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Mitigation of Alkali-Silica Reaction (ASR) in Concrete

Experimental Evaluation of a Liquid Admixture

Abstract

The alkali-silica reaction (ASR) is a documented degradation mechanism affecting certain concrete structures in several countries, including roads, leading to damage such as cracking and spalling.

This study examines a liquid concrete admixture developed for the mitigation of ASR, intended to limit the formation of expansive alkali-silica gels. Extensive laboratory testing was conducted to assess its effectiveness. Rapid mortar tests were used to select a highly reactive aggregate for subsequent concrete performance verification. In alternating climate storage tests, concrete specimens containing the admixture maintained expansions well below critical thresholds. Microscopic examination confirmed the absence of ASR-related damage in treated specimens.

The admixture was found to be compatible with standard concrete mix designs and to have no adverse impact on fresh or hardened concrete properties at the tested dosage levels. The use of regional aggregates and recycled concrete gravel was feasible without negative effects. The findings indicate that the tested admixture can contribute to ASR risk mitigation in infrastructure applications.

Introduction

Concrete infrastructure across Europe is increasingly subject to long-term durability threats, including ASR.

ASR was first identified around 1920 in the USA as a cause of concrete damage and is now a well-documented degradation mechanism. ASR refers to a chemical reaction between various forms of silica (SiO_2) in the concrete aggregates and the alkali hydroxides (NaOH, KOH) in the pore solution of the hardened concrete or alkalis penetrating from the outside. The resulting alkali-silica gel expands due to water absorption, exerting internal pressure, and can lead to concrete damage, such as internal cracking, and eventual loss of load-bearing capacity.

Challenges

ASR is of growing concern in several countries, including Poland, where documented ASR-related damage has affected parts of motorways and regional road networks. Notable locations include sections of the S8 and S7 expressways, as well as the A4, A2, and A1 motorways, where reactive aggregates have been identified, leading to cracks and surface degradation.

Public reports and research, e.g. from the Instytut Podstawowych Problemów Techniki PAN, confirm the presence of reactive aggregates and problematic interaction with deicing salts, indicating a need for regulatory attention as well as action from construction professionals.

Conventional ASR mitigation measures, such as low-alkali cements or supplementary cementitious materials, may not sufficiently address ASR risk—particularly in environments that combine reactive aggregates with cyclic salt exposure and freeze-thaw conditions. This discrepancy between laboratory screening and field performance presents a serious challenge for all stakeholders in concrete infrastructure.

Traditional strategies for ASR protection, such as the selection of low-alkali cements or the use of inactive aggregates, are increasingly reaching their limits. The availability of suitable materials is regionally restricted, and alternative binders are not always economically or technically feasible in every project. As a result, the likelihood of a concrete-damaging reaction remains in many cases, especially where exposure to deicing salts cannot be avoided. The reliable mitigation of ASR under these conditions remains a key challenge.

Evaluation and performance verification

For this purpose, a liquid admixture developed by Ha-Be Betonchemie GmbH, added to the concrete at the plant during mixing, following standard procedures for liquid admixtures, was subjected to laboratory investigations.

Its effectiveness in mitigating ASR under defined exposure conditions was evaluated at the F.A. Finger Institute for Building Materials Science, Bauhaus University Weimar, Germany, an independent third-party laboratory, in accordance with European standards.

Scope of testing

The testing program was divided into three sections:

1. Characterization of the admixture
2. Verification of its compatibility with concrete performance
3. Verification of its effectiveness.

The tests for admixture characterization and compatibility were carried out in accordance with DIN EN 934.

1. Characterization of the admixture

The admixture is a clear aqueous solution with the following properties:

Parameter	Value
pH	7.54
Density	1.20 g/cm ³
Solid content	32.9 mass-%

It remained visually homogeneous and stable over 12 months, with no segregation or discoloration. No corrosion-promoting behavior was observed.

2. Verification of its compatibility with concrete performance

Compatibility tests evaluated potential impacts on key concrete properties, including:

- 2.1 Effects on water demand, setting behaviour, and volume stability of cement paste
- 2.2 Effects on fresh concrete properties (air content, consistency, workability retention) and effects on hardened concrete properties (compressive strength)

2.1 Effects on water demand, setting behaviour, and volume stability of cement paste

The tests were carried out using the maximum proposed dosage of the concrete admixture, 3.5% b.w.o.c. The admixture's water content of 70% was fully considered as part of the mixing water. To evaluate its performance with various cement types, tests on setting behavior and volume stability were conducted in accordance with DIN EN 196-3, using a total of nine different cements.

Results indicated a reduction in water demand, typically by 0.5% b.w.o.c., and up to 2.0% in individual cases. Compliance with the setting time requirements of the cements was fully maintained. All results of the volume stability tests remained well within the permissible expansion limit of 10 mm. Slight variations in expansion were observed, all within a stable and consistent range.

2.2 Effects on fresh and hardened concrete properties

The objective of the testing was to systematically assess the influence of the admixture on key fresh and hardened concrete properties under standardized conditions. Concrete tests were conducted on three different mix designs to make any potential effects as evident as possible. Two of the mixes used different types of cement, while the third was formulated as air-entrained concrete. All mixes utilized natural gravel-sand aggregates in compliance with DIN EN 12620, with particle size distributions specified in DIN 1045-2.

For the hardened concrete, compressive strength at 28 days was measured.

Concrete mix design

Mix	Ia		Ib		II	
	Reference concrete	with ASR-mitigating admixture	Reference concrete	with ASR-mitigating admixture	Reference concrete	with ASR-mitigating admixture
Cement type	CEM I 42,5 N		CEM III/A 42,5 N		CEM I 42,5 N	
Cement content	300 kg/m ³		300 kg/m ³		350 kg/m ³	
w/c ratio	0.6		0.6		0.50	
Added water	180 kg/m ³	172.6 kg/m ³	180 kg/m ³	172.6 kg/m ³	175 kg/m ³	166.4 kg/m ³
Water in ASR-mitigating admixture	–	7.4 kg/m ³	–	7.4 kg/m ³	–	8.6 kg/m ³
Aggregates	657 kg/m ³		654 kg/m ³		530 kg/m ³	
0/2mm	460 kg/m ³		458 kg/m ³		260 kg/m ³	
2/8 mm	737 kg/m ³		733 kg/m ³		434 kg/m ³	
8/16 mm	A16/ B16		A16/B16		520 kg/m ³	
16/32 mm					A32/B32	
Grading						
Target air content	1.5 Vol. -%		1.5 Vol. -%		4.5 Vol. -%	
ASR-mitigating admixture	–	10.5 kg/m ³	–	10.5 kg/m ³	–	12.3 kg/m ³
Air entraining agent	–	–	–	–	0.36 kg/m ³	0.36 kg/m ³

* Water content in ASR-mitigating admixture: 70%

Fig. 1: Table of concrete mix design

Summary of results

	Ia Reference concrete	Ia with ASR-mitigating admixture	Ib Reference concrete	Ib with ASR-mitigating admixture	II Reference concrete	II with ASR-mitigating admixture
Flow table test a_5 [mm]	560	530	490	480	560	580
Flow table test a_{50} [mm]	440	430	420	420	490	500
Air content	0.4	0.9	1.3	1.7	4.3	4.5
Compressive strength 7 d	28	28	21	21	28	24
Compressive strength 28 d	39	36	35	37	36	31

Fig. 2: Table of Results

No systematic influence was observed on concretes with the admixture for the mitigation of ASR regarding air content and fresh concrete densities. In concrete with an air entraining agent, the air content remained nearly constant, demonstrating stability in the mixture's properties.

Similarly, no effect on the consistency of the concrete was observed, as measured by the flow table test 5 minutes after mixing. No impact on the setting behavior of the concrete was noted. Compressive strength values remained within the expected range.

3. Verification of its effectiveness

The objective of the tests was to verify the ability of the admixture to prevent or reduce ASR in concrete within the specified dosage range.

For the effectiveness testing, a highly reactive aggregate from the group of slowly and late-reacting aggregates ("slow late") was selected. The choice of this aggregate was based on rapid mortar tests performed in accordance with TP B-StB, Part 1.12. These tests served to comparatively assess the alkali sensitivity of potential aggregates.

Based on the selected critical aggregate, the concrete effectiveness tests were carried out using two standardized mix designs specified in ARS 04/2013 "Prevention of damage to concrete pavements caused by alkali-silica reaction (ASR)", published by the German Federal Ministry of Transport and Digital Infrastructure (BMVI), as part of the WS baseline test protocol (WS refers to a moisture exposure class characterized by continuous moisture, potential external alkali ingress, and high dynamic loading, typically encountered in structural elements exposed to deicing salts and heavy traffic).

Concrete mix design for top concrete 0/8 mm

Cement content: 430 kg/m³

w/c - ratio = 0.45

Air content: 5.5–6.5 vol.-%

Aggregates:

- 30 vol.-% sand 0/2 mm
- 70 vol.-% critical aggregate 2/8 mm

Concrete mix design for top concrete ($D > 8$ mm) and base concrete

Cement content: 360 kg/m³

w/c-ratio = 0.45

Air content: 4.0–5.0 vol.-%

Aggregates:

- 30 vol.-% sand 0/2 mm
- 15 vol.-% critical aggregate 2/8 mm
- 25 vol.-% critical aggregate 8/16 mm
- 30 vol.-% critical aggregate 16/22 mm

The cement used was the official test cement for the WS baseline testing, with a sodium equivalent of approximately 0.80 wt.-%. The effectiveness evaluation was conducted using the alternating climate storage method, a well-established procedure that has proven reliable over several decades for assessing the ASR potential of concrete mixtures.

3.1 Rapid Mortar Tests

The rapid mortar tests assess the ASR potential of individual aggregate fractions or blends.

The test involves producing mortar prisms ($4 \times 4 \times 16$ cm³) from the aggregate under investigation, an alkali-rich cement, and an additional NaOH dosage. Prisms are cured for 28 days at 70 °C above water. Coarse aggregates are crushed to a maximum particle size of $D \leq 2$ mm. The expansion of the prisms at the end of the curing period serves as the evaluation criterion. Expansions exceeding 2.0 mm/m indicate a high ASR potential, though confirmation by concrete testing is required.

This method is suitable for monitoring changes in alkali sensitivity of aggregates intended for concrete traffic areas. In the present case, it was used to preselect aggregates with sufficient ASR potential for subsequent concrete testing.

Five aggregates with varying reactivity levels were tested. As shown in Figure 3, two of them exhibited pronounced reactivity, with expansions significantly exceeding 2.0 mm/m. Based on these results, Rhyolite 1 was selected for the concrete investigations. The expansion at the end of the rapid mortar test was 4.01 mm/m.

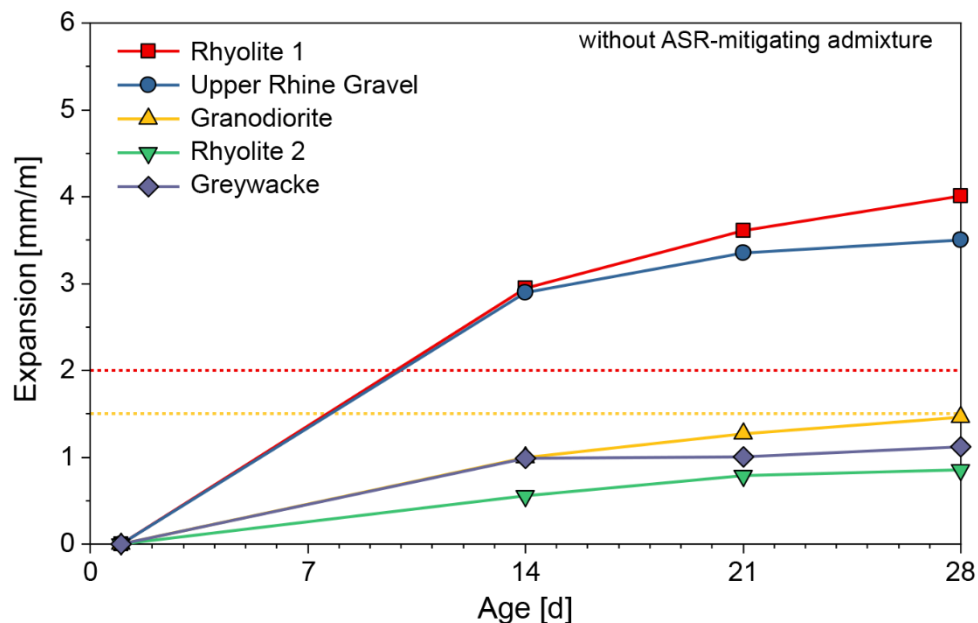


Fig. 3: Rapid mortar test to identify alkali-reactive aggregates

3.2 Alternating climate storage method

The effectiveness of the concrete mix was evaluated using alternating climate storage in accordance with the German “Technical Test Specification for Concrete Structures” (TP B-StB, Part 1.1.10). This method simulates alternating environmental conditions in 21-day cycles consisting of drying, mist exposure, and freeze-thaw phases. For pavement concretes, 12 cycles (approx. 8 months) are applied to assess ASR durability. After each cycle, strain and mass change of the specimens are measured. Test solutions included water, 3.6% NaCl solution, and potassium acetate.

The strain limit for water exposure is 0.40 mm/m; due to the hygroscopic nature of salts, a higher strain limit of 0.50 mm/m applies under deicing salt exposure. Microstructural changes and phase formations are assessed via thin-section analysis using polarized light microscopy after completion of the test cycles. In this specific study, additional evaluation will determine the extent of nitrate leaching from the concrete.

3.2.1 Base concrete

The tests on the base concrete were carried out using the mix designs shown in Figure 4, both without and with 3.5% b.w.o.c. of the admixture for the mitigation of ASR.

	Base Concrete 0/22 Reference	Base Concrete 0/22 with ASR-mitigating admixture
Cement type	WS-test cement CEM I 42,5 N	WS-test cement CEM I 42,5 N
Cement amount	360 kg/m ³	360 kg/m ³
w/c-ratio*	0.45	0.45
Aggregates	1771 kg/m ³	1771 kg/m ³
Grading	A/B 22	A/B 22
ASR-mitigating admixture [% b.w.o.c.]	–	3.5
Air entraining agent [% b.w.o.c.]	0.03	0.02

* Water content in ASR-mitigating admixture: 70%

Fig. 4: Table of base concrete 0/22

3.2.1.1 Base concrete without ASR-mitigating admixture

All tested concrete series exhibited an initial expansion of less than 0.2 mm/m, which is characteristic of alternating climate storage and attributed to hygric expansion due to initial moisture uptake. Under exposure to water only, the expansions remained uncritical throughout the test period. In contrast, when external alkalis were introduced via NaCl solution or deicing solution, a significant increase in expansion was observed starting from the 5th cycle. The expansions continued to rise markedly until the end of the 12th cycle. The critical expansion limit of 0.5 mm/m was exceeded between the 8th and 9th cycle under these conditions. Based on these results, the concrete mix must be classified as critical with respect ASR when subjected to external alkali input (Fig. 5).

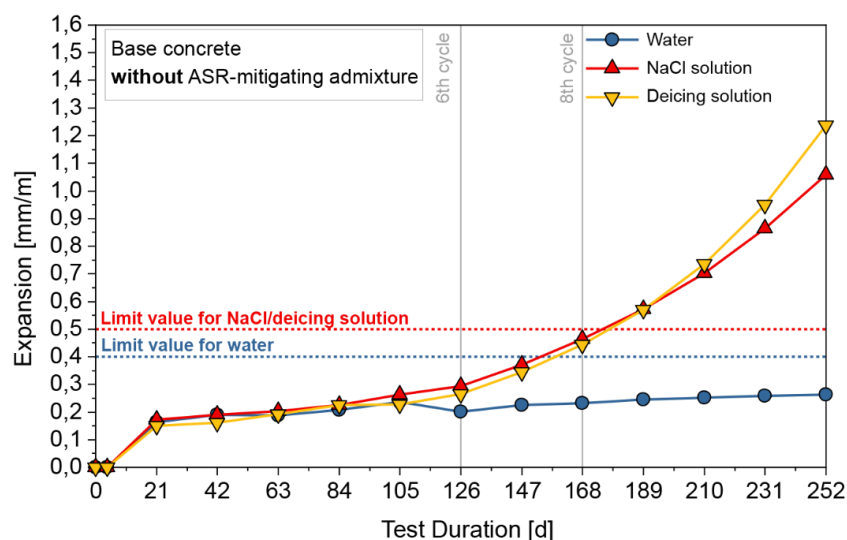


Fig. 5: Expansions base concrete without ASR-mitigating admixture

3.2.1.2 Base concrete with ASR-mitigating admixture

All test series show an uncritical expansion behavior. External alkali input did not cause greater expansion than exposure to water alone. This concrete mix is therefore to be classified as non-critical with regard to ASR (Fig. 6).

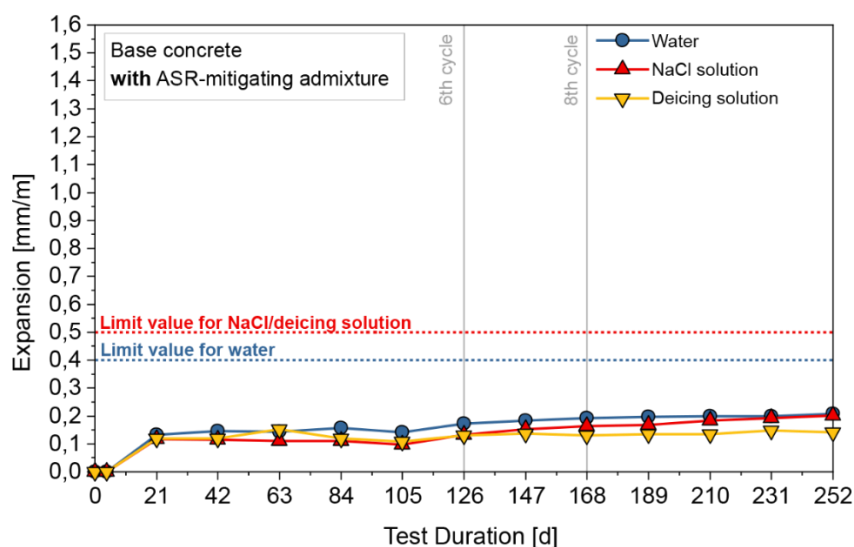


Fig. 6: Expansions base concrete with ASR-mitigating admixture

3.2.2 Top concrete

The tests on the top concrete were carried out using the mix designs shown in Figure 7, both without and with 3.5% b.w.o.c. of ASR-mitigating admixture.

	Top Concrete 0/8 Reference	Top Concrete 0/8 with ASR-mitigating admixture
Cement type	WS-test cement CEM I 42,5 N	WS-test cement CEM I 42,5 N
Cement amount	430 kg/m ³	430 kg/m ³
w/c-ratio*	0.45	0.45
Aggregates	1583 kg/m ³	1583 kg/m ³
Grading	A/B 8	A/B 8
ASR-mitigating admixture [% b.w.o.c.]	–	3.5
Air entraining agent [% b.w.o.c.]	0.02	0.02

* Water content in ASR-mitigating admixture: 70%

Fig. 7: Table of top concrete 0/8

3.2.2.1 Top concrete without ASR-mitigating admixture

The testing of the top concrete, which contains a significantly higher cement content and consequently more alkalis, confirms the results from alternating climate storage of the base concrete. Under exposure to water only, the expansions remain uncritical. However, when external alkalis are introduced via NaCl solution or deicing solution, expansion begins to increase from the 5th cycle onward. This trend continues with a significant rise in expansion until the end of the 12-cycle test period. The critical expansion limit of 0.5 mm/m is exceeded after the 8th cycle under external alkali exposure. Based on these results, the concrete mix must be classified as critical with respect to ASR when subjected to external alkali input (Fig. 8).

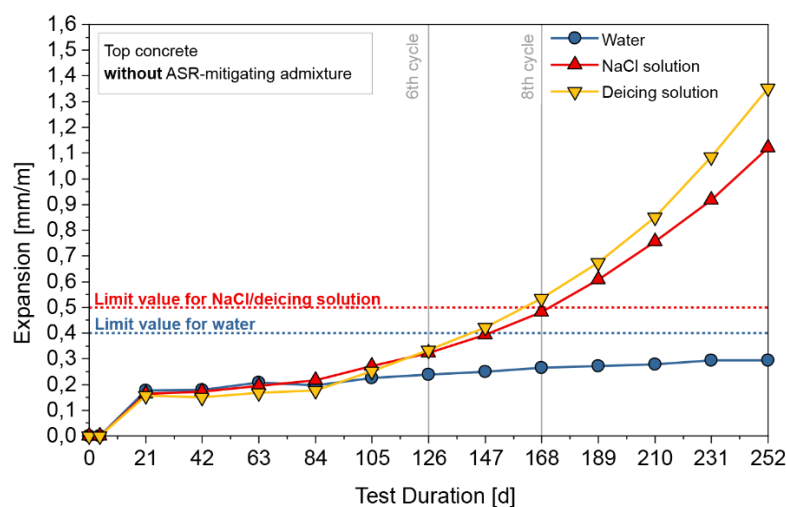


Fig. 8: Expansions top concrete without ASR-mitigating admixture

3.2.2.2 Top concrete with ASR-mitigating admixture

All test series exhibit an uncritical expansion behavior. External alkali input caused only slightly increased expansions, well below the limit value, toward the end of the alternating climate storage, compared to exposure to water alone. This concrete mix is therefore to be classified as non-critical with regard to ASR.

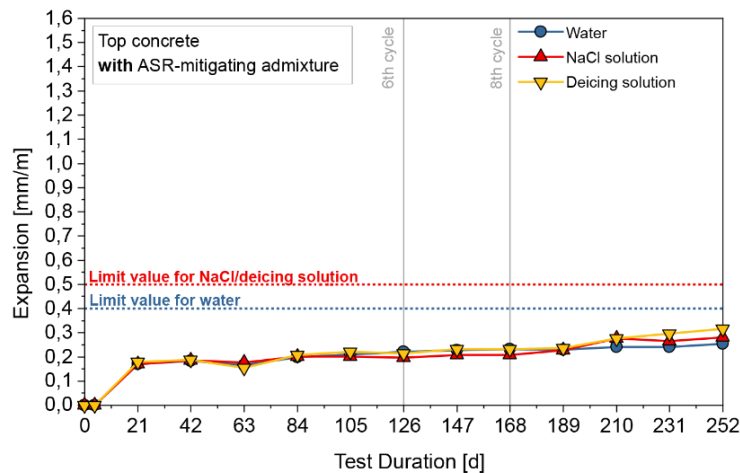


Fig. 9: Expansions top concrete with ASR-mitigating admixture

3.2.3. Light microscopic analysis

Following alternating climate storage, selected concrete mix designs underwent light microscopic analysis of thin sections. The evaluation confirmed distinct signs of ASR in specimens without admixture for mitigation of ASR.

Figure 10 shows a representative micrograph from a surface concrete mix without admixture for mitigation of ASR that had been exposed to deicing solution. The image clearly reveals a fractured rhyolite grain in the upper right area and an adjacent pore filled with ASR gel. These features are characteristic of advanced ASR damage and highlight the susceptibility of the unmodified mix design.



Fig.10: Light microscopic detail image of a saw-cut surface; surface concrete 0-8 without ASR-mitigating admixture

In the specimen of the surface concrete mix with admixture for mitigation of ASR no signs of ASR were detectable in this specimen (see Figure 11).

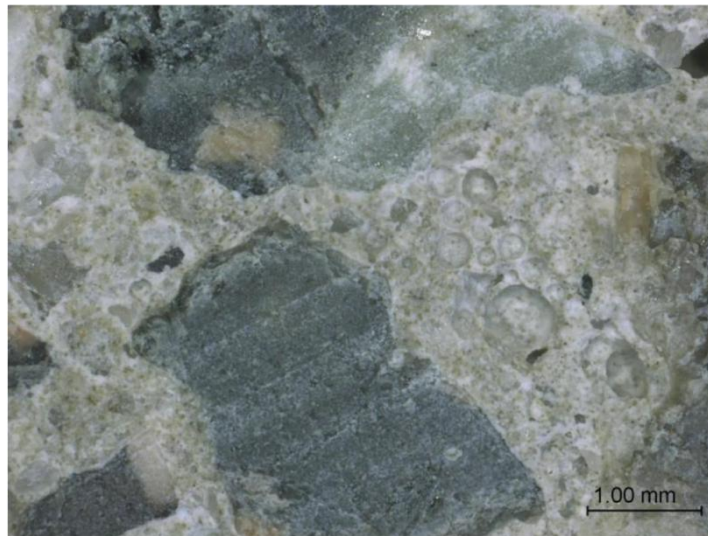


Fig.11: Light microscopic detail image of a saw-cut surface; surface concrete 0-8 with ASR-mitigating admixture

Conclusion

Alkali-silica reaction (ASR) presents a significant risk to concrete durability, particularly in infrastructure projects. This reaction can lead to the formation of expansive gels within the concrete, causing cracks and structural damage over time. Therefore, it is essential to implement measures to mitigate ASR risks in concrete construction.

A liquid ASR-mitigating admixture developed by Ha-Be Betonchemie GmbH was evaluated for its effectiveness in reducing ASR-related damage under standardized testing. In rapid mortar tests (TP B-StB, Part 1.1.12) and alternating climate storage tests (TP B-StB, Part 1.1.10), treated specimens consistently exhibited deformations below critical thresholds. Microscopic analysis confirmed the absence of ASR-related damage.

The admixture was incorporated into concrete mixes following standard procedures for liquid admixtures, without adversely affecting other concrete properties. Its compatibility with regional aggregates and recycled concrete gravel was also assessed. Considering ASR risks in infrastructure projects, including those in Poland, these results provide evidence of the admixture's potential to enhance concrete durability.

References

Stark, J., B. Wicht. 2001. Dauerhaftigkeit von Beton: Der Baustoff als Werkstoff, 288-330. Birkhäuser Verlag.

Müller, Dr.-Ing. M. 2024. Test Report ASR-mitigating admixture. BMC Building Materials Consult GmbH.

Glinicki, M.A., A. Antolik, M. Dąbrowski, K. Dziedzic, K. Gibas, D. Józwiak-Niedźwiedzka, and M. Sobczak. 2018. Diagnostyka betonu w nawierzchni drogi S8 Wolbórz–Polichno na podstawie badań odwiertów. Polska Akademia Nauk, Instytut Podstawowych Problemów Techniki PAN.