

# Long-term ASR Mitigation of Outdoor Exposure Blocks made with High-alkali Cement- SCM Combinations

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## Abstract

The impact of high-alkali portland cements on the prescribed level of SCMs required in the Canadian standard for ASR mitigation was evaluated. Based on the results, in 2019 the following revisions were made: for concretes containing aggregates exhibiting moderate reactivity, the maximum allowable cement alkali limit was raised from 1.00% to 1.15% and, for all levels of aggregate reactivity, cements with alkali contents are allowed up to 1.25% provided that the level of recommended level of mitigation by SCMs is increased.

In the initial laboratory study, mortar bars and concrete prisms were cast and monitored using two different reactive aggregates and recommended levels of fly ash and slag. For concrete prism tests, the alkali contents of the three cements (0.97 to 1.11% Na<sub>2</sub>O<sub>eq</sub>) were (a) increased to 1.25% Na<sub>2</sub>O<sub>eq</sub>, as per the standard, or (b) were increased by 0.25% Na<sub>2</sub>O<sub>eq</sub>. Later, a series of 37 instrumented outdoor exposure concrete blocks 400 x 400 x 700 mm (along with additional concrete prisms stored at both 38 and 60°C) was cast from 32 mixtures made with cement alkali equivalents ranging up to 1.22%. This paper updates long-term performance of laboratory prisms and the concrete blocks after 12 and 27 years in outdoor exposure. The performance of outdoor exposure blocks is also compared to predicted performance based on the accelerated mortar bar and concrete prism test results.

**Keywords:** high-alkali cement; SCMs; mitigation; concrete prisms; outdoor exposure blocks

## 1. SUMMARY

Prior to 2019, the Canadian CSA test methods for assessing ASR mitigation limited portland cements to a maximum equivalent alkali contents of 1.00%, but alkali contents of some Canadian cements have increased in recent years. This study provided data that was used to modify the CSA Standard A23.2-27A in 2019 that now allows testing of cements with equivalent alkali contents greater than 1.00% in the Canadian Standard CSA A23.2-14A concrete prism test and to the prescriptive alternatives allowed for ASR mitigation using SCMs together with cements with equivalent alkali contents ranging from 1.00 to 1.25%.

In this study, long-term exposure block data confirmed that higher mitigation levels are required with increasing cement alkali contents and that this is particularly the case for borderline replacement/mitigation levels. Also, the slag mixtures seemed to be slightly more sensitive to cement alkali contents than the fly ash mixtures. The experimental details and results are provided in [1].

In addition to the work detailed in this study, an example of a concrete structure performing well that was made with reactive aggregate and high-alkali cement properly mitigated using SCMs, is the Lower Notch Dam in Ontario. It was built in 1970 with reactive greywacke-argillite aggregate and 1.08% Na<sub>2</sub>O<sub>eq</sub> alkali cement in combination with 20% and 30% Class F fly ash. ASTM C227, mortar bar tests with the same aggregates found that 20% Class F fly ash was sufficient to mitigate deleterious expansions. The dam is still performing well after more than 50 years with no signs of ASR.

## 2. CONCLUSIONS

This study [see 1] of outdoor exposure blocks was carried out in order to determine the safe alkali content in portland cement that could be used in concrete incorporating alkali-reactive aggregate together with the recommended SCM replacement levels given in Table 6 of CSA A23.2-27A. Expansions indicated that higher levels of mitigation with slag were needed than were indicated by the

60°C prisms and the 12-year exposure blocks. The outdoor exposure blocks will continue to be monitored since they are still likely to continue to expand.

1. Based on analysis of 20 and 27-year expansions from other outdoor exposure studies using these same reactive aggregates, it was concluded that 12 years is too early to determine whether mitigation by different levels of slag or fly ash is adequate.
2. The six-month RILEM AAR-4 60°C concrete prism test results are consistent with the outdoor exposure blocks after 12 years exposure, when using 0.04% expansion in concrete prisms and 0.05% in the blocks as the failure criteria.
3. The 2-year 38°C concrete prism expansions indicated that higher levels of mitigation with slag were needed than were indicated by the 60°C prisms and the 12-year exposure blocks. These outdoor exposure blocks will continue to be monitored to at least 20 years since as indicated from older exposure site data, they are still likely to continue to expand.
4. Ignoring the premature 12-year expansions of exposure blocks cast as part of this study, a review of all the 2-year, 38°C and 6-month 60°C concrete prism expansions combined with the 20-year expansions of outdoor exposure blocks from a previous study, the following conclusions can be drawn:
  - a) As currently required in CSA A23.1-27A, concretes made with (a) moderately reactive aggregates and cements containing up to 1.15 % alkali equivalent, and (b) highly reactive aggregates and cements containing up to 1.00 % alkali equivalent the required minimum levels of supplementary cementitious materials appear to be adequate for mitigating ASR (30% fly ash and 50% slag for Spratt; 25% fly ash and 35% slag for Sudbury). The one exception is after 20-years outdoor exposure with 35% slag and the moderately reactive Sudbury aggregate, that is known to release alkalis into the concrete pore solution over time. In this case, 50% slag was required. Therefore, the CSA guidance may need to consider adding a warning regarding reactive aggregates that release alkalis into the concrete.
  - b) For concretes made with highly and extremely reactive aggregates and cements containing between 1.00 and 1.25 % alkali equivalent, CSA A23.2-27A requires an increase in minimum levels of supplementary cementitious materials for mitigation of ASR. In the concrete prism tests, these increased levels (35% fly ash and 60% slag) were found to be sufficient for mitigating ASR for the highly reactive Spratt aggregate tested. The 20-year blocks did not include a 35% fly ash mixture but 30% fly ash was insufficient and it is not known if the 35% fly ash mixture in the 12-year blocks will undergo future expansion.
  - c) For concretes made with moderately reactive aggregates and cements containing between 1.15 and 1.25 % alkali equivalent, CSA A23.2-27A requires increasing the minimum SCM levels to 30% fly ash and 50% slag. These levels of mitigation were adequate, with the exception of the 20-year outdoor block expansions with 50% slag. Again, this may be due to alkali release from the Sudbury aggregate into the concrete over time.

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