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Nebraska's Aggregates Reactivity Evaluation-Phase I-II

Nebraska Department of Roads

Research Project Title:

Nebraska Aggregates Reactivity Evaluation

Research Project Number: R-2009-01

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Principle Investigators:

Wally Heyen
PCC Engineer

Lieska Halsey
NDOR Research

Chemistry Laboratory:

Jasmine Dondlinger
Highway Chemical Tests Manager

PCC Laboratory:

Tim Krason
Highway Quality Assurance Manager
Tom Gernert
Highway Mat. & Test Technician III

Terry Master
Highway Mat. & Test Technician III

Jeremy Weigel
Highway Mat. & Test Technician II

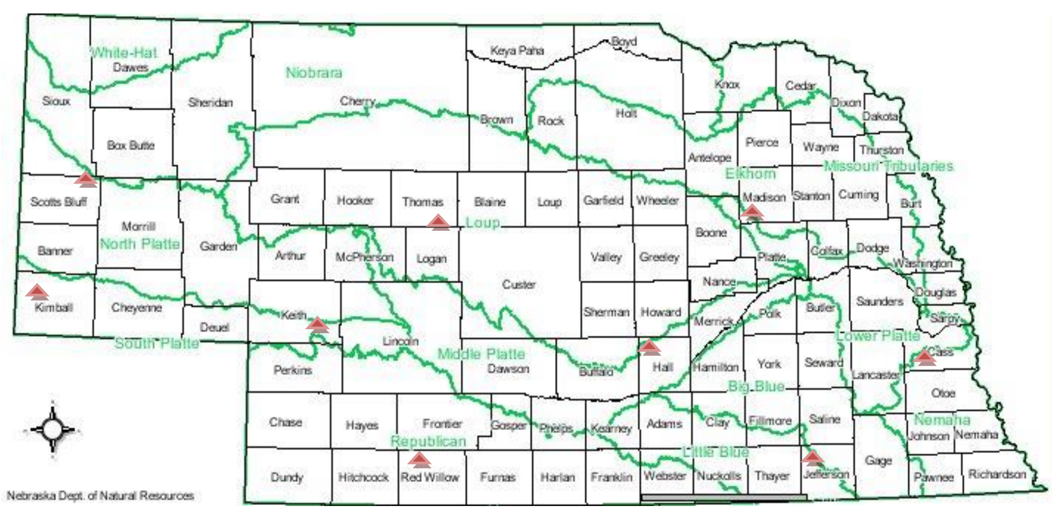
Debra Swanson
Highway Mat. & Test Technician II

Purpose of the Research Project:

The Nebraska Department of Roads started this investigation due to the long history of Alkali Silica Reaction (ASR) in Nebraska. ASR is a reaction between the cement pore fluids in concrete with certain types of silica, which may be found within the concrete aggregate. Due to this reaction a gel is formed which can expand and lead to widespread cracking and failure of the concrete.

The purpose of this investigation is to study the nature of Nebraska's aggregates' reactivity from various locations across the state. The evaluation is based on the standard test methods for Potential Alkali Reactivity of Aggregates-ASTM C 1260 and ASTM 1567. The ASTM 1260 determines and characterizes the reactivity of the aggregates within 28 days according to NDOR specifications and ASTM 1567 determines the mitigation of ASR with the use of supplemental cementitious materials (SCM). Also, this evaluation consists of measuring the length change of concrete due to ASR according to ASTM C 1293. This test takes 12 months when performed with ordinary portland cement (OPC) and 24 months when using supplemental cementitious materials (SCM).

Upon the completion of this investigation, Nebraska Department of Roads will have an overall understanding of the level of aggregate reactivity within Nebraska's regions as shown in Figure 1. The results of this study will be used to evaluate NDOR's current specifications for ASR testing and future potential changes to SCM levels.



Represent Aggregate pit locations being tested

Figure 1.

Objectives of Research Project:

* Create a database and categorize the reactivity of Nebraska's principal quarried aggregate sources.
* Compare the results obtained from the ASTM C 1293 and ASTM C 1567 with known Blended Cements used in Portland Cement Concrete Pavement.
* Correlate the ASTM C 1293 and ASTM C 1567 for future specifications.

Laboratory Investigation General Approach:

The laboratory investigation consists of two phases, as follows:

- Phase I: Evaluated 9 different aggregates according to ASTM C 1293 and ASTM C 1260 testing methods
- Phase II: Evaluated the aggregates tested in Phase I according to ASTM C 1567 and ASTM 1293 testing method using Supplemental Cementitious Materials SCM's percentage currently used in Nebraska.

Phase I - Materials and Experimental Laboratory Testing:

The materials used in this investigation were 9 different aggregates and one cementitious material having the same chemical composition. All testing followed the ASTM C 1260 and ASTM C 1293. After one year stored period to completed the ASTM C 1293 , the changes in length were measured for each individual aggregates. The results of length change for the ASTM C 1260 and the ASTM C 1293 are shown on Table 1.

Table 1.- Phase I Evaluation according by ASTM C 1260 and ASTM C 1293

	Type of Aggregate	Aggregate - Location	Cementitious Material	ASTM C 1260 Results 28 days Duration (%)	ASTM C 1293 Results 1 Year Duration (%)
PHASE I	Platte River	Grand Island	Type I/II	0.39	0.09
	Dry Pit	Kimball	Type I/II	0.32	0.21
	Republican River	Indianola	Type I/II	0.48	0.45
	North Platte River	Scottsbluff	Type I/II	0.46	0.15
	South Platte River	Ogallala	Type I/II	0.25	0.06
	Middle Loup River	Thedford	Type I/II	0.39	0.19
	Little Blue River	Fairbury	Type I/II	0.48	0.10
	Elkhorn River	Norfolk	Type I/II	0.57	0.30
	Platte River	Linoma-Omaha	Type I/II	0.46	0.15

The analyses of the results were based on AASHTO PP 65-10- 2010's special provision guide titled "Determining the Reactivity of Concrete Aggregate and Selecting Appropriate Measures for Preventing Deleterious Expansion in New Construction". The aggregate degree of aggregate reactivity evaluation was guided as shown in Table 2 with the identification of the reactivity classification according to AASTHO Protocol; followed by determining the level of ASR risk as shown Figure2; as well as the classification of the type of the structure shown on Figure3; followed Figure 4 and Figure 6, which covers the minimum replacement level of SCM for various level of prevention. Table 3 list the summary of results and evaluation according to Aggregate Reactivity.

Table 2.- Degree of Aggregate React ivy According to Protocol AASTHO PP-65

Aggregate-Reactivity Class	Description of Agg. Reactivity	1 Year Expansion in CPT (%)	14-Day Expansion in AMPT (%)
R0	Non-reactive	<0.04	≤0.10
R1	Moderate Reactive	0.040 - 0.120	>0.10 , ≤0.30
R2	Highly reactive	0.120 - 0.240	>0.30 -≤0.45
R3	Very highly Reactive	> 0.240	> 0.45

Figure2.- Determining the Level of ASR Risk

Table 2. Determining the Level of ASR Risk

Size and exposure conditions	Aggregate-Reactivity Class			
	R0	R1	R2	R3
Non-massive† concrete in a dry‡ environment	Level 1	Level 1	Level 2	Level 3
Massive† elements in a dry†† environment	Level 1	Level 2	Level 3	Level 4
All concrete exposed to humid air, buried or immersed	Level 1	Level 3	Level 4	Level 5
All concrete exposed to alkalis in service†††	Level 1	Level 4	Level 5	Level 6

†A massive element has a least dimension > 3 ft (0.9 m)

††A dry environment corresponds to an average ambient relative humidity lower than 60%, normally only found in buildings

†††Examples of structures exposed to alkalis in service include marine structures exposed to seawater and highway structures exposed to deicing salts (e.g. NaCl) or anti-icing salts (e.g. potassium acetate, sodium formate, etc.)

Figure 3.- Structure Classification

Table 4. Structures Classified on the Basis of the Severity of the Consequences Should ASR† Occur (Modified for Highway Structures from RILEM TC 191-ARP)

Class	Consequences of ASR	Acceptability of ASR	Examples††
S1	Safety, economic or environmental consequences small or negligible	Some deterioration from ASR may be tolerated	▪ Non-load-bearing elements inside buildings ▪ Temporary structures (e.g. < 5 years)
S2	Some safety, economic or environmental consequences if major deterioration	Moderate risk of ASR is acceptable	▪ Sidewalks, curbs and gutters ▪ Service-life < 40 years
S3	Significant safety, economic or environmental consequences if minor damage	Minor risk of ASR acceptable	▪ Pavements ▪ Culverts ▪ Highway barriers ▪ Rural, low-volume bridges ▪ Large numbers of precast elements where economic costs of replacement are severe ▪ Service life normally 40 to 75 years
S4	Serious safety, economic or environmental consequences if minor damage	ASR cannot be tolerated	▪ Major bridges ▪ Tunnels ▪ Critical elements that are very difficult to inspect or repair ▪ Service life normally > 75 years

†Note: this table does not consider the consequences of damage due to ACR. This protocol does not permit the use of alkali-carbonate aggregates

††The types of structures listed under each Class are meant to serve as examples. Some owners may decide to use their own classification system. For example, sidewalks and culverts may be placed in the S3 Class is some jurisdictions.

Figure 4.- Determining the level of Prevention

Table 3. Determining the Level of Prevention

Level of ASR Risk (Table 4)	Classification of Structure (Table 4)			
	S1	S2	S3	S4
Risk Level 1	V	V	V	V
Risk Level 2	V	V	W	X
Risk Level 3	V	W	X	Y
Risk Level 4	W	X	Y	Z
Risk Level 5	X	Y	Z	ZZ
Risk Level 6	Y	Z	ZZ	††

††It is not permitted to construct a Class S4 structure (see Table 4) when the risk of ASR is Level 6. Measures must be taken to reduce the level of risk in these circumstances.

Figure 5.- Level of Prevention

Table 6. Minimum Levels of SCM to Provide Various Levels of Prevention

Type of SCM	Alkali level of SCM (% Na_2Oe)	Minimum Replacement Level†† (% by mass)				
		Level W	Level X	Level Y	Level Z	Level ZZ
Fly ash ($CaO \leq 18\%$)	< 3.0	15	20	25	35	Table 7
	3.0 – 4.5	20	25	30	40	
Slag	< 1.0	25	35	50	65	
Silica Fume† ($SiO_2 > 85\%$)	< 1.0	1.2 x LBA or 2.0 x KGA	1.5 x LBA or 2.5 x KGA	1.8 x LBA or 3.0 x KGA	2.4 x LBA or 4.0 x KGA	

†The minimum level of silica fume (as a percentage of cementing material) is calculated on the basis of the alkali (Na_2Oe) content of the concrete contributed by the portland cement and expressed in either units of lb/yd^3 (LBA in Table 6) or kg/m^3 (KGA in Table 6). LBA is calculated by multiplying the cement content of the concrete in lb/yd^3 by the alkali content of the cement divided by 100. For example, for a concrete containing 500 lb/yd^3 of cement with an alkali content of 0.81% Na_2Oe the value of LBA = 500 x 0.81/100 = 4.05 lb/yd^3. For this concrete, the minimum replacement level of silica fume for Level Y is 1.8 x 4.05 = 8.1%. KGA is calculated by multiplying the cement content of the concrete in kg/m^3 by the alkali content of the cement divided by 100. For example, for a concrete containing 300 kg/m^3 of cement with an alkali content of 0.91% Na_2Oe the value of KGA = 300 x 0.91/100 = 2.73 kg/m^3. For this concrete, the minimum replacement level of silica fume for Level X is 2.5 x 2.73 = 6.8%. Regardless of the calculated value, the minimum level of silica fume shall not be less than 7% when it is the only method of prevention.

†† Note: the use of high levels of SCM in concrete may increase the risk of problems due to deicer salt scaling if the concrete is not properly proportioned, finished and cured.

Table 3 represent the classification according to the AASTHO PP-65 specification, the color code representation follows Table 2 according to the level of reactivity:

Table 3.- Summary of Results and Evaluation According to Aggregate Reactivity

			(Table 1-AASTHO PP-65)	(Table 2-AASTHO PP-65)	(Table 3-AASTHO PP-65)	(Table 6-AASTHO PP-65)
Type of Aggregate	ASTM C 1293 Results (%)	Description of Agg. Reactivity	Aggregate Reactivity Class	Determining the Level of ASR Risk	Determining Level of Prevention	Min. Replacement Level of SCM to Provide Various Levels of Prevention
Platte River	0.09	Moderate Reactive	R1	Level 3	X	20
Dry Pit Coarse Agg.	0.21	Highly reactive	R2	Level 4	Y	25
Republican River/ Indianola	0.45	Very Highly Reactive	R3	Level 5	Z	35
North Platte River	0.15	Highly Reactive	R2	Level 3	Y	25
South Platte River	0.06	Moderate Reactive	R1	Level 3	X	20
Middle Loup River	0.19	Highly Reactive	R2	Level 4	Y	25
Little Blue River	0.10	Moderate Reactive	R1	Level 3	X	20
Elkhorn River	0.30	Very Highly Reactive	R3	Level 5	Z	35
Platte River Omaha	0.15	Highly Reactive	R2	Level 4	Y	25

Discussion:

The continuation of this evaluation will be cover on Phase II using the same aggregates tested in Phase I. This evaluation will be according to method ASTM C 1567 and ASTM 1293 in order to evaluate these two methods.

Phase II - Materials and Experimental Laboratory Testing:

The materials used in this investigation were 9 different aggregates plus one additional aggregate from the Linoma region (eastern part of the state); the cementitious material and fly ash used have the same chemical composition. All testing followed the ASTM C 1260 and ASTM C 1293. Two years stored period in order to completed the ASTM C 1293 , the changes in length will be measured for each individual aggregates. The Results to date with the ASTM C 1567 and ASTM C 1293 using SCM's percentage currently used in Nebraska are shown in Table 4. The current evaluation has proven NDOR's Standard Specification mitigates all currently used aggregate across the state, as summarized in Table 4. In addition, a database will be created that fully categorizes the reactivity of Nebraska's principal aggregate sources. Also, this study will review past performance of NDOR projects built with SCM's.

Table 4. Phase II Evaluation according by ASTM C 1567 and ASTM C 1293

	Type of Aggregate	**Aggregate - Location**	**Cementitious Material**	**ASTM C 1567 Results 28 Days Period (%)**	**ASTM C 1293 Results 2 Year Period (%)**
PHASE II	Platte River	Grand Island	Type IPF (25%)	0.04 @ 28 Days	0.02
	Dry Pit Coarse Agg.	Kimball	Type IPF (25%)	0.07 @ 28 days	0.01
	Republican River	Indianola	Type IPF (25%)	0.09 @ 28 Days	0.01
	North Platte River	Scottsbluff	Type IPF (25%)	0.04 @ 28 Days	0.02
	South Platte River	Ogallala	Type IPF (25%)	0.04 @ 28 Days	0.01
	Middle Loup River	Thedford	Type IPF (25%)	0.05 @ 28 Days	0.01
	Little Blue River	Fairbury	Type IPF (25%)	0.04 @ 28 Days	0.01
	Elkhorn River	Norfolk	Type IPF (25%)	0.04 @ 28 Days	0.01
	Linoma	Omaha	Type IPF (25%)	0.05 @ 28 Days	0.03

This investigation took a look at NDOR project field performance with reactive aggregates from the category of moderate reactive to very highly reactive aggregate, as summarized in Table 5. Field performance analysis was based on the AASHTO PP 65-10 (2010) special provision guide.

Table 5. Field performance analysis was based on the AASHTO PP 65-10 (2010) special provision guide

Route Built	Project Number	Cement Type Used	Source of Aggregate	ASTM C 1293 Results 1 Years (%)	Min. Replacement Level of SCM to Provide Levels of Prevention	Reduce the min. amount of SCM one prevention Level due to low alkali Cement-Table 8 - Protocol A	Performance 2011
Chester Hebron 1994	F-81-1(1017)	Type I Added 17% Class F	Grand Island	0.10 Moderate Reactive	20%	15%	
Ansley 2001	S-2-3 (1019)	Type I Added 17 % Class F	Thedford	0.19 Highly Reactive	25%	20%	
Norfolk East 1995	275-5-(1013)	IPF Interground 22% Class F	Norfolk	0.30 Very Highly Reactive	35%	25%	
Norfolk East 2005	F-275-6 (1020)	Led with 98 Spec Type 17% IPN+9% C	Norfolk	0.30 Very Highly Reactive	35%	25%	

Performance review provided a good correlation with the special provision guidance of AASHTO PP65-10 (2010). In fact, the protocol correlates well when reviewing the field performance (Figure 6 and 7) of Ansley built in 2001 using highly reactive aggregate with not enough SCM to mitigate the reaction.

Figure 6 - Field Performance
(Highly Reactive Aggregate)
Ansley built 2001

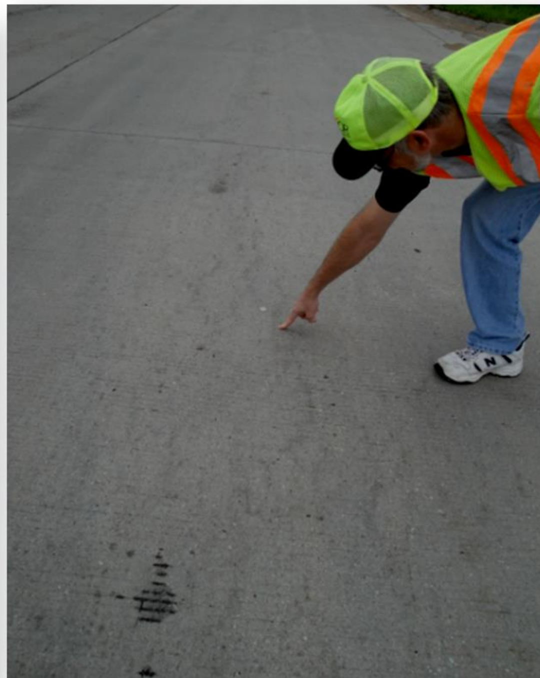


Figure 7 - Field Performance
(Highly Reactive Aggregate)
Ansley built 2001

Comparing the results with NDOR's current specifications for minimum replacement levels when using SCM, it was found the Elkhorn River a Very Highly Reactive aggregate, which required up to 35 percent SCM replacement, could perform well with replacement up to 25 percent SCM as per AASTHO PP 65-10 states when using a low alkali cement. Figure 8 shows Norfolk East project built with 22 percent interground IP with Class F fly ash field performance.

Figure 8 - Field Performance (Very Highly Reactive Aggregate)
Norfolk East built 1995

The same correlation was found when evaluating the field performance (Figure 9) of Norfolk East built in 2004 using very highly reactive aggregate with not enough prevention measure to mitigate the reaction.

Figure 9 - Field Performance (Very Highly Reactive Aggregate)
Norfolk East built 2004

The analysis of Phase II was guided by the composition of the ashes being used in the evaluation and the classification of aggregate reactivity as per Protocol A.