MPC-539
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Project Title:
Ultra-accelerated Method to Evaluate Recycled Concrete Aggregate in New Construction

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University of Wyoming

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Research Needs:
The Rocky Mountain Region has experienced considerable difficulty due to the presence of alkali-silica reaction (ASR) in concrete construction. Several sources of aggregate that have produced poorly performing concrete have been removed from service. As an example, DIA runways were damaged by ASR and the repair cost exceeded 30 million [1]. On a positive note, Wyoming Department of Transportation (WYDOT) was successful in using RCA on Interstate 1-80 and with limited ASR damage. In this portion of the road, WYDOT observed a 30 year service life. This performance, coupled with data from a previous study help confirm that using RCA combined with natural aggregates produces durable long-term concrete that will benefit the transportation network in this region. This study intends to provide experimental data that permits RCA to be used in applications beyond base fill for roads.

Recent work funded by the Mountain-Plains Consortium and WYDOT indicate that mortar bar precision statements need relatively little change to incorporate RCA into the equation. Existing prism statements for within laboratory precision should be slightly relaxed and no change is required for interlaboratory precision. Unfortunately, this test method continues to eliminate aggregates that are only moderately reactive and does not consider the effects of coarse aggregate which is a critical player in alkali-silica reaction.

Research Objectives:
1. Determine an appropriate level of RCA to be used in new concrete.
2. Develop precision statement for the inter-laboratory use of an ultra-accelerated test method to evaluate ASR.
3. Perform a round of testing among ASR researchers to determine if the current CPT precision statements need to be modified to include RCA in this ultra-accelerated test method.

In 1998, the infrastructure in the United States earned a grade of D by the American Society of Civil Engineers and over the last 20 years improved to a D+ in 2017 [2]. The goal of this report card is to "depict the condition and performance of American infrastructure based on physical condition and needed investments for improvement." Some of this premature degradation is attributed to concrete cracking and water ingress which provides the moist environment necessary to initiate chemical processes such as alkali-silica reaction (ASR) [3, 4].

Reducing waste generation should be a primary player in the long-term solution for sustainability. This can be accomplished by increasing the durability of new structures and responsibly planning for waste products in the design phase [3, 5-7]. Green design can continue by crushing of out-of-service concrete into sizes suitable for aggregate replacement in newly constructed concrete [8, 9]. Although, producing cement contributes up to 7 percent of the global CO2 production [3, 8, 10] this can be countered by replacing some fraction of cement with supplementary cementitious materials such as fly ash. This two-fold material replacement minimizes the two main environmental concerns of concrete production: depletion of natural resources, and increased generation of waste material [11]. It takes RCA to applications beyond using it as a road base material.

Alkali-silica reaction (ASR) occurs when alkalis present in cement paste react with silicates inherent in concrete aggregates. As ASR continues, it produces a hydrophilic gel. The gel absorbs water and swells to a point that internal stresses exceed the tensile strength of concrete resulting in map cracking of concrete. As crack width increases additional water enters and continues to produce more ASR gel, further deteriorating concrete. As a result, expansion continues and this self-propagating cycle causes serious damage in concrete structures (Figure 1).

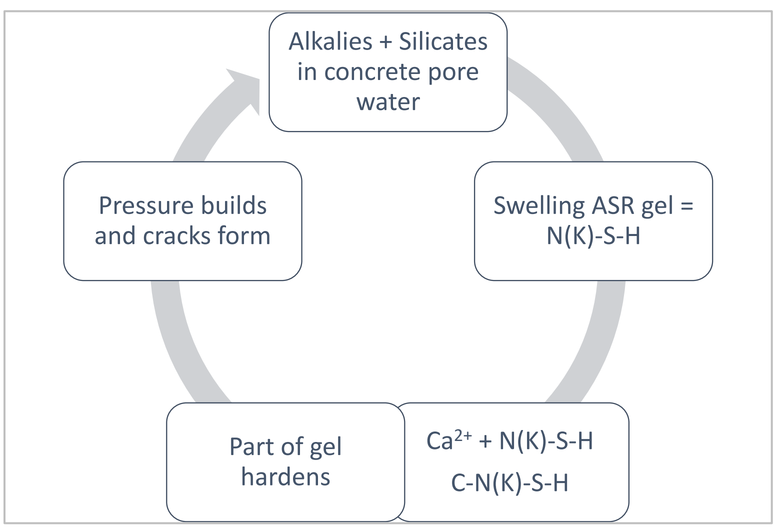

Figure 1. Illustration of viscous cycle of ASR damage

Pessimum Effect

In the 1940s, Stanton discovered an additional factor that contributes to the overall reactivity of an aggregate. This process is called the pessimum effect and is illustrated in Figure 2. This mechanism is where the reactivity of an aggregate is at its maximum at a certain amount of reactive constituents. As the amount of reactive silica deviates from this quantity, the overall reactivity is lessened. In Figure 2, this pessimum proportion occurs in specimens that contained roughly 20 percent reactive limestone. A possible reason for this may be in part the solubility of reactive silica and partly as the amount of reactive material approach the pessimum proportion, the amount of aggregate reactivity increases. After the pessimum proportion, the C-H is consumed by the reaction with the mature alkali silicate which forms fragmental calcium alkali silicate which reduces expansions [12].

There are many parameters that exhibit this behavior: “volume fraction, type and size of reactive aggregate, composition of the cement and mixture proportion of the concrete such as water-cement ratio” [13]. These effects have been well documented [12-16]. Previous work at UW indicates that using previously reactive RCA as an aggregate in new concrete demonstrates a pessimum effect [17].

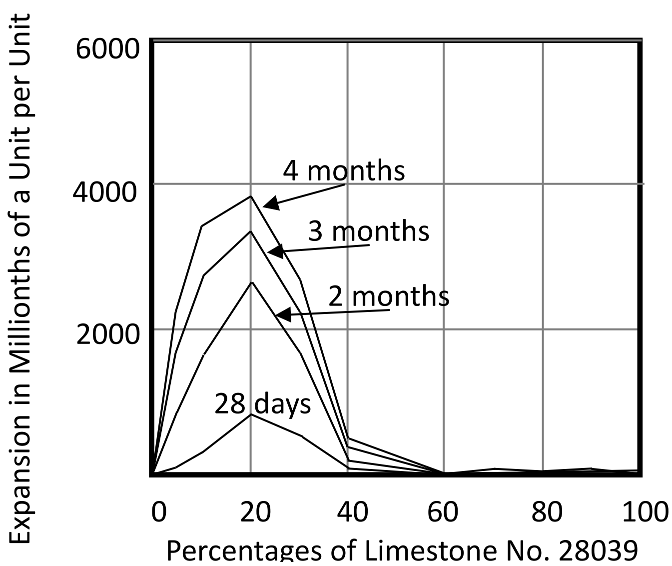

Figure 2. Graph. Pessimum effect [18]

Research Methods:

This project builds upon current work being completed at the University of Wyoming (UW), University of Alabama, and University of Texas [19, 20]. Several field block specimens boosted with additional alkalies will be broken down to provide RCA with substantial damage. WYDOT is currently funding the development of an ultra-accelerated test method that more closely represents concrete in field conditions because it is performed on a prism that includes both coarse and fine aggregates. This has the potential to reduce the exposure time from 1 or 2 years down to 1 week making a concrete prism test a realistic measure to evaluate the ASR potential of specific aggregate and cement combinations.

The first two objectives can be met at UW by subjecting a suite of CPTs to rapid environmental exposure. Initial trials using different replacement levels will be conducted. Next, two different batches will be mixed using various proportions of RCA and natural aggregates to determine consistency or natural variation between designs. Results of independent castings will be compared and analyzed to determine the adequacy of current ASTM precision statements for this type of test with the rapid exposure. Finally, averages and standard deviations of the test program can be used to recommend adjusted precision statements for using recycled concrete aggregates RCAs in new concrete construction. Combinations of moderately- and severely-damaged RCA combined with locally sourced non-reactive aggregates are proposed.

In a previous study funded by Oregon Transportation Research and Education Consortium (OTREC), RCA was produced by crushing exposed field blocks [21] [22]. The resulting RCA was subjected to AMBT testing by four laboratories. Two RCAs produced expansions below the limit (Bernier and Potsdam) and another two had expansions above the limit (Alberta and Springhill). In addition, test results for 50% RCA replacement with Alberta indicate that test results were outside the precision and bias limits defined by ASTM C1260 [23-25]. The set of data was further developed by a 2014 MPC grant to expand the number of sources and increase the participating laboratories to six [17]. This expanded data set, indicates a small modification to the within-laboratory precision statement was required. On the contrary, it also revealed that the existing interlaboratory precision statements apply to including RCA in the mortar bar test [17].

The third objective starts with completing a round robin study of ASR testing. Raw materials will be sent to each location and they will be mixed and placed in autoclaves using the recommended protocols and measurements. Priority will be given to laboratories with experience in testing and measuring ASR. Companion testing will be conducted to evaluate the standard CPT of concrete prisms using crushed RCA. This will provide additional data to determine natural variation in results. The following laboratories will be invited to participate: University of Alabama; University of New Brunswick; Penn State University; University of Texas at Austin; University of Wyoming; and Wyoming Department of Transportation.

Expected Outcomes:
This work is expected to produce reasonable replacement levels for RCA in new concrete construction. Once this has been identified, within laboratory variability of the study will be evaluated. Finally, results of a six-laboratory round robin study are expected to provide sufficient information to recommend precision statements for an ultra-rapid screening test to evaluate effects of RCA in aggregate cement combinations.

Relevance to Strategic Goals:

- State of Good Repair
- Environmental Sustainability

This project meets the strategic goal of reducing environmental impacts on infrastructure by using a waste material of RCA in new concrete construction. Currently, using RCA in transportation related fields is limited to base fill. Research has shown that using previously damaged concrete with ASR often yields innocuous concrete because the reaction has run its course.

The WYDOT funded portion of this project considers the effect of using locally sourced fly-ashes to mitigate ASR in natural aggregates. This permits the region to most effectively use local aggregates and fly ashes. Furthermore, more durable concrete roadways and bridge decks will improve infrastructure longevity.

Producing more durable concrete yields a more economically competitive transportation system in the Rocky Mountain Region. By promoting recycled concrete aggregates, we are reducing the environmental impacts associated with transportation infrastructure and reducing demand on our landfill space. Finally, extending the service life of our roads contributes to more cost effective and sustainable practices.

Educational Benefits:
A graduate student will conduct the CPT using both the autoclave and standard ovens. Materials developed during this study such as photos and a summary of results can be presented in the undergraduate civil engineering materials class and at research in progress sessions at the American Concrete Institute (ACI) meetings.

Tech Transfer:
Technology transfer can occur by training other laboratories on how to complete the Ultra-accelerated Concrete Prism Test. If this test becomes standardized, the technology will be transferred in a widespread fashion.

Materials developed during this study such as photos and a summary of results can be presented in the undergraduate civil engineering materials class and at research in progress sessions at the American Concrete Institute (ACI) meetings.

Work Plan:
1. Complete a suite of autoclave tests using various levels of RCA replacement.
2. Create companion specimens to be tested using ASTM C1293 for a reference point.
3. Complete multiple sets of concrete prism tests to evaluate within-laboratory precision.
4. Perform a series of autoclave prism tests at several laboratories.

Task 1 includes completing a suite of autoclave tests using various levels of RCA replacement. The research team will collect, crush and prepare RCA for use in this study. Next concrete will be cast and subjected to appropriate exposure conditions. During and after exposure measurements will afford researchers and opportunity to synthesize results and isolate the top performers. Results are expected 15 months after the project start date.

Results of Task 1 will be used create companion specimens to be tested using ASTM C1293 for a reference point. The team will use the best performers and prepare aggregates for companion ASTM C1293 specimens. Again concrete will be created and subjected to year-long exposure conditions. Measured expansions will be synthesized and compares to results from Tasks 1 and 2. These results are expected 18 months after the start date.

Next the team will compare multiple sets of concrete prism tests to evaluate within-laboratory precision. As before materials will be collected, crushed and prepared RCA for use in this study. Concrete will be cured under appropriate exposure conditions. Finally natural variation in test results will be quantified and written up including illustrations to compare the two sets of data. Results are expected eight months after starting.

Finally a group of autoclave prism tests at several laboratories. Materials will be shipped to five other schools. Each laboratory will perform autoclave testing for University of Wyoming. The collected data will be analyze results and written up to share repeatability of the test method. All results will be contained in a final report. This completion date is 24 months after the starting date.

Table 1. Project schedule

Phase	Task / Month	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
i	a	■	■	■																					
	b-c				■	■	■																		
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ii	a-c							■	■	■															
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	e																				■	■			
iii	a-d										■	■	■	■	■	■	■	■							
iv	a-b													■	■	■	■								
	c															■	■	■	■	■					
	d																			■	■	■	■	■	■

Project Cost:

Total Project Costs: $182,715
MPC Funds Requested: $52,834
Matching Funds: $129,881
Source of Matching Funds: Wyoming Department of Transportation

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