

Pennsylvania's Experiences and Challenges Implementing Comprehensive ASR Specifications 1990-2023

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Abstract

In 2015 the Pennsylvania Department of Transportation and the Pennsylvania Aggregates and Concrete Association implemented a unique concrete aggregate testing and evaluation protocol to mitigate the risk of deleterious alkali-silica reaction (ASR). The novel/cutting-edge approach, at that time, utilized widespread ASTM C1293 Concrete Prism tests to evaluate aggregate reactivity. The reactivity testing was required to be repeated once every five years. Based on the aggregate reactivity levels, prescriptive amounts of supplementary cementitious materials (SCMs) are utilized to mitigate the reaction, where increased reactivity levels require increased amounts of SCMs. The implementation of this specification brought about some beneficial results, along with some known and a few unanticipated challenges. With the implementation of the new specifications and the increase in SCMs, the northeast portion of the state saw a dramatic increase in scaling of flatwork. This presentation will review the reasons for adopting these specifications, the benefits realized, challenges faced during implementation, and current challenges.

Keywords: alkali-silica reaction, supplemental cementitious materials, aggregate reactivity, ASR test methods, ASR mitigation

Introduction

Alkali-silica reaction (ASR) is a potentially deleterious reaction that may occur in concrete. Three conditions must be present for ASR to form: the aggregate must contain reactive forms of silica, along with a sufficient amount of alkalis, and abundant moisture. Just because an aggregate contains ASR reactive phases, and most do, it does not mean that deleterious ASR gels will form in the concrete.

This paper will provide details of the history of Pennsylvania's ASR specification development and revisions, beginning in the early 1990's and until the present day. Results from the widespread testing of Pennsylvania's aggregates with the currently approved test standards are presented along with issues of the repeatability of these test methods. Challenges with durability and constructability due to high levels of mitigation are discussed, along with an outline of plans to address the current limitations that have been encountered.

Geology of Pennsylvania

The Commonwealth of Pennsylvania is fortunate to have been granted a valuable and varied geology. This includes bedrock formations from the oldest geologic eras, Pre-Cambrian, to sand and gravel deposits from the most recent Quaternary era.

The oldest formations are found at the extreme southeast corner of Pennsylvania. The geology trends younger as you move towards the north and West. Sedimentary rocks compose the overwhelming majority of Pennsylvania's bedrock formations. There are igneous and metamorphic formations in the southeast portion of the state. Recent glacial deposits of sand and gravel occur primarily in the northern portion of the Commonwealth. [1]

The varied geology of Pennsylvania has provided great economic benefit not only to the Commonwealth but to The United States and beyond. These resources have provided benefits prior to colonization and continuing through today. These include the abundant anthracite coal resources in northeast Pennsylvania and the

bituminous coal fields of central and western Pennsylvania. The first production of Portland cement in the United States occurred in eastern Pennsylvania followed closely by production in western Pennsylvania. Significant cement production continues today. The first commercial oil well in North America was drilled in northwestern Pennsylvania. The proximity of coal and iron ore fostered iron and then steel production primarily in Pittsburgh and Bethlehem as well as other locations across the state. Today Pennsylvania is one of the leading states in the production of natural gas.

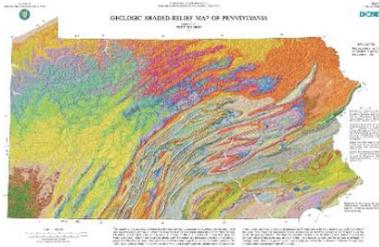


Fig. 1 Geologic Map of Pennsylvania

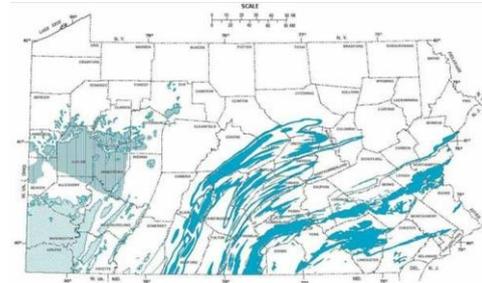


Fig. 2 Carbonate Formations of Pennsylvania

Pennsylvania Construction Aggregates

Construction aggregates are produced from many types of formations across Pennsylvania. However, most construction aggregates produced come from carbonate formations. Figure 2 shows the location of carbonate formations in Pennsylvania. The Limestone formations of central and eastern Pennsylvania tend to be higher in calcium than the Loyalhannah and Vanport limestone formations of western Pennsylvania which tend to be more siliceous. There are portions of the Vanport formation that are high in Calcium and have been and are currently being used to produce Portland cement.

Pennsylvania generally ranks among the leading states in the annual production of crushed stone. [2]

Table 1 Production of Pennsylvania Crushed Stone 2018 - 2022

	2018	2019	2020	2021	2022
Production (Tons)	116,035,315	122,770,951	111,145,775	121,406,578	103,644,960

A History of ASR Occurrences and Specifications

1990 - 2010 ASR Occurrences and Specifications

Beginning in the late 1980's an interstate pavement located in Northeast Pennsylvania began to show centerline deterioration and excessive cracking. Investigation began in 1990 with cores being taken. Petrographic examination revealed the presence of ASR in this twelve-year-old pavement. The predominant coarse aggregate available in this region is sandstone. This was the first noted occurrence of deleterious ASR in a Pennsylvania Department of Transportation (PennDOT) owned asset. Petrographic analysis from three other pavements also revealed the presence of ASR.

PennDOT joined the Mid-Atlantic task force on ASR and in 1991 began testing aggregates using the accelerated mortar bar test (AMBT) according to ASTM C1260/AASHTO T 303. The test results showed:

464 aggregates tested - 75% had expansion results over 0.10%

To reduce the occurrence of ASR limiting the alkali content in the cement was one of the first options studied by PennDOT. Originally, the alkali content maximum was 0.85 Na₂O_{eq} with an alkali content of 0.60 considered to be low alkali requiring no mitigation. Subsequently, the Northeast Cement Shippers Association drafted a letter recommending a higher maximum as it was too restrictive and would cause a hardship for concrete producers who lacked sufficient silo capacity to store more than three cementitious materials. Many aggregate

and concrete producers indicated that there was no historical data to show that their aggregates had caused any Alkali Silica Reactivity and felt that the historical data should have greater influence in determining reactive aggregate sources.

In 1992, a Special Provision was implemented modifying the specifications for concrete when aggregate having the potential for alkali silica reactivity is utilized. Concrete producers had the option of utilizing a low alkali cement to mitigate ASR or using a supplementary cementitious material, such as fly ash, ground granulated blast furnace slag, or silica fume. The specifications requirements were:[3]

If one or more reactive aggregates have T303 expansion >0.10%, mitigate expansion as follows:

- Pozzolans as cement replacement (by mass)
 - Fly Ash (Class F)
 - 15-25%
 - (20% min. if expansion is greater than 0.40%)
 - Ground granulated blast furnace slag (in Slag Cement)
 - 25-50%
 - (40% min. if expansion is greater than 0.40%)

The overwhelming majority of aggregate sources had T303 expansions between 0.10% and 0.20%. A few sources, located primarily in the northeast and north central PA, had expansions greater than 0.20%. This required mitigation at the higher levels, 20% fly ash or 40% ground granulated blast furnace slag (in slag cement). These sources were primarily sandstones and gravels. Many PennDOT Districts allowed a simple “paper” change to mix designs to the low alkali cement for concrete being supplied for state projects. Other producers chose to redesign their mixtures using the supplementary cementitious materials (SCMs) at the levels prescribed above.

By the early 2000’s many Pennsylvania cement producers were no longer able to efficiently produce cement with an alkali content below 0.60 Na₂O_{eq} due to changes in environmental regulations. Mitigation at the above noted levels became the common practice. During this time a significant portion of Pennsylvania’s electricity generation was fueled by coal. This provided Pennsylvania concrete producers with reliable sources of high-quality fly ash. Also, during this time, several sources of slag cement entered the Pennsylvania marketplace. This offered concrete producers another option that could be used for mitigation. Both materials were in abundant supply.

By 2007, particulate matter emissions were fully phased in to comply with the Clean Air Act Amendments of 1990 [4], leaving the electric utilities with several options:

- Switch to low sulfur coal
- Add equipment such as scrubbers to remove sulfur dioxide emissions
- Purchase permits from other utilities that exceeded the reductions required to comply
- Employ other means of reducing emissions to levels below the cap, such as operating high sulfur units at lower capacity

As was commonly referred to as a “low Nox conversion”, many power plants added equipment such as scrubbers to remove sulfur dioxide emissions, which affected the quality of the fly ash produced for concrete and diminished the supply for ready mixed concrete.

2010 – 2016 ASR Occurrence, Testing and Specification Revisions

In 2010 a concrete pavement in southeast Pennsylvania exhibited deterioration associated with ASR after 10 to 12 years of service. The aggregate used in this pavement had been tested using AASHTO T 303/ASTM C1260 and had been identified as moderately or non-reactive. These were a Gneiss coarse aggregate and a natural quartz sand fine aggregate. Additional pavements, located primarily in southeast and south-central Pennsylvania, were examined and showed the presence of ASR.

An ASR Pro-Team was created in September 2013, represented by industry associations, PennDOT and Pennsylvania Turnpike officials, and the FHWA. Dr. Michael Thomas from the University of New Brunswick participated in the inaugural meeting. Recognized nationally as a leader in the field of ASR research, his insights and contributions were invaluable. In trying to develop a “stop gap measure”, consideration of the following was evaluated and discussed:

- Continuing with the current aggregate testing and ASR measures
- Require measures for all aggregate
- Inability to identify aggregates solely via petrographic examination
- Impacts to industry (SCM availability)

After much consideration, the decision to was made to mitigate all concrete mixtures, classifying all aggregate as reactive until the latest research and mitigation strategies could be implemented. A survey was conducted of industry and suppliers of fly ash and slag, and all felt that there was sufficient supply of SCMs for mitigation of all mixes for the interim.

As a result of the ASR Pro-Team discussions, a clearance transmittal with a new specification was instituted. Retesting of aggregate in accordance with the concrete prism test (CPT) in accordance with ASTM C1293 and implementation of a modified version of the ASR guidelines AASHTO PP-65 (currently AASHTO R-80) began. To expediate testing of the aggregate, four independent laboratories were vetted to participate in the initial evaluation of Pennsylvania’s aggregates. Aggregate sources with AASHTO T 303/ASTM C1260 expansion less than or equal to 0.15% were chosen for the initial testing.

Shortage of Supplementary Cementitious Materials

During this same time, the U.S. Energy Information Administration had reported that about 30% of U.S. coal-fired generation capacity had been retired since 2010 with a 2028 goal for all coal-fired units to be shuttered. These closures created a supply issue for the fly ash industry and the realization that alternative pozzolans needed to be evaluated. With little to no supply of low alkali cement, and the shortage of viable fly ash, concrete producers had little choice but to begin utilizing slag as the primary SCM for mitigation purposes.

Discussion of Test Results

The results from these large number of tests, conducted by the two most widely used ASR laboratory test methods, present two highly contrasting pictures of the potential reactivity of Pennsylvania's aggregates. Existing research has documented the tendency for ASTM C1260/AASHTO T 303 results to overestimate the potential reactivity of aggregates [5]. The pavement project in southeast Pennsylvania that failed at an early age may be an occurrence where aggregates that pass the ASTM C1260/AASHTO T 303 test are reactive under field conditions. This has been noted in prior research [5].

The results of these numerous tests on Pennsylvania’s aggregate sources point to an additional contradiction reported by many Pennsylvania aggregate producers. Many Pennsylvania aggregate producers have sources that have been in production for decades, and yet they have never encountered an instance where deleterious ASR in concrete containing their aggregates has been reported.

1992 ASTM C1260	
(AASHTO 303)	
464 Aggregates Tested	
< 0.10%	25% Non-Reactive
> 0.10%	75% Reactive

F. 4 1992 Aggregate Test Results

2017 ASTM C1293		
Reactivity Level	Number of Aggregates	
R0 (≤ 0.04)	240	} 64% Non-Reactive 36% Reactive
R1 ($> 0.04 - \leq 0.12$)	99	
R2 ($> 0.12 - \leq 0.24$)	33	
R3 (> 0.24)	2	

Fig. 5 2017 ASTM C1293 Results

2017 to 2023 Durability & Constructability Concerns, Specification Revisions and Concrete Finisher Education

In the spring of 2017, just prior to the implementation of the revised specifications based upon the prescriptive requirements of AASHTO R80 (ASTM C1778), serious scaling occurred on multiple PennDOT projects in northeast Pennsylvania. These projects displayed distresses as noted in Figure 6 after their first winter in service. The common thread on these projects was that they were all done in accordance with the current PennDOT specifications, and that they all were supplied from one concrete producer. There was much public outcry over the condition of this concrete. This resulted in significant negative publicity from the local news media as well as involvement from the Pennsylvania legislature. Cores were taken and petrographic analysis conducted. Petrographic analysis showed a higher water/cementitious ratio in the upper portion of the concrete as well as significant depths of carbonation.

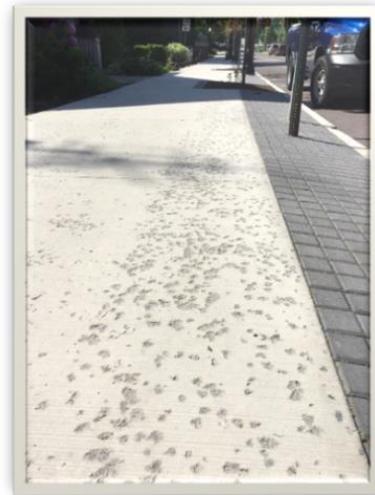


Fig. 6 2017 Scaling in Northeast Pennsylvania

Meetings were conducted with the contractors, the local PennDOT representatives, and the producers to attempt to resolve the questions prompted by this widespread scaling. During these meetings it was revealed that a program was developed in Delaware and Maryland, in conjunction with the National Ready Mixed Concrete Association (NRMCA), to provide education to the finishers. Its goal was to help provide education on the best practices for finishing exterior concrete, in particular the details when dealing with concrete mixtures containing significant levels of SCMs. Through a cooperative effort of PennDOT and Pennsylvania Aggregates and Concrete Association (PACA), specifications were enacted that require finishers to be certified by one of two nationally recognized programs, the American Concrete Institute (ACI) Flatwork Finisher program or the National Ready Mixed Concrete Association (NRMCA) Exterior Flatwork Finisher Certification program. This specification revision, which became final in 2022, requires that 60% of the finishers on all PennDOT placements to be certified by one of these programs (Fig. 7). Beginning in 2018 and to date, over 1600 Pennsylvania finishers have been certified according to this requirement. A separate training module was developed for PennDOT construction inspection personnel and provided during winter training programs across the state.

The material and construction specifications for sidewalk construction were also revised. A new designation for concrete to be used on sidewalks was developed, Class S concrete (Table 48). Its requirements include a 28-day compressive strength of 4000 psi, and a maximum water/cementitious ratio of 0.45. The specification also requires that the SCM contents for this mix should not exceed those required to provide ASR mitigation (prescriptive requirements of AASHTO R80, ASTM C1778). Curing specifications were revised and the use of penetrating sealers was mandated for sidewalk construction.

2.b. Concrete Finisher Certification. Provide ACI certified Flatwork Finishers, ACI certified Advanced Flatwork Finishers, or National Ready-Mix Concrete Association (NRMCA) certified Exterior Flatwork Finishers to control finishing of each concrete placement operation for all concrete finishing work associated with the following Sections:

501	502	505	506	516	518
519	520	523	525	527	530
540	545	548	623	630	633
640	641	658	676	695	852
910	1001	1040	1042	1090	

A minimum of 60 percent of the finishers finishing concrete on each concrete placement must possess at least one of the identified flatwork finisher certification types, unless approved by the Representative. Provide proof of flatwork finisher certification to the Representative before concrete placement.

Fig. 7 Publication 408, Section 704 Cement Concrete, 704.2.b

**Table A
Cement Concrete Criteria**

Class of Concrete	Use	Cement Factor ⁽²⁾⁽⁴⁾⁽¹⁰⁾ (lbs./cu. yd.)		Water Cement Ratio ⁽⁵⁾ (lbs./lbs.)		Minimum Mix ^(1,7) Design Compressive Strength (psi)				28-Day Structural Design Compressive Strength (psi)
		Min.	Max.	Min.	Max.	Days				
						3	7	28 ⁽⁸⁾	56 ⁽⁸⁾	
AAAP	Bridge Deck	560	640		0.45	—	3,000	4,000	—	4,000
AAA ⁽³⁾	Other	634	752		0.43	—	3,600	4,500	—	4,000
AAAP LW	Bridge Deck	600	730		0.45	---	3,000	4,000	---	4,000
AA	Slip Form Paving	517	611	0.37	0.42	—	3,000	4,000	—	3,500
AA	Form Paving	517	611	0.37	0.45	—	3,000	4,000	—	3,500
AA	Accelerated Paving ⁽⁶⁾	517	800		0.47	—	—	3,750	—	3,500
HES	Paving	517	800	0.37	0.42	2,000	---	4,000	---	3,500
S	Sidewalk	517	611	0.37	0.45	---	3,000	4,000	---	3,500
AA	Structures and Misc.	587	752		0.47	---	3,000	3,750	---	3,500
AA LW		587	752		0.47	---	3,000	3,750	---	3,000
ASC ⁽⁹⁾		587	846		0.47	---	---	4,000	---	4,000
A		564	752		0.50	---	2,750	3,300	---	3,000
C		394	658		0.66	---	1,500	2,000	---	2,000
HES		752	846		0.40	3,000	---	3,750	---	3,500

Table 4 Publication 408, Section 704 Cement Concrete, Table A

2012 - 2022 Retesting of Aggregates

In 2021, aggregate samples were obtained to begin the first round of scheduled retesting. These tests were all conducted by PennDOT Laboratory Testing Services (LTS). In May of 2022 results from these tests began to be distributed. A significant number of the retests showed substantial increases in potential reactivity values over and above those tested during 2013- 2016. Some of these results showed expansion levels that were two to four times higher than those previously tested. Correlation comparison of the initial 2013 - 2016 tests and 2022 results are shown in Figure 9.

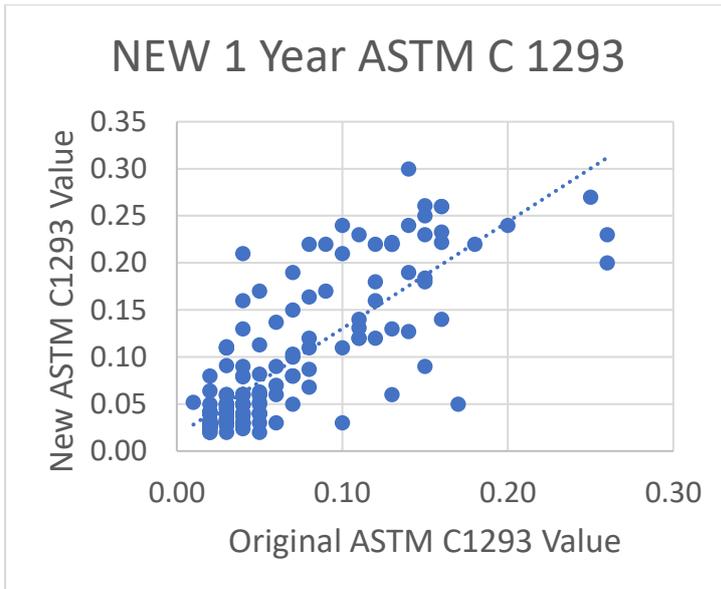


Fig. 9 Comparison of Initial Aggregate Test Results and the 2022 Test Results

Discussion of current challenges and furthering our understanding of the potential reactivity of our aggregate sources and concrete mixtures

The Concrete, Aggregate, and Cement Producers members of the Pennsylvania Aggregates and Concrete Association are committed to continue to work with the Pennsylvania Department of Transportation to further the understanding of the potential for deleterious ASR in our aggregates. To accomplish this the producers have committed to establishing and providing significant material support for a long-term exposure block study site. We have secured a one-acre site and have committed to maintaining this site for 25 years. We anticipate that this site will be operational in 2024.

This facility is in close proximity to Pennsylvania State University which will be one of the principal research institutions involved in this study. We have planned this site to be large enough to have abundant room to hold additional blocks from other researchers who may wish to conduct long-term block studies.

We are hopeful that long term exposure blocks will provide insights into the potential reactivity of the aggregates and concrete mixtures that are unable to be determined from the current laboratory tests. We believe this study may also provide validation and verification for test methods under development and provide an opportunity to establish the mitigation potential of alternative pozzolans that are and will be entering the marketplace.

Conclusions

The use of the ASTM C1260 test (AMBT), using 0.10% expansion as a limit, resulted in 75% of the 464 aggregates tested being classified as reactive. Testing of 374 sources using ASTM C1293 (CPT) classified only 36% of the sources to be reactive. This is a significant contradiction. Many of the sources classified as reactive have never reported a single occurrence of deleterious ASR, many with decades of production history. Some pavements containing concrete made with aggregates classified as non- reactive with the ASTM C1260 test suffered early age failure and distress from ASR.

The correlation of the ASTM C1293 (CPT) test results between the initial testing and the ongoing retesting of all active Pennsylvania sources has presented challenges and confusion.

Mitigation at high levels of SCMs, as required in AASHTO R80/ASTM C1778, has resulted in exterior flatwork with durability and constructability issues.

Education of concrete finishers is critical to providing durable exterior concrete, and vital when mixes containing high levels of SCMs are specified.

The joint effort of specifying agencies, researchers, and producers is needed to further the understanding of the potential for deleterious ASR, with a goal to yield specifications that will protect against the occurrence of deleterious ASR and reduce the durability and constructability issues associated with high levels of mitigation.

We are optimistic that the increased focus on determining the alkali threshold of aggregates may help solve the contradiction between the reactivity as determined by laboratory tests and the long-standing reliable field performance of many aggregate sources.

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