New York State Pollution Prevention Institute

Interim Report for:

KLAW Industries, LLC

Binghamton, NY

Performance Evaluation of Pantheon™ as a Replacement for Cement in Concrete

December 5, 2022

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This technical report is prepared consistent with the terms and purposes of the Research Agreement between KLAW Industries, LLC (the "Company") and Rochester Institute of Technology (RIT) on behalf of the New York State Pollution Prevention Institute (NYSP2I) that was effective April 4, 2021. This report is the product of work conducted by RIT for a project entitled, "Performance Evaluation of PantheonTM as a Replacement for Cement in Concrete," which was funded in part by a grant to RIT from by the Environmental Protection Fund as administered by the NYS Department of Environmental Conservation. All conclusions herein are subject to the research warranty and liability limitations, and other provisions, described in the Research Agreement executed by RIT and KLAW Industries, LLC.

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A. Executive Summary

The New York State Pollution Prevention Institute (NYSP2I) at Rochester Institute of Technology (RIT), in partnership with Clarkson University, conducted a project entitled, "Performance Evaluation of Pantheon™ as a Replacement for Cement in Concrete" for KLAW Industries, LLC (KLAW) to evaluate the performance of their new cement replacement material, Pantheon™, which utilizes waste glass material from recycling facilities, to ASTM standards. The results of this project will assist KLAW with accelerating commercialization of Pantheon™, expanding business in NY State.

Please reference Appendix A for the full interim project report as prepared by Clarkson University for NYSP2I and KLAW. The interim report reflects preliminary results considering tests performed between September 2021 and April 2022. Preliminary results from tests performed between September and December 2021, using three replicate specimens per test and a total of 36 specimens, suggest that partial cement replacement with 20-30% Pantheon™ effectively mitigates ASR in concrete with aggregates of varying reactivity, but additional long-term testing is needed to confirm these results. Preliminary results from tests performed between February and April 2022, using a single replicate per test and a total of nine specimens, also suggest that partial cement replacement with 20-30% Pantheon™ reduces the air content of fresh concrete, slightly reduces the workability of fresh concrete, and has no measurable influence on the setting time of concrete.

A final project report will be prepared at the conclusion of all test and analysis.

Appendix A

Performance Evaluation of Pantheon™ as a Replacement for Portland Cement in Concrete

Interim Report to:

New York State Pollution Prevention Institute
Rochester Institute of Technology
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Objective and Scope

The objective of this project was to evaluate the performance of Pantheon™ in a lab environment to ASTM test standards. To meet this objective, KLAW provided a prescribed amount of Pantheon™ to Clarkson for evaluation in Clarkson labs for the following performance parameters:

1. The potential for alkali-silica reaction (ASR) in Portland cement concrete made with Pantheon™ as a partial cement replacement.
2. The durability of Portland cement concrete made with Pantheon™ as a partial cement replacement in a freezing and thawing environment.
3. The effect of partial cement replacement with Pantheon™ on the setting time and workability of Portland cement concrete.

This interim report details the work completed between September 2021 and April 2022, which includes accelerated ASR testing and analysis of some fresh and hardened properties of concrete with 20-30% replacement of portland cement with Pantheon™.

Work Performed and Results

Alkali-Silica Reaction (ASR)

A series of tests were performed to evaluate the influence of Pantheon™ on the alkali-silica reactivity of concrete. Tests were performed with four aggregates of varying reactivity, and the performance of control samples (100% portland cement) was compared with that of samples where 20 or 30% of portland cement (by weight) was replaced with Pantheon™.

Materials used in this task include ASTM C150 Type I/II portland cement (PC), Pantheon™, nonreactive limestone coarse aggregate (AASHTO #67) and the four fine aggregates listed in Table 1. Fine aggregates included one nonreactive aggregate, two that were flagged by the supplier as moderately reactive, and a well-known highly reactive reference aggregate (Spratt limestone). These are listed in Table 1 by their reactivity class, the determination of which is discussed in Subtask 1.2.

Table 1. Fine aggregates used for ASR testing

Fine aggregate	Code	Source	Notes
Nonreactive	NR	Upstone Materials, Plattsburgh, NY (Malone Quarry)	Regraded per ASTM C1260
Slowly reactive	R0	New Enterprise Stone & Lime Co, Johnstown, PA (Vintondale Quarry)	
Moderately reactive	R1	New Enterprise Stone & Lime Co, Johnstown, PA (Roaring Spring Quarry)	
Highly reactive	R2	Ontario Ministry of Transportation (Spratt siliceous limestone)	Received as coarse aggregate, crushed and regraded per ASTM C1260

The compositions of PC and Pantheon™ were measured by X-ray fluorescence (XRF). Results are given in Table 2. The total alkali contents of PC and Pantheon™ were 0.89% and 13%, by mass.

Table 2. Composition of cementitious materials

Oxide	Composition (% by mass)	
	PC	Pantheon™
Na_2O	0.17	13
MgO	2.0	1.0
Al_2O_3	4.6	1.6
SiO_2	19	72
P_2O_5	0.15	*
SO_3	4.4	0.15
K_2O	1.1	0.52
CaO	63	11
TiO_2	0.19	*
Fe_2O_3	3.3	0.71
SrO	0.11	*
LOI**	2.5	0.6
Total alkalis	0.89	13

*not detected, **loss on ignition, ***$Na_2O+0.658K_2O$

Accelerated mortar bar tests (ASTM C1260 and ASTM C1567)

Mortar bar tests were performed in accordance with the specification of ASTM C1260 to determine the reactivity of the fine aggregates. Tests were performed between September and October 2021. Each test included three replicate specimens. Mortar bars were stored at 80 °C in a 1 N solution of sodium hydroxide and the linear expansion was measured over a period of 28 days. This test was performed using a standard reference mortar mixture with PC as the sole binder. Per ASTM C1778, reactivity of cement/aggregate combinations is classified based on the expansion after 14 days according to Table 3. Tests were run for an additional 14 days to test for latent expansion or slow reactivity.

Table 3. Classification of aggregate reactivity (ASTM C1778)

Reactivity Class	**Description**	**Expansion (%)**	
		ASTM C1293	**ASTM C1260**
R0	Nonreactive	<0.04	<0.10
R1	Moderately reactive	0.04–0.12	0.10–0.30
R2	Highly reactive	0.12–0.24	0.30–0.45
R3	Very highly reactive	≥0.24	≥0.45

Results are shown in Figure 1. The aggregate classifications previously listed in Table 1 were determined based on these results, following the classification scheme in Table 3. NR and R0 are both classified as nonreactive, but R0 exhibits latent expansion which suggests it is slowly reactive. This is not an explicit classification per ASTM C1778 but is useful to note because slowly reactive aggregates will test as nonreactive but may react later in the life of the concrete.

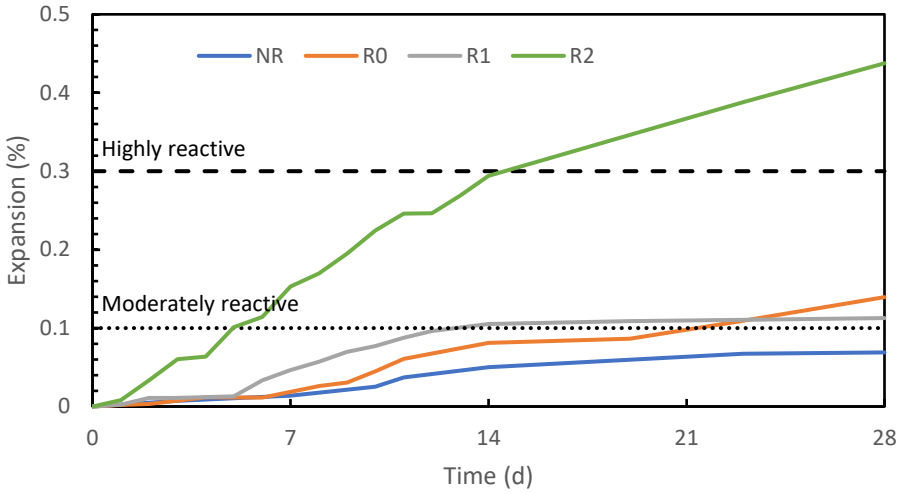

Figure 1. Mortar bar test results

Accelerated mortar bar tests were performed in accordance with the specifications of ASTM C1567. Test were performed in the same manner as the mortar bar tests, but with 20 and 30% replacement of PC with Pantheon™. Tests were performed between October and December 2021. Each test included three replicate specimens.

Results are shown in Figure 2–Figure 5. In all cases, specimens with Pantheon™ showed significantly less expansion than those without. In the case of slowly reactive aggregate (R0, Figure 3), Pantheon™ reduced the later age expansion to well below the threshold for moderate reactivity at both replacement levels. The same was observed for moderately reactive aggregate (R1, Figure 4). With highly reactive aggregate (R2, Figure 5), Pantheon™ reduced the expansion to below the 14-day limit for moderate reactivity at both replacement levels. Samples with 20% Pantheon™ exceeded the threshold for moderate reactivity at 28 days, but those with 30% Pantheon™ remained below the limit. In general, the reduction in expansion showed a direct relationship with the cement replacement level. Overall, these results suggest that Pantheon™ effectively mitigates ASR in concrete. Continued testing under the other protocols is necessary to confirm this result.

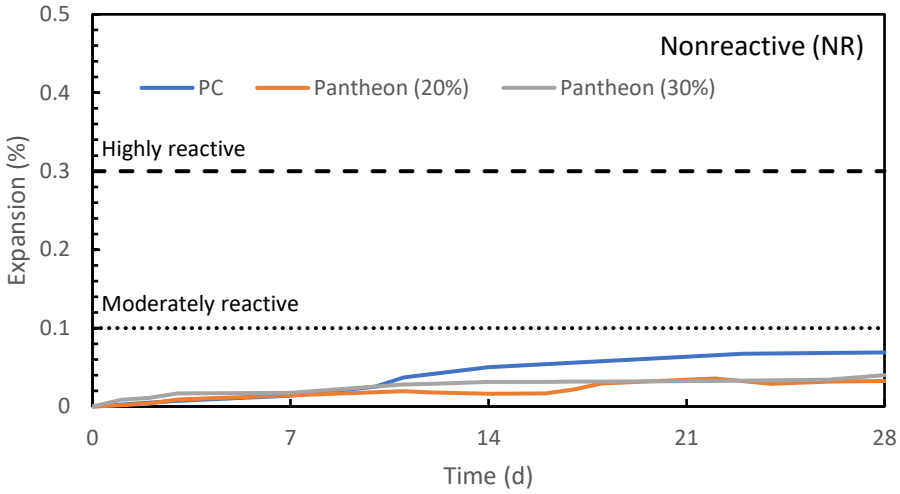

Figure 2. Accelerated mortar bar test results for nonreactive aggregate (NR)

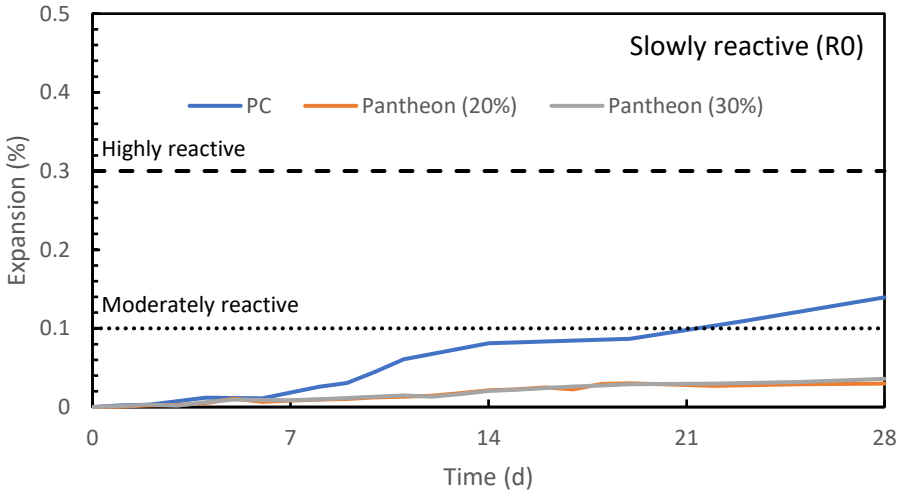

Figure 3. Accelerated mortar bar test results for slowly reactive aggregate (R0)

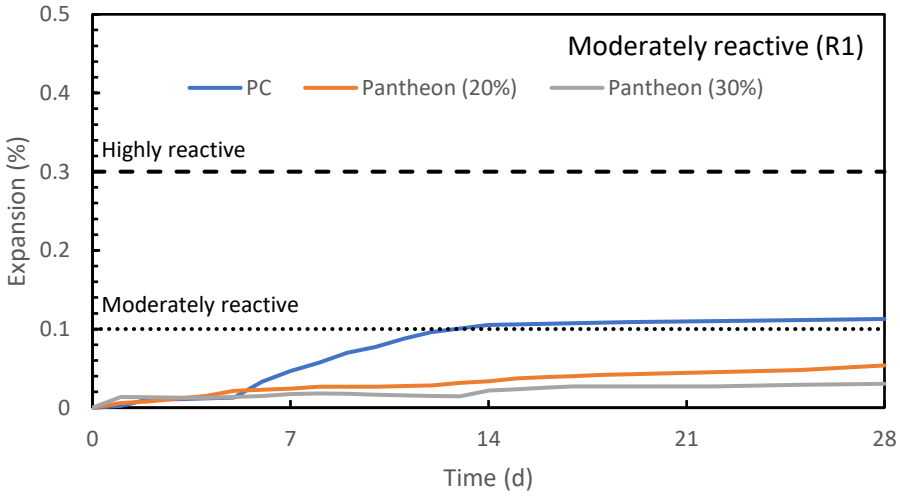

Figure 4. Accelerated mortar bar test results for moderately reactive aggregate (R1)

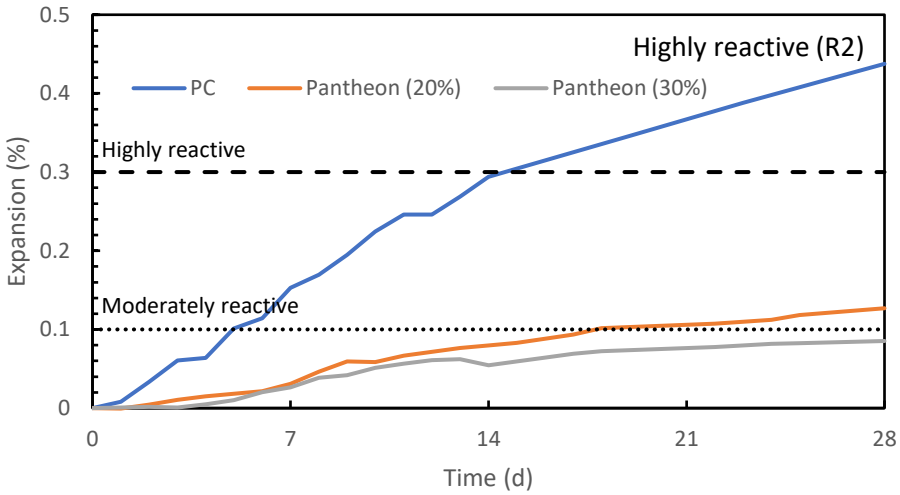

Figure 5. Accelerated mortar bar test results for highly reactive aggregate (R2)

Concrete prism test (ASTM C1293) and petrographic examination (ASTM C856)

While the results of accelerated mortar bar tests suggest that Pantheon™ effectively mitigates expansion resulting from ASR for a wide range of aggregate reactivities, these results must be validated by long-term testing and petrographic examinations. Concrete prism tests are currently being performed for a test period of at least one year. Petrographic examinations will follow to validate the hypothesis that expansions observed in both tests are due to ASR.

Fresh Properties

Additional experiments were performed to measure the influence of partial cement replacement with Pantheon™ on the fresh properties of portland cement concrete with a wide range of air contents.

Mixture proportions

Three portland cement concrete mixtures having air contents of 3, 5, and 7% by volume were designed according to standard practices. The target compressive strength was 6000 psi, and the target slump was 2 in. The mixture proportions shown in Table 4 were developed by direct experimentation to provide the desired properties. The materials used were the same as those used in the ASR study, except that no reactive aggregates were used. The air entraining admixture was Sika AIR-360.

Table 4. Mixture proportions for freeze/thaw durability study

Target air content (%)	**3 ± 1**			**5 ± 1**			**7 ± 1**		
Pantheon™ (wt% cementitious material)	0	20	30	0	20	30	0	20	30
w/cm	0.4			0.32					
Cement (lb/y^3)	813	650	569	1016	813	711	1016	813	711
Pantheon™ (lb/y^3)	0	163	244	0	203	305	0	203	305
Water (lb/y^3)	325								
Coarse aggregate (lb/y^3)	1500								
Fine aggregate (lb/y^3)	1326			1044			954		
Air entraining admixture (fl oz/cwt cement)	0.5			5.0			6.9		

Air content (ASTM C231)

The air content of concrete is the primary factor controlling its freeze/thaw durability. Air content was measured in accordance with the specifications of ASTM C231 using the pressure method. Testing was performed on the concrete mixtures described above with 0, 20, and 30% replacement of portland cement with Pantheon™. Tests were performed between February and April 2022. Each test included a single replicate.

Results are shown in Figure 6. In all cases, the air content decreased with the cement replacement level. This is likely due to the increased alkalinity of Pantheon™, which affects the stability of air bubbles produced by the surfactant air entraining admixture. The effects of this reduction in air content on the freeze/thaw durability of the concrete is a subject of ongoing testing. It is likely that the reduction in air content can be corrected by increasing the dosage of the air entrainer.

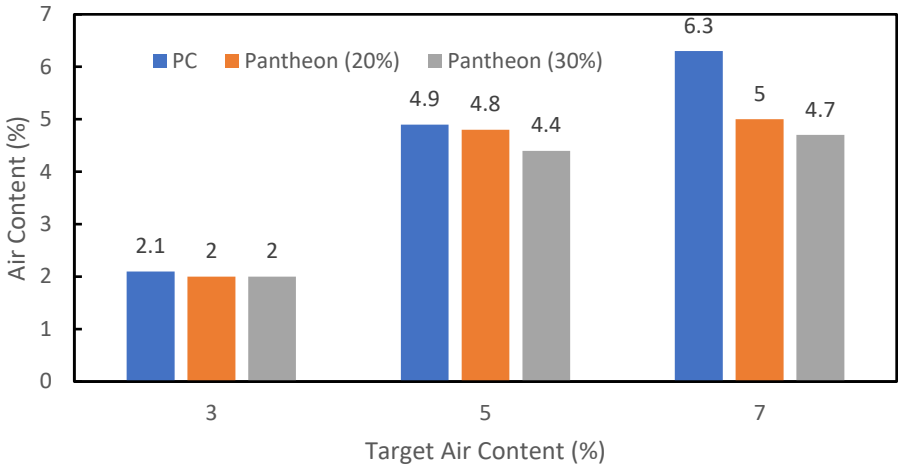

Figure 6. Air content test results

Slump (ASTM C143)

The workability of concrete is a primary factor affecting constructability. Workability was measured by the slump test in accordance with the specifications of ASTM C143. Testing was performed on the concrete mixtures described above with 0, 20, and 30% replacement of portland cement with Pantheon™. Tests were performed between February and April 2022. Each test included a single replicate.

Results are presented in Figure 7. Partial replacement of PC with Pantheon™ resulted in minor reductions in workability across all three mixtures. This is likely due to the fineness of Pantheon™ and can be corrected with water-reducing admixtures.

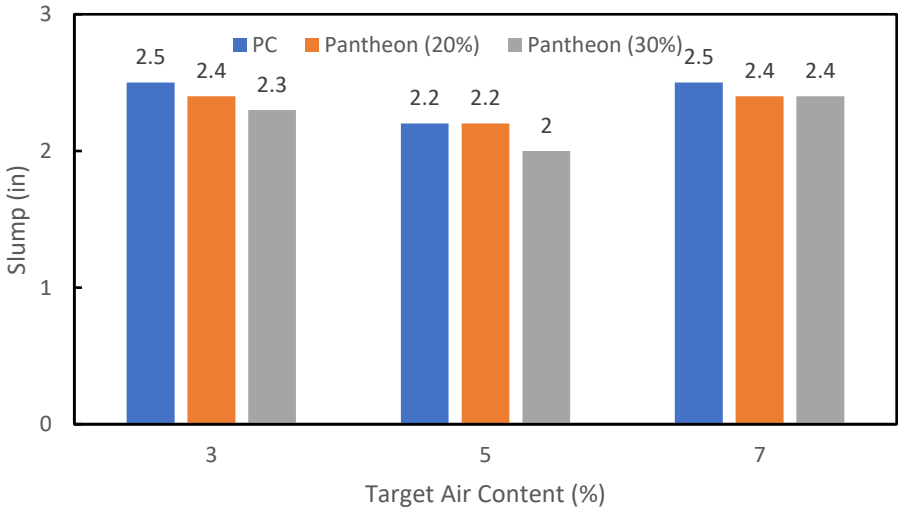

Figure 7. Slump test results

Setting time (ASTM C403)

The setting time of concrete determines the rate at which the concrete solidifies and primarily affects the time for placement and finishing. Setting time was measured by the Acme penetration test in accordance with the specifications of ASTM C403. Testing was performed on the concrete mixtures described above with 0, 20, and 30% replacement of portland cement with Pantheon™. Tests were performed between February and April 2022. Each test included a single replicate.

Results are presented in Figure 8. The initial and final setting times of the control mixture (100% PC) were 230 and 318 min, respectively. With 20% Pantheon™, the initial setting time increased by 4% to 240 minutes and the final setting time decreased by 2% to 312 min. With 30% Pantheon™, the initial setting time also increased by 4% to 240 min and the final setting time decreased by less than one percent to 316 min. These changes are statistically insignificant.

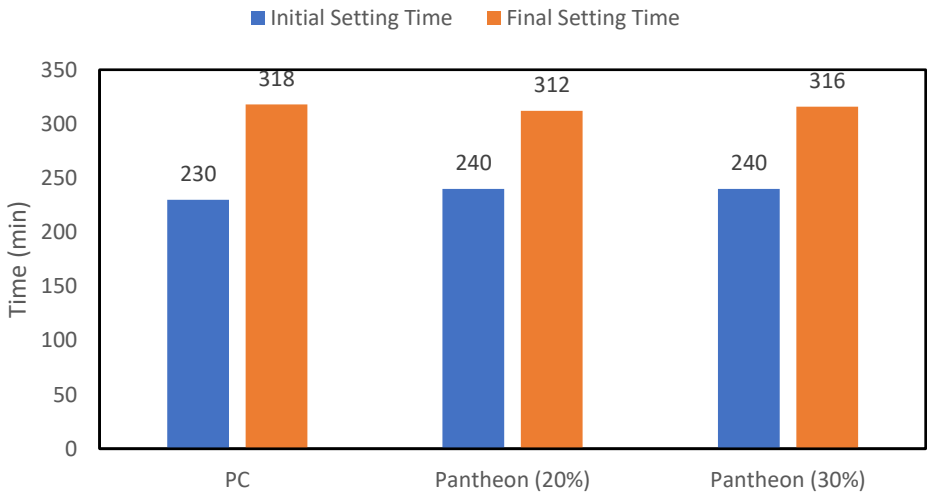

Figure 8. Setting time test results

Conclusions

This Interim Report detailed the preliminary results of a performance evaluation of Pantheon™ as a partial cement replacement material, considering tests performed between September 2021 and April 2022. Preliminary results from tests performed between September and December 2021, using three replicate specimens per test and a total of 36 specimens, suggest that partial cement replacement with 20-30% Pantheon™ effectively mitigates ASR in concrete with aggregates of varying reactivity. Additional long-term testing is needed to confirm these results. Preliminary results from tests performed between February and April 2022, using a single replicate per test and a total of nine specimens, also suggest that partial cement replacement with 20-30% Pantheon™ reduces the air content of fresh concrete, slightly reduces the workability of fresh concrete, and has no measurable influence on the setting time of concrete.