCA in new concrete paving mixtures in order for them to realize more of the environmental benefits associated with its use. The plan should include a strategy for opening up an opportunity to discuss possible owner-agency incentives.

Contractor

The primary concern of the contractor is to maintain their competitiveness, which is done in part by meeting the agency specifications in an economical way. Unless there are incentives or specifications, the effects on the environment (need for sustainable practices) are rarely a consideration in practice. Instead, a contractor will often weigh the benefit of using a material with the risk that there will be increased costs.

Figure 2. Contractor perspective when considering RCA

Two benefits to the contractor when using RCA include the potential for reducing project costs and expediting construction schedules. Reduced project costs are realized when the acquisition, production, and use of RCA for an application are more economical than if virgin aggregates are used. RCA sources and processing plants in close proximity to the paving site can reduce haul times and potentially expedite construction schedules. This, in turn, may reduce project costs. However, these benefits must outweigh costs associated with the risk of failure in meeting specifications and/or warranty commitments.

In cases where the contractor acquires RCA from the project site, there can be an additional benefit by not paying to dispose of RCA. However, this is not a common issue since RCA can be used in a variety of other applications (e.g., riprap). A contractor will choose to use RCA in whatever application is the most cost-effective. This will be influenced by how much RCA is readily available (i.e., supply) and how it will have to be processed.

For the specific application of using RCA in new concrete paving mixtures, the contractor has to evaluate the costs associated with the production and verification testing of RCA in order to meet specifications for use as an aggregate in new concrete. In addition, the costs associated with the ability to maintain consistency and uniformity are considered. These costs are compared to the costs of using RCA in other applications. The application that provides the most potential for overall reduced project cost is often the application for which RCA is used unless there is enough of a supply for use in multiple applications or its use is specified for some specific application.

Issues that contractors face with production and verification of RCA in new concrete paving mixtures that could potentially increase the cost for this kind of application include consistency, supply, experience, and the time required for and results of verification testing.

Consistency is a big issue for contractors because quality control and quality assurance testing depend on it. If there is no consistency, then there is a higher risk that concrete will not meet specifications for slump, strength, and air content. Additional costs to the contractor will thus be accrued when concrete is rejected or repairs become necessary.

Some verification testing takes time, which is an issue for contractors; time is money. In addition to taking time, it is well documented that RCA does not meet all of the requirements of common freeze-thaw durability tests. Therefore, if the source for RCA needs to be tested for use in new concrete and the testing impacts the construction schedule in such a way that it results in additional costs to the contractor, RCA will likely be used in another application. If the contractor already assumes that the RCA will fail verification testing, RCA will likely be used in another application.

RCA supply is an important issue in the contractor's decision-making process that affects the application for which RCA will be used. For use in new concrete paving mixtures, there must be enough material for the entire project. If there is not a readily available supply of RCA—particularly RCA of similar quality— it will most likely be used in another application.

Contractor experience is another issue that can affect the cost of using RCA in new concrete paving mixtures and influence the decision-making process. Concrete with RCA should be engineered, and furthermore, a contractor should know how to optimize construction methods to maintain consistent quality and workability. If there is no education or clear guidance for a contractor and/or the contractor has no experience, it is left up to trial and error. This can have costly ramifications.

A technology deployment plan must recognize the contractor issues. The plan should have an approach for teaching contractors how to overcome consistency issues, and deal with supply shortages. Guidelines on how to store material properly should be developed. This will be essential for both contractors that acquire and process their own RCA as well as for RCA producers who supply contractors with material for various applications. As part of these guidelines, proper removal of contaminants and a method for separating RCA material based on origin, strength, and air content should be established; how to handle moisture conditions of RCA in the stockpile should be addressed; and an awareness of environmental restrictions that govern storage and potential runoff of toxic chemicals from RCA should be conveyed. In addition, a guidance tool should be developed for evaluating various applications for RCA based on risk management and a cost analysis.

TECHNOLOGY DEPLOYMENT PLAN OBJECTIVE

The primary objective of the technology deployment plan is to develop a method for providing education and training to owner-agency and industry personnel. To do this, a strategy must be developed that encourages the use of RCA for new concrete mixtures by addressing the questions shown in Figure 3.

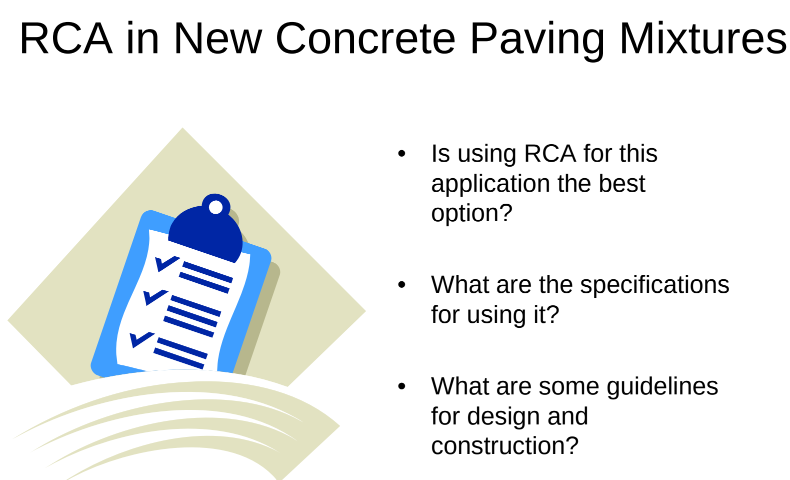

Figure 3. Focus for encouraging RCA in new concrete paving mixtures

The plan includes an approach for absolving the preconceived notion that RCA is a waste material not fit for use in new concrete paving mixtures. The plan includes programs aimed at conveying an understanding of the thought processes of both the owner-agency and the contractor. The plan discusses the balance that must be achieved for managing the risks associated with using RCA. The plan also identifies a method for providing recommendations on improved and innovative techniques, as well as a strategy for identifying future/additional research needs.

EXECUTING THE PLAN

The plan should be guided by a crosscutting Technical Working Group (TWG) and should include four programs: outreach and communication, training, technical support, and demonstration projects.

Each program contains subcategories with tasks intended to support the plan's efforts towards meeting the vision of the future (Figure 4).

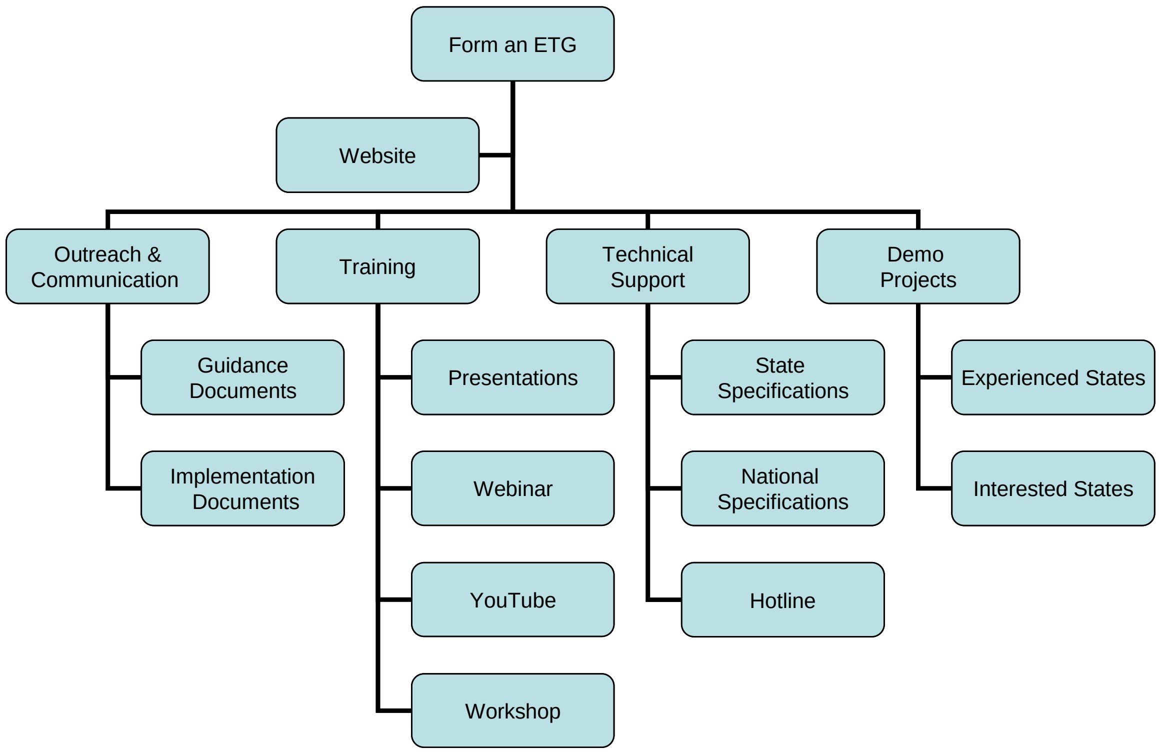

Figure 4. Flowchart showing the breakdown of the proposed plan

Technical Working Group

A TWG should be created to lead the concrete paving community by providing expert knowledge and experience as guidance. The TWG will assist in establishing and maintaining the momentum of the plan, and assuring that there is synergy between each of the components of the plan. The TWG should be a group of industry leaders that have knowledge of and experience with RCA. At a minimum, the TWG should consist of representatives from the following organizations:

- FHWA
- State DOTs
- Recycled Materials Resource Center (RMRC)
- ACPA
- Portland Cement Association (PCA)
- National Ready-Mixed Concrete Association (NRMCA)
- National Stone, Sand & Gravel Association (NSSGA)
- National Concrete Consortium (NC^2)

A dedicated website should be created as a means for communication between the TWG members and to facilitate the implementation of and products from the four technology deployment plan programs. Each program will have subtasks developed by the TWG that will guide the community towards realizing the vision for RCA.

Outreach and Communication

The plan will include a program for outreach and communication (O&C). The purpose for O&C is to inform the concrete paving community of the TWG's vision for the future of RCA and to provide a means for identifying owner-agency and contractor needs for additional education and training. The goal is to establish O&C with regional federal, state, and local agencies, as well as with contractors.

O&C program content will provide an overall picture of RCA and specific information on the use of RCA in new concrete paving mixtures. Examples of successful case studies will be highlighted. It will also convey an understanding of owner-agency/contractor specific issues. Initially, most of this information will reflect what was gathered during the literature search. As more implementation projects occur, however, it is anticipated that the program content will be updated to reflect the most up-to-date results of innovations and any new issues. This is where the TWG will be vital in working toward the overall vision, because it is through the TWG that experiences, outcomes of new projects, and a need for future research will be identified.

As part of the O&C program, a methodology for evaluating RCA applications using cost analysis and risk management will be developed. This may include protocols on how to assess risk based on a life-cycle analysis (LCA). Therefore, as part of this task, LCA tools currently available (such as PaLATE) or those in development (such as current research work funded by FHWA for developing a comprehensive LCA tool for pavement sustainability) will be investigated. It is anticipated that the benefits of RCA with respect to social, environmental, and economic issues will be included.

The main method for providing O&C will be through guidance documents that can be exchanged through some form of communication (e.g., e-mail, telephone calls, and visits to meet with key owner-agency personnel). These guidance documents will be an accumulation of existing references supplemented by new documents as needed. For example, recent work by Washington State DOT will be included in the O&C because it provides a summary of RCA in just a few pages and even identifies an approach for concrete mixture design [8]. This approach can be further developed for other owner-agencies and made specific to their materials. In addition, work by Cuttell et al. will be included because it provides information on the performance of RCA in existing case studies [9,10].

Among the supplementary documents that will be needed as part of this program, the development of an implementation guide that discusses a step-by-step process for identifying what considerations need to be made for modifying existing specifications is recommended. This document will include benefits (economic, sustainability, etc.) and documented case studies.

Training

The purpose of a training program is to provide detailed information to the owner-agency and/or contractor on how to use RCA in new concrete paving mixtures. The content will include any documents identified as part of the O&C program. The method for providing the content could include webinars, workshops, YouTube videos, and both electronic and hard copies of O&C documents.

Webinars will be designed to provide an overview of the O&C content, an introduction to the workshops that will be developed, and more detailed information.

The workshops are envisioned as one-day events, delivered on a regular schedule, and intended to cover each part of the country (4-5 regions). The content of the workshops will include review of the basics of RCA and present better practices for using RCA in new concrete pavement mixtures. Based on information gathered from the literature search and at the discretion of the TWG, the design of new concrete paving mixtures, methods for optimizing quality and consistency, and pavement performance will be addressed. Case studies will be presented in detail so that the audience can gain an understanding of what all is involved in a successful implementation project. Key references will be identified. Providing the audience with electronic versions of O&C documents along with a list of references will be a good way to promote education for improved use of RCA in new concrete paving mixtures, and may work to increase the potential for more implementation projects.

The workshop will also be broken down into condensed versions for shorter workshops, webinars, and YouTube videos. The condensed versions developed for webinars will focus on parts of the information presented by a workshop. For example, "Part 1" may just cover RCA basics. The webinars provided as part of this plan will build off currently available webinars by ACPA, National Highway Institute (NHI), and RMRC. The YouTube videos will be even more condensed versions of the webinars. They will be short, ranging from five to 10 minutes, and will only include general information, case studies, and information on how to learn more.

Technical Support

The technical support program will be geared toward developing a method for answering common questions about RCA, helping form strategies for developing and /or improving standards and specifications, and realizing additional research needs.

As part of the O&C program, a website will be developed for communicating general information about RCA in concrete paving mixtures. As part of this website, contact information for a dedicated secretary can be provided. The secretary can then facilitate between the TWG and anyone interested in using RCA for a new concrete mixture but needing some additional education or training. In addition, a forum for asking questions on the website will be developed. This will allow website users to identify commonly asked questions and to quickly research answers to those questions without having to contact someone. Questions posed for which there are no immediate answers will be a quick way for the TWG to identify research needs.

There are states that have modified policies that regulate RCA and that have developed specifications for the use of RCA in new concrete paving mixtures [5]. This program will work toward assisting other owner-agencies in modifying their regulations and specifications based on the lessons learned. While developing specifications for owner-agencies that have none, specifications developed by other countries and the innovative research that led to those specifications will also be considered. Developing state specifications will go a long way in promoting this application of RCA.

In addition to state specifications, this program will strive to support current efforts to develop national guidance standards. The RMRC has assisted with the development of a draft document, AASHTO MP 16, which is currently under review for acceptance by AASHTO. The document, however, only addresses the use of RCA as a coarse aggregate. As part of the technical support program, the TWG would work to further develop this document or generate another draft document for the use of RCA fine material as an aggregate in new concrete paving mixtures.

Any specifications and standards developed for the use of RCA in new concrete paving mixtures have to consider the fact that RCA is different from virgin aggregate. As part of the technical support program, alternative test methods and caveats to current test methods for quality and assurance should be evaluated and addressed.

For example, results of the literature search concluded that more time is necessary for absorption testing to be accurate. In the Meinhold et al. report, the amount of water RCA absorbs within the first ten minutes correlated to an average of 65 percent of the total absorption for the mixes investigated [25]. This report proved that a correlation could be established for a quick determination of absorption, but that initial efforts to establish the correlation based on the job-specific RCA source is necessary.

Another example of modifications to be considered by the TWG as part of this program may be based on the work done by Schouenborg et al. [30]. Schouenborg concludes that by modifying gradation and abrasion testing methods, a more accurate characterization of RCA can be achieved.

In addition to recognizing existing alternatives, needs for additional research in order to determine whether or not the aforementioned or any other alternative test methods are appropriate will be identified by the TWG.

Demonstration Projects

Demonstration projects will focus on encouraging agencies to implement new practices that incorporate RCA in new concrete paving mixtures. The program will be organized to help interested agencies identify ways to fund, design, and construct projects that can act as a showcase for the potential of RCA in new concrete paving mixtures.

As part of the demonstration projects, the TWG will work to facilitate collaborative efforts between the public and private sectors to obtain funding for these demonstration projects. States responding to the survey that are interested in learning how to use RCA in new paving mixtures could be targeted initially. These targeted states will be given the opportunity to have continuous training and support during the design, construction, and maintenance of these sections. Implementing RCA for new concrete paving mixes in states that are reluctant because of misguided perceptions that RCA is not good enough will require an approach that eases the agency into a feeling of confidence. This can be accomplished by first using RCA in new concrete mixtures for barriers, then for pavement sections along less trafficked areas, and finally in short sections along highways.

PLAN PROGRAM SYNERGY

Feedback from each of the demonstration projects will help the TWG develop new or supplementary educational material for the O&C, training, and technical support programs. It will be essential that the TWG help maintain synergy between all of the programs so that forward progress is made toward achieving the future vision.

CHAPTER 5: CONCLUSION

The technology deployment plan presented in this report is a strategy for moving towards a future vision in which RCA is a viable option as an aggregate in new concrete paving mixtures. A TWG consisting of representatives from a list of organizations will be created, forming a partnership between industry, academia, and government that will encourage unity and forward progress towards that vision.

The TWG will be the guiding, governing body of the four main programs that make up the plan: outreach and communication, training, technical support, and demonstration projects.

Through an outreach and communication program, the TWG will be able to recognize individual agency needs for education and training. A flow of information will be established. Various methods for more detailed and individual educational experiences will be developed as part of the training program. Existing material and informational courses will be supplemented with new material developed as part of the outreach and communication program. The technical support program will work to develop national and local specifications, as well as offer support to answer commonly asked questions and identify research needs. Finally, the demonstration projects will focus on encouraging agencies that want to use RCA in new concrete paving mixtures but have little or no experience to construct small sections as trials. Continuous support through design and construction, as well as assistance in identifying potential sources for funding will be included. It will be the goal of the demonstration projects to instill confidence in owner-agencies that concrete with RCA will perform well, and to convince contractors that concrete with RCA can be a cost-effective application.

As a whole, the technology deployment plan will be structured to address perceptions of owner-agencies and contractors, including those that might be limiting the use of RCA in new concrete paving mixtures. Issues with compliance, quality, and production will be overcome with the development and availability of clear and comprehensive educational tools, guidelines, and specifications.

CHAPTER 6: RECOMMENDATIONS

Based on the information gathered during the literature review and the survey, there are definite barriers that limit the use of RCA in new concrete paving mixtures. Most of these barriers, however, can be overcome with education and training, clear guidelines, and successful implementation projects. It is important that barriers to using RCA be overcome because there are real benefits not being realized. In particular, the use of RCA in new concrete paving mixtures can potentially reduce project costs, minimize negative impacts on the environment, and expedite project delivery. It is recommended, therefore, that the technology deployment plan presented in this report be initiated with the organization of a TWG as soon as possible.

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3. Van Dam, T. and P. Taylor. "Building Sustainable Pavements with Concrete," National Concrete Pavement Technology Center, Ames, Iowa, 2009.

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4. Obla, K., H. Kim, and C. Lobo. "*Crushed Returned Concrete as Aggregates for New Concrete*," Final Report, National Ready Mixed Concrete Association (NRMCA), on-line, 2007.

   The report documents research that investigates the potential for returned concrete to be recycled as aggregate for use in new concrete mixtures. It is reported that many European countries allow 20 percent crushed concrete aggregate for use in new concrete mixtures. It is also reported that if only 20 percent or less of the aggregate for a new concrete mixture is recycled crushed concrete then there is little to no effect on concrete properties.

5. Gonzales, G. and H. Moo-Young, *"Transportation Applications of Recycled Concrete Aggregate, FHWA State of the Practice National Review,"* Federal Highway Administration, Washington, D.C., 2004.

   This report documents a state-of-the-practice national review. The report identifies RCA applications for 50 states, of which 5 are recognized as using RCA the most. The experiences of these five states are highlighted individually. In addition, the report identifies key economic, environmental, and construction issues. Concluding recommendations include applications and the need for additional research.

6. ACPA. "*Recycling Concrete Pavements*," American Concrete Pavement Association, Skokie, Illinois, 2009.

This document is a comprehensive report that documents the production of, and applications for, RCA. Benefits and limitations associated with RCA are presented. Recommendations and guidelines for removing hardened concrete, for using RCA in base/subbase, and for using RCA in new concrete paving mixtures are provided.

7. Larsen, T. and J. Armaghani. "*Florida Econocrete Test Road*," Florida Department of Transportation, Gainesville, Florida, 1988.

   This report presents a study that evaluated the use of Econocrete in various test sections. Similar to two-lift construction, the idea for using Econocrete was to prove that concrete with aggregates of lesser quality could be used as a layer beneath the surface layer. Sections evaluated as part of this study included Econocrete subbase beneath a concrete surface coarse constructed just after bleed water evaporated from the Econocrete surface, and Econocrete subbase beneath a concrete surface coarse constructed within 24 hours after Econocrete placement. Results of this study suggest that a thin concrete surface layer over a thicker layer of Econocrete performs well.

8. Anderson, K., J. Uhlmeyer, M. Russel. "*Use of Recycled Concrete Aggregate in PCCP: Literature Search*," Washington Department of Transportation, Olympia, Washington, 2009.

   This report explored the potential for using RCA in new concrete mixtures for pavement applications. Faced with reduced virgin aggregate sources and knowing that existing concrete structures contain aggregates of high quality, WSDOT wanted to investigate the benefits and any issues associated with the recycling of existing concrete for use in new concrete. The report includes a discussion of RCA and concrete made with RCA properties and characteristics, which is based on reportedly unpublished research by Mark Snyder. U.S. case studies are also identified and performance over time is reported.

9. Cuttell, G., M. Snyder, J. Vandenbossche, M. Wade. *"Performance of Rigid Pavements Containing Recycled Concrete Aggregates,"* Transportation Research Record 1574, Paper No. 971071, Washington, D.C., 1997.

   This report documents the results of a data collection program developed to evaluate the performance of 9 different pavement projects that include a total of 16 pavement sections constructed with new concrete paving mixtures that incorporate RCA. Among the conclusions listed, it was determined that five states used RCA successfully, RCA can affect load transfer, RCA from D-cracked concrete can be used without reoccurrence of D-cracking, and RCA from concrete with ASR may exhibit the potential for ASR in new concrete.

10. Gress, d., M. Snyder, and J. Sturtevant. "Performance of Rigid Pavements Containing Recycled Concrete Aggregates – 2006 Update," Transportation Research Board, Materials and Construction, Vol. 2113, on-line, 2009.

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11. Hall, K., D. Dawood, S. Vanikar, R. Tally Jr., T. Cackler, A. Correa, P. Deem, J. Duit, G. Geary, A. Gisi, A. Hanna, S. Kosmatka, R. Rasmussen, S. Tayabji, and G. Voigt. "*Long-Life Concrete Pavements in Europe and Canada*," Federal Highway Administration, Washington, D.C., 2006.

The purpose of this scan tour was to identify innovative highway design and construction methods for long-life concrete pavements that could potentially be implemented in the U.S. The report documents the use of RCA in European base applications and as an aggregate in the new concrete mixture designed for the lower layer of two-lift construction projects.

12. Englesen C., J. Mehus, C. Pade, and D. Sæther. "*Carbon Dioxide Uptake in Demolished and Crushed Concrete*," Project Report 395-2005, Norwegian Building Research Institute, Oslo, Norway, 2005

    The focus of this report was to present results of laboratory testing performed to determine the amount and rate of carbon dioxide absorption by various concrete mixtures. A rapid test method for quantifying carbonation rates and current levels of recycling for Norway, Sweden, and Finland are presented.

13. Sagoe-Crentsil, K., and T. Brown. "*Waste Minimisation and Recycling in Construction, Guide for Specification of Recycled Concrete Aggregates (RCA) for Concrete Production*," Final Report, Commonwealth Scientific and Industrial Research Organisation (CSIRO), Victoria, Australia, 1998.

    This report documents research efforts that focused on developing guidelines for high-quality RCA for use in commercial, non-structural applications.

14. Dosho, Y. "*Development of a Sustainable Concrete Waste Recycling System: Application of Recycled Concrete Aggregate Concrete Produced by Aggregate Replacing Method*," Tokyo Electric Power Company (TEPCO), Tokyo, Japan, 2007.

    This report discusses how approval for the use of RCA was achieved by combining RCA with natural aggregates in what is referred to as an "aggregate replacement method". In addition, a method for indexing quality was developed and is discussed.

15. Zhang W. and J. Ingham. "Using Recycled Concrete Aggregates in New Zealand Ready-Mix Concrete Production," Journal of Materials in Civil Engineering, ASCE, Vol. 22, No. 5, on-line, 2010.

    This report documents laboratory and field tests used to evaluate RCA as a potential alternative in new concrete mixtures. This research was an effort to identify the feasibility of RCA for use as an aggregate in New Zealand's conventional ready-mix operations. The report concludes that for medium-to-high strength concrete with RCA, the RCA must originate from concrete of similar strength.

16. Etxeberria, M., A. Marí, and E. Vásquez. "*Recycled Concrete as Structural Material,*" Materials and Structures, Vol. 40, on-line, 2007.

    The research documented in this report presents the results of laboratory testing methods aimed at establishing shear and strength values for concrete beams cast with concrete containing varying amounts of RCA as a an alternative to virgin aggregate. It was concluded that new concrete mixtures containing more than 25 percent RCA in place of virgin coarse aggregate would experience decreased shear and strength values when all other variables were kept constant. In addition, it was concluded that the type of reinforcement made a difference for mixtures containing 50 and 100 percent RCA coarse aggregate.

17. Limbachiya m., A. Koulouris, J. Roberts, and A. Fried. *"Performance of Recycled Aggregate Concrete*," RILEM International Symposium on Environmental-Conscious Materials and Systems for Sustainable Development, Print-ISBN: 2-912143-55-1, RILEM Publications SARL, 2004.

Research documented herein was focused on identifying properties of RCA versus virgin aggregate, and to evaluate the properties of concrete with RCA in foundation, new paving, and reinforced or prestressed applications. Up to 100 percent replacement of coarse virgin aggregate with RCA was investigated. It was concluded that RCA can lead to reduced slump, instability of the fresh mix properties when RCA content is greater than 50 percent, more harsh, and increased bleeding. Loss of workability was less than control mixes with virgin aggregate. Compressive strength at 28 days decreased when RCA content was greater than 30 percent. Increased cement content was concluded to cause, in part, increased ultimate shrinkage and creep in mixtures with RCA. Mixes with up to 100 percent RCA coarse aggregate content performed well in freeze-thaw testing and were comparable to virgin aggregate in abrasion testing. Concrete specimens tested for expansion in a sodium sulfate solution experienced a small amount of increased expansion when RCA content was greater than 50 percent.

18. Delhez, X., F. Michel, and L. Courad. "*Use of Concrete Recycled Aggregates in Roller Compacted Concrete*," Construction and Building Materials, Vol. 23, Issue 11, on-line, 2009.

This report presents the use of RCA in RCC. Conclusions include recommendations for minimum cement content, strength, Vibration Weighing Test (VWT) instead of Optimum Proctor Modified (OPM) test.

19. EPA, Environmental Protection Agency, website: http://yosemite.epa.gov/ee/epa/eed.nsf/fa6512c6e51c4a208525766200639df2/386f9db10fd75e418525777d000cbcc2!OpenDocument

This website discusses landfill taxes in the U.S.

20. ACI Committee 555, "*Removal and Reuse of Hardened Concrete*," American Concrete Institute Committee 555, ACI 555R-01, 2001.

This report provides guidance on the removal of hardened concrete for the purpose of recycling it. Methods of removal (including a discussion on various types of equipment), the process required for generating RCA from the removed concrete, and the production of new concrete incorporating the RCA are presented.

21. Sommer, H. "*Recycling of Concrete for the Construction of the Concrete Pavement of the Motorway Vienna – Salzburg*," 7th International Symposium on Concrete Roads, Vienna, 1994.

This report documents the reconstruction of a roadway in Salzburg-Vienna. It is reported that 100 percent of the original pavement was recycled and that the new concrete paving mixture included RCA. Hydration of the mortar attached to the RCA was reported to improve flexural strengths of the concrete.

22. ASTM. "*Standard Specification for Concrete Aggregates*," C33 – 01a, American Society for Standard Test Methods International (ASTM International), West Conshohocken, Pennsylvania, 2001.

This document lists all of the tests that an aggregate source will be subjected to in order to qualify as aggregate for use in new concrete mixtures. Limits for each of the tests listed are provided.

23. CP Tech Center, "*Guide to Cement-Based Integrated Paving Solutions*," Draft, National Concrete Pavement Technology Center, Ames, Iowa, 2011.

This document presents a variety of pavement applications for which cement can be incorporated. The document includes a short, but informative section on RCA and discusses the benefits along with the issues associated with using RCA. It is currently in final review and publication.

24. FHWA. "*Use of Recycled Concrete Pavement as Aggregate in Hydraulic-Cement Concrete Pavement*," Technical Advisory T 5040.37, Washington, D.C., 2007.

T 5040.37 defines RCA, discusses possible applications for the use of RCA, highlights how to remove existing concrete for processing, presents mitigation requirements when existing concrete may contain aggregate susceptible to freeze-thaw damage (D-cracking) or alkali-silica reaction (ASR), gives an overview of what is required so that the RCA is of good quality, and discusses what to expect of concrete produced with RCA.

25. Meinhold, U., G. Mellmann, and M. Maultzsch. "*Performance of High-Grade Concrete with Full Substitution of Aggregates by Recycled Concrete*," Third CANMET/ACI International Symposium on Sustainable Development of Cement and Concrete, ISBN 0-87031-041-0, 2001.

This research evaluated the use of building rubble as RCA. Properties including strength, creep, modulus, shrinkage, and durability were investigated. It was found that there is good correlation of total water absorption to porosity and that total water absorption is influenced by density. Porosity was found to be directly related to the properties investigated. The study included replacing a wide range of virgin aggregate fractions with RCA and explored the effects of using 50 percent and 100 percent replacement of fines with RCA fines. The findings of the investigation concluded that replacement with RCA decreased the modulus and that RCA fines caused the modulus to decrease even more; RCA fines caused 20 to 30 percent decrease in strength; freeze-thaw resistance increases with increased porosity; RCA may cause an increase in the rate of carbonation. It is recommended to use RCA with porosity of less than 15 percent.

26. Stark, D. "*The Use of Recycled Concrete Aggregate from Concrete Exhibiting Alkali-Silica Reactivity*," Research & Development Bulletin RD114, Serial No. 2033, Portland Cement Association, Skokie, Illinois, 1996.

Research work documented in this report concluded that RCA from concrete known to exhibit ASR used as aggregate in new concrete mixtures could result in ASR in the new concrete. The use of a class F ash was shown to mitigate this potential.

27. CEN/TC 154. "*Aggregates for Concrete*," European Committee for Standardization, EN 12620:2002+A1, Brussels, 2008.

This document includes tests, limits, and some guidance on the use of RCA in new concrete mixtures. This standard applies to 31 countries in accordance to CEN/CENELEC Internal Regulations.

28. Oikonomou, N. *"Recycled Concrete Aggregates,"* Cement & Concrete Composites, Vol. 27, Greece, 2005.

This report presents proposed testing methods and limits for defining suitable RCA material for use in new concrete mixtures in Greece. The recommendations are based on local testing experience, EN 206-1, and DafStb.

29. Gómez, J., L. Agulló, and E. Vázquez. "*Repercussions on Concrete Permeability Due to Recycled Concrete Aggregate*," Third CANMET/ACI International Symposium on Sustainable Development of Cement and Concrete, ISBN 0-87031-041-0, 2001.

This work investigated recycled concrete (RC) with RCA tested for permeability. RCA was generated in a lab and used for this study. It was determined that there is a relationship between the w/cm of RC and the RCA quality. Absorption and porosity increase with RCA content as density decreases. Conclusions are that RCA can lead to increased permeability; the w/cm of the OC and the processing of RCA affect the amount of mortar that makes up RCA; durability issues must be addressed properly to prevent problems.

30. Schouenborg, B., J. Aurstad, P. Pétursson. *"Test Methods Adapted to Alternative Aggregates,"* Conference on the Use of Recycled Materials in Building and Structures, Abstract 253, Barcelona, Spain, 2004.

This paper documents Swedish research and testing methods for RCA in concrete. The purpose of the work was to evaluate standard test methods and determine if alternate test methods better characterize RCA aggregate and their performance in concrete. It is concluded that the process for determining gradation affects the accuracy of the results because the shaking during sieving causes mortar particles to fall off. Instead, test several smaller samples. The order in which gradation and abrasion testing is done with the same sample also affects the results. For abrasion testing, or fracture resistance, it is recommended that the sample be tested as a unit (modified compression test for lightweight aggregates). Absorption testing requires more time for accuracy; a vacuum method could be a future alternative.

31. Hansen T., H. Narud. *"Strength of Recycled Concrete Made from Crushed Coarse Aggregate,"* Concrete International, January Edition, Farmington Hills, Michigan, 1983.

This report documents research focused on evaluating RCA and concrete with RCA properties based on properties of the concrete from which the RCA originated. Among the conclusions, it was determined that RCA strength is dependant on the w/cm of the original concrete; more cement is needed for concrete with RCA to attain the same strength as an identical mix with virgin aggregate; the amount of mortar affects new concrete drying and shrinkage, creep, and durability properties.

32. Sánchez de Juan, M., P. Gutiérrez. *"Influence of Recycled Aggregate Quality on Concrete Properties,"* Conference on the Use of Recycled Materials in Building and Structures, Abstract 347, Barcelona, Spain, 2004.

This paper presents laboratory test results on concrete mixtures that incorporate 20, 50, and 100 percent RCA coarse aggregate. Conclusions suggest pre-wetting aggregates in order to maintain workability. Also, there is a decrease in concrete strength when all other mix design variables are held constant; reduction coefficients can be used to design RCA concrete based on conventional methods; modulus of elasticity is affected when RCA content is less than 50 percent; at 100 percent RCA coarse aggregate content, all properties are affected.

33. Burke, T., M. Cohen, C. Scholer. "*Synthesis Study on Use of Concrete Recycled from Pavement and Building Rubble in the Indiana Highway System*," Joint Highway Research Program, Purdue University, West Lafayette, Indiana, 1992.

As defined by the abstract, this report is a synthesis of RCA. The report presents RCA sources, processing methods, typical applications, and economic considerations associated with RCA. General properties of RCA as an aggregate, as well as properties of concrete with RCA as a component, are presented. This report recommends that INDOT implement the use of RCA in new concrete mixtures. A survey to identify agency use of RCA and Indiana specifications for RCA in new concrete is provided in the appendices.

34. Cement Concrete & Aggregates Australia. "*Use of Recycled Aggregates in Construction*," Cement Concrete & Aggregates Australia, on-line, 2008.

Although not specific to RCA, this report does include a section that presents the typical applications of RCA, which includes a discussion on the use in new concrete mixtures for curb and gutters. A Class 1A RCA is required which is considered good quality and allows a very small percentage of brick contaminant.

35. RILEM. "*Specifications for Concrete with Recycled Aggregates*," International Union of Laboratories and Experts in Construction Materials, Systems, and Structures (RILEM), Materials and Structures, Vol. 27, 2004.

This document identifies three classes for RCA and defines the requirements for each. This specification is geared towards RCA as coarse aggregate.

36. Smith J., S. Tighe, J. Norris, E. Kim, X. Xu. *"Coarse Recycled Aggregate Concrete Pavements – Design, Instrumentation, and Performance," Recycled* Materials and Recycling Process for Sustainable Infrastructure Session, Conference of the Transportation Association of Canada, Toronto, Ontario, 2008.

This report presents pavement performance results of new concrete mixtures containing varying RCA and cement content. Laboratory testing was conducted and field trials were constructed. It is concluded that a mix design including quality RCA will have similar or better performance than a mix with virgin aggregate.

37. Otsuki, N., S. Miyazato, W. Yodsudjai. *"Influence of Recycled Aggregate on Interfacial Transition Zone, Strength, Chloride Penetration and Carbonation of Concrete," Journal* of Materials in Civil Engineering, September/October Edition, ASCE, Reston, Virginia, 2003.

This report presents laboratory-testing results that support the conclusion that the properties of the transition zone between the virgin aggregate and old mortar fraction affect RCA properties and performance of new concrete. The affect on strength, chloride penetration, and carbonation are discussed.

38. Tavokali M., P. Soroushian. *"Strengths of Recycled Aggregate Concrete Made Using Field-Demolished Concrete as Aggregates," ACI* Materials Journal Technical Paper, March/April Edition, ACI, Farmington Hills, Michigan, 1996.

    This report documents laboratory testing done to compare strengths of concrete with RCA versus concrete with virgin aggregate. It is concluded that strengths of concrete with RCA can be lower or higher than concrete with virgin aggregate. Strength of new concrete with RCA is influenced by properties of the original concrete from which the RCA was processed and on the w/cm of the new concrete.

39. Gokce, A., S. Nagataki, T. Saeki, M. Hisada. *"Freezing and Thawing Resistance of Air-Entrained Concrete Incorporating Recycled Coarse Aggregate: The Role of Air Content in Demolished Concrete," Cement* and Concrete Research, Vol. 34, Issue 5, Japan, 2004.

    This document reports test methods and conclusions that suggest new concrete mixtures with RCA from air-entrained concrete will perform better in freeze-thaw environments. It also suggests that removing the mortar has less of a positive affect than if the RCA is air-entrained.

40. *"New Standards on Recycled Aggregates and Molten-Slag in Japan,"* Japan Society of Civil Engineers, newsletter 08, on-line, 2002.

    This document presents the Japanese Type H classification for RCA as defined by the Japanese Standards Association 2005, and lists the appropriate applications for both H and L classes.

APPENDIX A – SURVEY RESULTS

	Which of these categories best applies to you?	Are you interested in using RCA in concrete pavement mixtures, but aren't sure how to do so effectively?	Have you used RCA that was reclaimed from the existing pavement for the reconstruction or expansion of the same roadway?	Have you used RCA reclaimed from sources other than the existing pavement in new concrete pavement mixtures?	If you have used RCA, briefly describe your experience	Three main barriers ***you*** face with RCA
Alabama	State agency	Knew	No	No	Spec allows; never done	Supply Quality & consistency Lack of experience
Alaska	State agency	Yes	No	N/A	N/A	Lack of specification Uniformity Cleanness
California	State agency	Yes	No	No	N/A	Spec not allow Negative impact on performance Unknowns not researched yet
Colorado	State agency	Knew	Yes	Yes	Aggregate base coarse; pipe bedding Benefit is unknown; low bidder's choice	None
Florida	State agency	No	No	No	Used in HMA on interstate. Graded agg base In non-structural concrete, pipe bedding	Coef. TE when mixed RCA sources Deleterious materials (e.g., asbestos)
Illinois	State agency	Knew	No	No	8-mile interstate section in1986 Viable rehab option Low elastic modulus; high drying shrinkage; workability	N/A
Indiana	State agency	Knew	No	No	Uses as base/subbase	D-Cracking Variability in quality and agg properties Influence on concrete properties (water demand, workability, placement, strength, durability)
Iowa	State agency	Knew	Yes	No	1977 research High absorption; harsh mix Curling	High absorption; harsh mix Operational burden; another type of agg.

	Which of these categories best applies to you?	Are you interested in using RCA in concrete pavement mixtures, but aren't sure how to do so effectively?	Have you used RCA that was reclaimed from the existing pavement for the reconstruction or expansion of the same roadway?	Have you used RCA reclaimed from sources other than the existing pavement in new concrete pavement mixtures?	If you have used RCA, briefly describe your experience	Three main barriers ***you*** face with RCA
Kansas	State agency	Knew	Yes	Yes	Perceived cost savings Harsh mix Has to meet all virgin agg requirement	D-cracking & ASR Insufficient supply; used in CTB Harsh mix
Louisiana	State agency	Knew	Yes	No	Used on I-12 Gradation and cleanliness were problem Lack of experience Unsuccessful; overlaid	Bad past experience
Maine	State agency	*Maine DOT has not constructed a PCC pavement since 1980's thus has no experience with RCA in PCC pavements*				
Minnesota	State agency	Knew	Yes	Yes	80s and at MnROAD in 2010 in composite On I-35 in 1997 >> Unwashed; difficulty obtaining 0.40 w/c; drying shrinkage cracking	Water demand Uniformity & absorption Deterioration (e.g., ASR, D-cracking, de-icer distress)
Mississippi	State agency	Yes	No	No	Used as a base and as HMA agg Save virgin material High absorption; not cost effective for HMA	No new PCC construction Not allowed in new PCCP Not used in other applications
Missouri	State agency	Yes	No	No	N/A	Anticipated problems: Lack of consistent strength Lack of soundness Verifiable source approval
New Jersey	State agency	Yes	No	No	N/A	Mixture from different sources; quality might be questionable
New Mexico	State agency	No	No	No	N/A	ASR is extensive; long-term validation needed

	Which of these categories best applies to you?	Are you interested in using RCA in concrete pavement mixtures, but aren't sure how to do so effectively?	Have you used RCA that was reclaimed from the existing pavement for the reconstruction or expansion of the same roadway?	Have you used RCA reclaimed from sources other than the existing pavement in new concrete pavement mixtures?	If you have used RCA, briefly describe your experience	Three main barriers ***you*** face with RCA
New York	State agency	Knew	No	No	Specs allowed but quality verification cost prevents its use Used in base and subbase	Insufficient amount Testing/evaluation cost is high Material quality/consistency is very low
North Dakota	State agency	Yes	Yes	No	25 years ago; existing road crushed reused in new; less virgin agg.	Durability Perception based on past experience Lack of experienced contractor and staff
Ohio	State agency	Knew[3]	No	No	Pavements, sidewalks, median, barrier 15 years ago in Toledo; performing well Only coarse; limit absorption to 7%	Specs require; Quality of material Developing a workable mix QC to maintain consistent mix
Oregon	State agency	Yes	Yes	No	High absorption Watering of stockpiles	No specs. Cost might be higher compared to virgin
South Carolina	State agency	Knew	Yes	No	10 miles on I-95 in 2001 Coarse agg in new mix; High absorption w/ high variation Performing well	Existing concrete is allowed in reconstruction
South Dakota	State agency	No	No	No	Only as agg base	Quality ASR
Texas	State agency	Knew	Yes	Yes	Coarse RCA up to 100%; Fine RCA up to 20% for non-structural, up to 100% for base Cost saving drives the use	Overlays instead of recycling Contaminants in RCA Lack of tests ensuring durability Local zoning restriction of crushers Water demand

	Which of these categories best applies to you?	Are you interested in using RCA in concrete pavement mixtures, but aren't sure how to do so effectively?	Have you used RCA that was reclaimed from the existing pavement for the reconstruction or expansion of the same roadway?	Have you used RCA reclaimed from sources other than the existing pavement in new concrete pavement mixtures?	If you have used RCA, briefly describe your experience	Three main barriers ***you*** face with RCA
Utah	State agency	No	No	No	As base agg	No specs Quality concerns: ASR, soundness, C33
Wisconsin	State agency	Knew	Yes	No	Can use up to 100% RCA as coarse aggregate in new concrete; CA as fine aggregate in new concrete is prohibited, due to extremely high absorption values (causing fluctuating water demand) and mixture harshness RCA must be from the existing project RCA is allowed at contractor discretion RCA is prohibited in structures Benefits – reduces demand for virgin aggregate Disadvantage – RCA increases water demand due to higher absorption and higher angularity (harshness)	Contractor discretion Usually as base or subbase
British Columbia	State agency	*We have very little concrete pavements, as most of our Highway system is based on an asphalt pavement design. Just RAP in Asphalt Pavements.*				

	Do concerns regarding the structural performance of concrete pavements containing RCA prohibit the use of RCA in new concrete pavement mixtures ?	Does your state believe that concrete strength requirements limit the use of RCA in new concrete pavement mixtures?	Has the existence of a specification for use of this material as an aggregate been a constraint?	What requirements of your specfications will RCA not be able to comply with?	Do sulfate soundness requirements prohibit RCA from being used in new concrete pavement mixtures in your state?	Does the presence of ASR in RCA prohibit it from being used in new concrete pavement mixtures in your state?	Is the use of RCA in new concrete pavement mixtures cost effective in your area?	What are the production challenges with using RCA in your state?	Do material (quality) verification requirements restrict the use of RCA in new concrete pavement mixtures in your state?	If there were incentives – such as green credits or tax credits – will this stimulate increased use of RCA in your state?
Alabama	No	No	No	LA Abrasion Sodium soundness	Yes	Yes	N/A	N/A	Yes	No
Alaska	Yes	Yes	N/A	N/A	Yes	Yes	Maybe	N/A	Yes	Yes/maybe
California	N/A	No	Yes	N/A	N/A	No	N/A	N/A	N/A	N/A
Colorado	No	No	No	None; higher flexure	No	No	Depends on project	Virgin agg is cheap	No	No
Florida	Yes	No	No	None	No	No	Maybe	Nonexistence of large-scale producers	No	No info
Illinois	No	No	No	N/A	No[1]	No	No	N/A	No	No
Indiana	Yes	No	Yes	AP agg quality requirements	No	No	Depends on project	What to do with fines Only using INDOT concrete sources	Yes	Yes
Iowa	No	No	No	N/A	No[1]	No	No	N/A	No	Yes/maybe
Kansas	No	No	No	LA abrasion might be problem	No	Yes	Yes	Insufficient supply Used in 4" base Harsh mix	Yes	No
Louisiana	Yes	No	Yes	Not allowed in PCCP but base	No	Yes (ACR)	No	None	No	Yes (if base included)
Maine	*Maine DOT has not constructed a PCC pavement since 1980's thus has no experience with RCA in PCC pavements*									
Minnesota	No	No	No	Maximum w/c	No	Yes	Yes	None	Yes	Yes/maybe
Mississippi	N/A	N/A	No	N/A	N/A	N/A	N/A	N/A	No	No
Missouri	Yes	Yes	No	Not tested one yet	Maybe	No	N/A	N/A	Maybe	Maybe
New Jersey	No	No	Yes	ASR verification	Yes	Yes	Maybe	N/A	No	Yes

	Do concerns regarding the structural performance of concrete pavements containing RCA prohibit the use of RCA in new concrete pavement mixtures ?	Does your state believe that concrete strength requirements limit the use of RCA in new concrete pavement mixtures?	Has the existence of a specification for use of this material as an aggregate been a constraint?	What requirements of your specifications will RCA not be able to comply with?	Do sulfate soundness requirements prohibit RCA from being used in new concrete pavement mixtures in your state?	Does the presence of ASR in RCA prohibit it from being used in new concrete pavement mixtures in your state?	Is the use of RCA in new concrete pavement mixtures cost effective in your area?	What are the production challenges with using RCA in your state?	Do material (quality) verification requirements restrict the use of RCA in new concrete pavement mixtures in your state?	If there were incentives – such as green credits or tax credits – will this stimulate increased use of RCA in your state?
New Mexico	No	No	No	ASR mitigation	No	Yes	Maybe	Fractionation & stockpiling issues[2]	No	No
New York	Yes	No	No	Soundness Gradation Absorption	Yes	Yes	No	Managing stockpile >> saturating and draining; maintaining uniform absorption	Yes	No
North Dakota	No	No	No	N/A	No	Yes	Maybe	N/A	No	No
Ohio	No	No	No	Absorption <7% LA abrasion <50% Cl content <1.5% Spec. Grav. variation <0.1 Abs. variation <0.8%	Yes	No	Maybe	N/A	No	N/A
Oregon	No	No	Yes	N/A	Maybe	Maybe	No	N/A	N/A	Yes
South Carolina	No	No	No	Soundness but waived for RCA	No	No	Yes	Elimination of foreign material Stockpile management Absorption	No	No
South Dakota	No	No	No	#200 sieve fraction LA abrasion Sodium Sulfate Soundness	Yes	Yes	Maybe	N/A	Yes	Yes
Texas	No	No	No	Depends on the project	No	Yes	Depends on the project	Restriction of crushers location	No	No
Utah	Yes	Maybe	Yes	N/A	Maybe	Maybe	Maybe	N/A	Yes	Maybe
Wisconsin	No	No	No	N/A	No	Yes	Yes	Maintaining uniform slump due to absorption; prevented by watering the stockpiles	No	No[4]

	Do concerns regarding the structural performance of concrete pavements containing RCA prohibit the use of RCA in new concrete pavement mixtures ?	Does your state believe that concrete strength requirements limit the use of RCA in new concrete pavement mixtures?	Has the existence of a specification for use of this material as an aggregate been a constraint?	What requirements of your specifications will RCA not be able to comply with?	Do sulfate soundness requirements prohibit RCA from being used in new concrete pavement mixtures in your state?	Does the presence of ASR in RCA prohibit it from being used in new concrete pavement mixtures in your state?	Is the use of RCA in new concrete pavement mixtures cost effective in your area?	What are the production challenges with using RCA in your state?	Do material (quality) verification requirements restrict the use of RCA in new concrete pavement mixtures in your state?	If there were incentives – such as green credits or tax credits – will this stimulate increased use of RCA in your state?
British Columbia	*We have very little concrete pavements, as most of our Highway system is based on an asphalt pavement design. Just RAP in Asphalt Pavements.*									

[1] *Poor test for aggregate quality.*

[2] *Could be easily solved.*

[3] *Ohio DOT is in the process of implementing RCA specs: AASHTO MP 16-10 and ACPA recommendations were sued to develop.*

[4] *100% RCA is typically used in base layers in every project.*