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Research Article

Accelerated alkali-silica reaction after a seven-year ASR-dormancy period

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ABSTRACT

The ongoing alkali-silica reaction (ASR) in concrete can be halted by dryness, which is important for repairing ASR-suffered concrete structures. Drying of the concrete establishes an ASR-dormancy period until the end of the dryness. The residual expansion of such concrete after the ingress of water—the end of the dormancy period—is a significant risk, especially for repair works. In this experimental study, the post-dormancy expansion of various mixtures prepared by eight different Portland cement and three different supplementary cementitious materials (SCM) were tested using an accelerated mortar bar test. After accelerated ASR expansions, an ASR-dormancy period was established by keeping the specimens dry for seven years; the residual ASR expansions of the specimens were tested by the same accelerated method. The effect of pre-dormancy reactions on the residual expansions was discussed through two perspectives. The post-dormancy expansion behavior of mixtures without or with insufficient SCM indicated that expansions were primarily driven by the swelling of old gel, whereas in specimens with sufficient SCM, the dominant mechanism was new gel formation, a result of lower pre-dormancy expansions due to the ASR-mitigating effect of SCMs.

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1. INTRODUCTION

Alkali silica reaction is one of concrete's significant and commonly seen durability problems; therefore, innumerable studies have been carried out for decades worldwide to understand its nature and overcome its deleterious effects. Since Stanton's paper [1], dealt with the chemistry of ASR, many test methods have been developed to analyze the reactivity of aggregates and to assess the effectiveness of various ASR-mitigation approaches. However, there are still many ASR-suffered structures and many at risk of being suffered. Therefore, the repair and maintenance works—techniques include, but are not limited to, injection of epoxy resins into cracks [2], precast prestressed concrete confinement [3], CFRP sheet bonding [4], surface coating using acrylic and urethane-based continuous fiber sheets, and concrete jacketing [5] as well as novel methods such as applying bacteria-containing grout to the surface of ASR-suffered concrete [6]—have been carried out for many years worldwide and will be executed in the future.

A successful repair must be accompanied either by a waterproofing application or drainage/removal of water in contact with the concrete. In other words, the dryness of the ASR-suffered concrete must be ensured— such as improvement of drainage, sealing surface of the structure to prevent water ingress, and silane treatment of the structure [7]—to halt reactions (ASR-dormancy period) and to avoid swelling of the existing ASR gel. Otherwise, the reaction and the expansion will continue; thus, the deterioration will occur again. Daidai et al. [3] have reported that the water trapped

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Table 1. The additive content of the Portland cement used in this study

Cement type	Additive content
CEMI-1 (CEM I 42,5 R)	None
CEMII-1 (CEM II/B-M (L-W) 42,5 R)	24% fly ash (calcareous) and 6% limestone
CEMI-2 (CEM I 42,5 R)	None
CEMII-2 (CEM II/B-M (L-W) 42,5 R)	22% fly ash (calcareous) and 7.5% limestone
CEMI-3 (CEM I 42,5 R)	None
CEMII-3 (CEM II/A-M (V-LL) 42,5 R)	6.98% fly ash (siliceous) and 5.95% limestone
CEMI-4 (CEM I 42,5 R)	None
CEMII-4 (CEM II/A-LL 42,5 R)	10% limestone

inside the concrete before the injection repair and surface coating works was the main reason behind the continuous expansion of the repaired bridge concrete. They have also emphasized that penetration of the drainage water and deicing salts to the repaired concrete bridge piers accelerated the ASR reactions. The ASR-dormancy period can be maintained as long as the concrete is dry.

The ASR-dormancy period established by preventing water ingress will be over whenever water penetrates any ASR-suffered concrete. To the best of the author's knowledge, only one scientific paper dealt systematically with the post-dormancy (after 14 14-month drying period) ASR expansions [8]. Multon and Toutlemonde [8] have investigated the effect of moisture conditions and transfers on ASR-suffered concrete specimens. They showed that water supply causes new ASR expansions in the ASR-suffered dry concretes. However, there is a lack of information regarding the effects of pre-dormancy expansion levels and supplementary cementitious material usage on post-dormancy expansions. This study endeavored to understand this matter through accelerated reactions and a seven-year ASR-dormancy period (7Y-DP). It can also shed light on using recycled concrete aggregates obtained from ASR-suffered concrete structures.

2. EXPERIMENTAL PROGRAM

2.1. Materials

Two different cement types, Ordinary Portland cement (CEM I 42.5R) and Portland composite/blended cement (CEM II 42.5R), supplied by four different producers, were used in this study. The contents of these eight cements are presented in Table 1. The fly ashes used in this study were Class-F fly ash (FF) and Class-C fly ash, according to the ASTM C618-19 [9]. Moreover, a ground granulated blast furnace slag (S) was used in this study. The chemical compositions of the cement and the SCMs are presented in Table 2.

The reactive aggregate was an andesitic basalt, crushed and quarried from the Aliağa region north of Izmir, Turkey. Its ASR potential, albeit no reported case in structures, has been observed in a few studies up to now [10–14]. The studies conducted by Copuroglu et al. [15] and Yuksel et al. [11], for instance, revealed that the fine fraction of this aggregate caused, respectively, 0.55% and 0.5% expansions (14-day) in accelerated mortar bar test. The mineralogical and microstructural characteristics of the aggregate were studied in detail by Copuroglu et al. [15]. They revealed that the primary source of the observed expansion can be explained by the reactive glassy phase of the basalt matrix having approximately 70% SiO_2 [15].

2.2. Preparation of Specimens

Mortar bars with 25×25×285 mm dimensions were prepared according to ASTM C1260 [16] and ASTM C 1567 [17] with a water-to-binder ratio of 0.47 and a sand-to-binder ratio of 2.25. The replacement ratios of fly ashes were, respectively, 30% and 25% (by cement weight)— the maximum recommended ratios in the TS13515 [18] standard —for the CEMI and CEMII cement. These ratios were 45% and 30% for the Slag.

2.3. Accelerated Mortar Bar Test

The initial lengths of mortar bars were measured immediately after demolding, prior to immersion in 80 °C water for 24h. After that, the lengths of mortar bars immersed in the 80 °C NaOH solution were measured periodically. As the primary purpose of this research was to scrutinize the effects of pre-dormancy expansion levels on the post-dormancy expansions, it was aimed to have different expansion ranges before the 7Y-DP; therefore, various (almost determined randomly) exposure durations were applied—of course, not so divergent (42–59 days). After the last length measurement, the specimens were taken from the solution and dried; then, they were stored in plastic storage boxes. They were kept in the boxes for more than seven years (7Y-DP) until the post-dormancy measurements. A similar measurement procedure was carried out after the 7Y-DP up to 43 days as if the specimens had just been demolded. In other words, each one of the specimens had gone through at least 42 days of accelerated ASR expansion, then a 7-year dormancy period (dried), and again 43 days of accelerated ASR expansion.

3. RESULTS AND DISCUSSION

In the ASTM C 1260 method, aggregate is usually considered reactive if the cement-aggregate combinations (mortar bars) immersed in the 80 °C NaOH solution exhibit expansions greater than 0.10% after 14 days of exposure

Table 2. The chemical compositions of the cement and the SCMs

	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	Cl	SO_3	Free CaO	Loss on ignition	Total alkali
CEMI-1 (CEM I 42,5 R)	18.48	4.40	3.12	64.13	1.35	0.44	0.78	0.006	3.51	1.34	3.75	0.95
CEMII-1 (CEM II/B-M (L-W) 42,5 R)	23.36	7.98	3.50	54.03	1.81	1.23	0.92	0.073	3.40	2.32	2.85	1.83
CEMI-2 (CEM I 42,5 R)	20.68	6.24	2.34	62.28	1.50	0.23	0.97	0.008	3.12	0.95	2.14	0.87
CEMII-2 (CEM II/B-M (L-W) 42,5 R)	22.11	7.56	2.63	55.92	1.48	0.23	1.03	0.009	3.26	1.55	5.27	0.90
CEMI-3 (CEM I 42,5 R)	19.57	4.65	3.00	63.07	1.55	0.21	0.87	0.010	3.00		4.08	0.78
CEMII-3 (CEM II/A-M (V-LL) 42,5 R)	21.7	6.68	2.92	56.96	2.17	0.37	0.86	0.008	2.60		4.84	0.93
CEMI-4 (CEM I 42,5 R)	19.27	4.78	3.75	63.39	2.16	0.13	0.61	0.0085	2.92	1.81	2.99	0.53
CEMII-4 (CEM II/A-LL 42,5 R)	17.90	4.28	3.15	61.53	3.00	0.12	1.02	0.01	2.82	1.00	6.09	0.79
CF (Class-C fly ash)	41.52	19.52	4.34	22.61	2.26	1.02	1.41		3.11	4.24	0.91	1.94
FF (Class-F fly ash)	52.38	17.14	10.23	<0.00111	4.676	0.197	1.526	0.003	0.444	0.01	0.77	1.20
S (GG-Blast Furnace Slag)	43.58	10.62	1.06	33.19	7.29	0.26	0.77	0.0096	0.40		0.08	0.76

according to ASTM C 1778-20 [19]. In addition, combinations of SCMs and aggregates (ASTM C 1567) [17] that result in an expansion of less than 0.10% after 14 days are considered an "acceptable" level.

As mentioned earlier, the ASR-mitigation ability of SCMs, after all now, is a well-known phenomenon; therefore, this study endeavors to focus on the further expansion of various specimens following a relatively long ASR-dormant period. However, the 14-day expansions should be briefly evaluated. Despite the concerns regarding the severe test conditions of the accelerated mortar bar (AMB) test, Bérubé et al. [20] have emphasized that it can be applied for evaluation of the ASR-mitigation performance of SCMs as long as the test period is restricted to 14 days.

As shown in Figure 1, the performance of the blended cement, type II (CEMII), depends, obviously, on their additive contents. The CEMII-1 and CEMII-2 had significantly lower— of course, they were not below the critical level— expansions compared to those of the CEMs, while the expansions of the 3rd and 4th CEMIIs were almost the same with the CEMIs. Given the contents of the blended cement, these results are expected outcomes; the CEMII-1 and 2 include 22–24% fly ash, but none in the CEMII-4 and only ~7% in the CEMII-3.

The utilization of the FF and S had almost similar effects and could keep the expansion of the mortars, no matter the cement type, below the critical level. However, the CF couldn't do so. In other words, the 30% and 25% replacement ratios were insufficient for the class C fly ash. The relatively poorer performance of class C fly ashes is not an unexpected nor unknown outcome [11, 21].

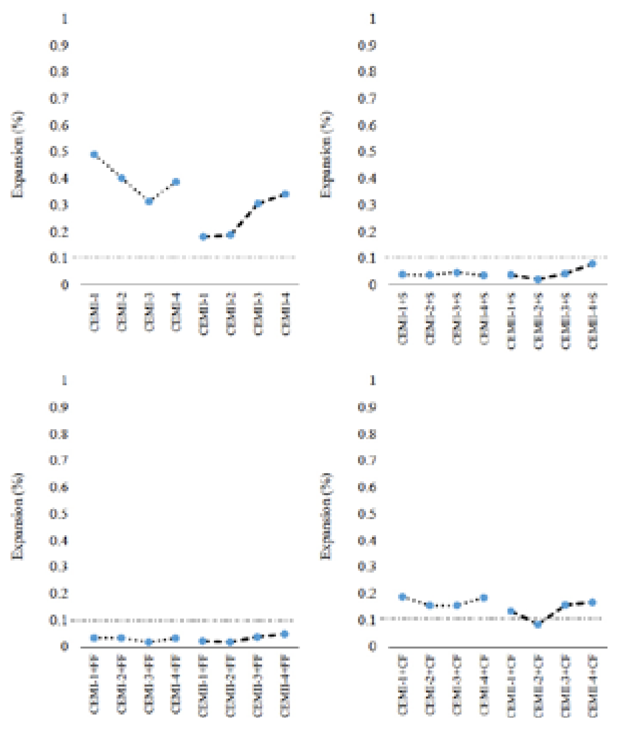

Figure 1. The expansions of the mortar bars before and after the 7Y-DP.

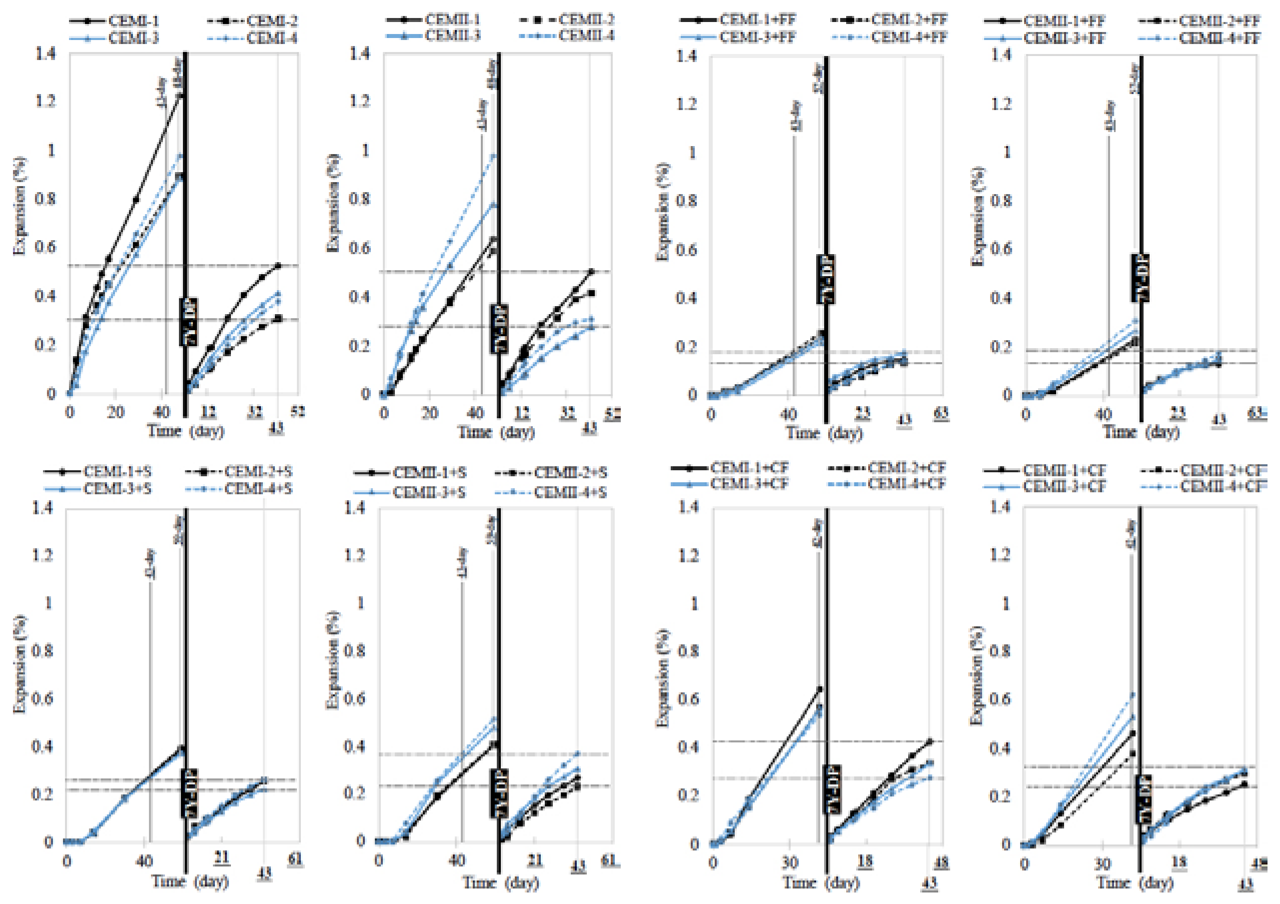

Figure 2. The expansions of the mortar bars before and after the 7Y-DP.

The expansions of the mortar bars after the 7Y-DP will be evaluated through two different types of graphs: 1) Ignoring the expansion values before the 7Y-DP as if the specimen were subjected to the NaOH solution for the first time, 2) Continuous (cumulative expansion) curves; as if there was no a dormancy period.

Figure 2 shows the expansions of the mortar bars before and after the 7Y-DP. It is obvious that the pre-7Y-DP (48 days) reactions considerably reduced the post-7Y-DP expansions of all CEMI mixtures as compared to the pre-7Y-DP's expansions — as pointed out earlier, this 7-year can be considered as a period in which ASR reactions is halted, for example, by preventing water ingress. This behavior is also valid for the plain CEMII mixtures; nevertheless, the extent of the decrement, as expected, is not high for the CEMII-1 and CEMII-2 mixtures—because the pre-7Y-DP expansions were lower than those of the other plain CEMI/CEMII mixtures. It must be mentioned that the CEMII-1 and 2 include 22–24% fly ash, but none in the CEMII-4 and only ~7% in the CEMII-3. Generally speaking, the higher the pre-7Y-DP expansion of a mixture reaches, the lower post-7Y-DP expansion would be—of course, compared to its pre-7Y-DP expansions. This fact is much more apparent in the plain CEMI mixtures with no ASR-mitigation mechanism. In other words, a great extent of the possible accelerated ASR reactions/or expansions—given the severe test condition of the AMB test, it is not necessary to have the same expansion level in the site even up to the end of service life of a real structure—that can be observed in these mixtures within a certain period had already occurred prior to the 7Y-DP.

The source of the post-7Y-DP expansions is the swelling of the old gel (absorption of water by the dry gel) and further ASR reaction, thus forming a new gel. The swelling of the old gel is more likely to be the dominant mechanism in the mixtures with higher pre-7Y-DP expansions, or at least, the contribution ratio of the post-7Y-DP expansions was higher in such mixtures. In other words, the residual available reactive silica would be limited in the mixtures in which there was no or insufficient SCM. Multon and Toutlemonde [8] showed that absorption of water (re-wetting) by old gel at any time of the life of an ASR-damaged structure can cause rapid swelling. This phenomenon was also reported in a few studies that dealt with the ASR reactivity of recycled concrete aggregates (RCA) obtained from ASR-suffered concrete. The expansion of old gel in the RCA is considered one of the contributing factors to the higher expansion (concrete prism test) of the RCA-containing concrete compared to the concrete containing the same virgin reactive aggregate [22, 23]. In addition, one of the reasons behind the lower expansion of the same RCA in AMBT was attributed to the loss of the old gel—that would swell by absorbing the moisture—as a result of further crushing of the coarse RCA to produce sand-size fraction for the test [22, 24].

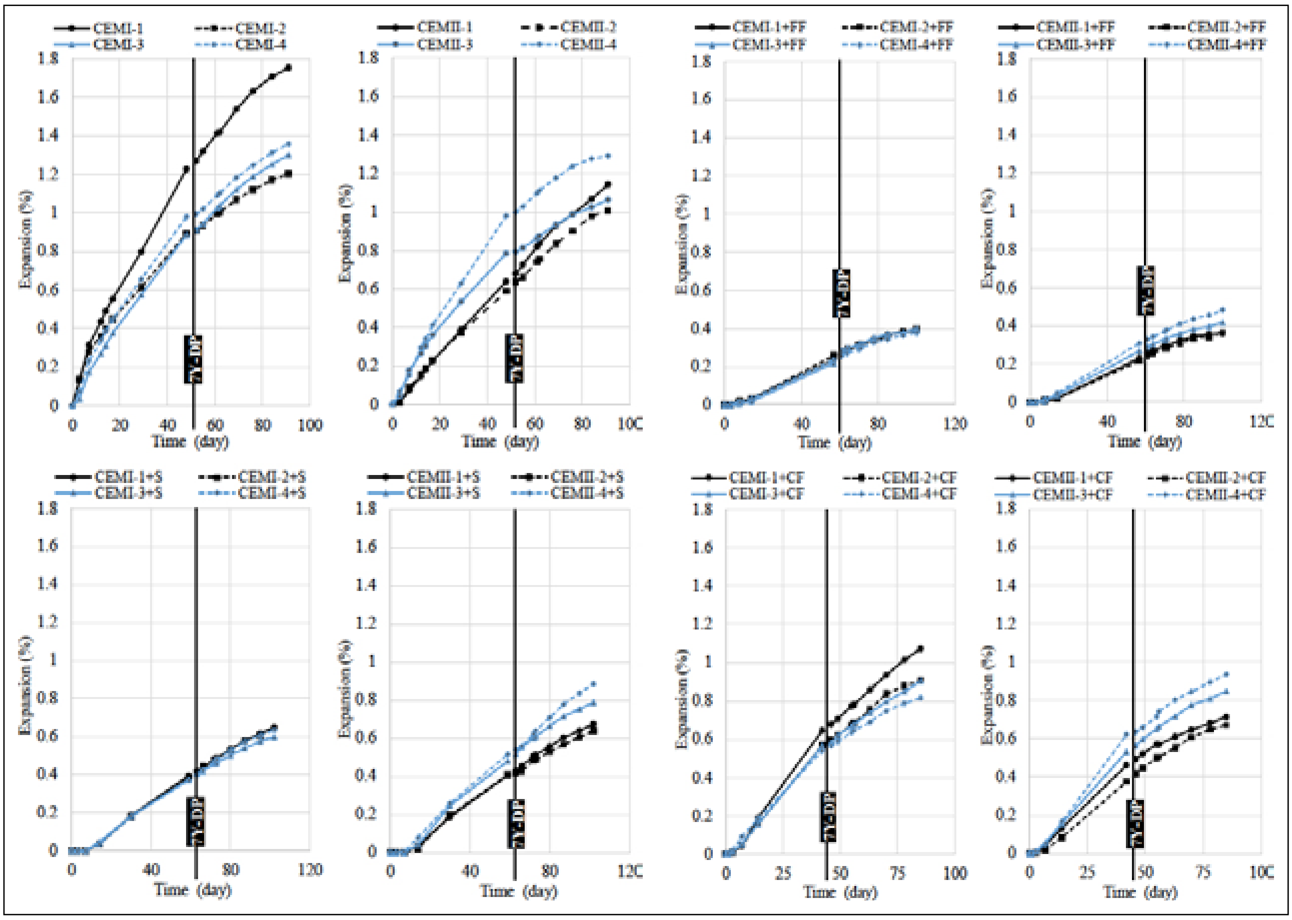

Figure 3. The cumulative expansions of the mortar bars before and after the 7Y-DP.

The post-7Y-DP expansions of S-containing and FF-containing mixtures were almost the same level as those of the pre-7Y-DP (43-day), even though the pre-7Y-DP exposure period (57–59 days) of them was 9–11 days longer than that of plain (48 days) mixtures. This finding shows that a significant amount of the ASR reaction/expansion was delayed owing to the ASR-mitigation effect of the S and FF; therefore, the specimens expanded almost like the pre-7Y-DP —except the first 14 days in which the ASR-mitigation effect of SCMs are much more dominant (it will be discussed later)— as if they were subjected to the NaOH solution for the first time and did not have an ASR history. It can be assumed that the contribution ratio of the new ASR-gel (post-7Y-DP gel) on the expansion was higher in these mixtures. On the other hand, the CF-containing mixtures acted almost like the plain mixtures because of the poorer ASR-mitigation performance of the class C fly ash. In other words, the 30% and 25% CF replacement ratios were not sufficient to delay the ASR reaction of, respectively, the CEMI and CEMII mixtures; therefore, a great extent of the possible accelerated ASR reactions/or expansions that can be observed in these mixtures within a certain period of time had already occurred before the 7Y-DP. It should be noted that the pre-7Y-DP exposure period (42 days) was even one day shorter than that of the post-7Y-DP; it was 15 and 17 days shorter than the post-7Y-DP exposure periods of S-containing and FF-containing mixtures, respectively. The abovementioned behavior would be more evident if the pre-7Y-DP exposure period were extended.

An interesting point comes out when the post-7Y-DP expansions are cumulatively added to the pre-7Y-DP curves as if there was no dormancy period (Fig. 3). Meanwhile, it should be noted that ASR-induced expansion is permanent and cumulative in the presence of water [8]. Multon and Toutlemonde [8] have reported that the shrinkage of ASR-suffered concrete due to drying at 30% RH had perfectly the same kinetics and range— no matter the conditions of ASR-induced damage and the direction of measurements— as for the sound concrete. They have stated that the drying shrinkage cannot balance the expansion; thus, the expansions and cracks are irreversible [8].

As shown in Figure 3, the appearance of the cumulative curves is almost like continuous ASR expansions, as if there were no 7Y-DP—especially S and FF-containing mixtures. Moreover, the increasing rates of the initial portion of the post-7Y-DP expansions almost match the pre-7Y-DP expansion trends. This behavior can be considered solid proof for the finding of Multon and Toutlemonde [8], who showed that water absorption by the dry old gel at any time can cause rapid swelling. If not, the formation of new gel—without the expansion of the old gel— would cause lower expansion rates. This phenomenon is much more critical for the mixtures in which there was no or insufficient SCM. As pointed out earlier, the residual available reactive silica

Table 3. The levene and ANCOVA analysis results

Mixture	Levene (Sig.)	ANCOVA P—T int. (Sig.)	Mixture	Levene (Sig.)	ANCOVA P—T int. (Sig.)
CEMI-1	0.207	0.001	**CEMI-1+S**	0.125	**0.88**>0.05
CEMII-1	0.666	0.003	**CEMII-1+S**	0.134	**0.124**>0.05
CEMI-2	0.126	0.001	**CEMI-2+S**	0.123	**0.108**>0.05
CEMII-2	0.559	0.001	**CEMII-2+S**	0.71	**0.47**>0.05
CEMI-3	0.186	0.001	CEMI-3+S	0.76	0.007
CEMII-3	0.096	0.001	**CEMII-3+S**	0.70	**0.40**>0.05
CEMI-4	0.134	0.001	**CEMI-4+S**	0.142	**0.276**>0.05
CEMII-4	0.070	0.001	**CEMII-4+S**	0.230	**0.916**>0.05
CEMI-1+FF	0.316	0.014	CEMI-1+CF	0.341	0.001
CEMII-1+FF	0.215	0.005	CEMII-1+CF	0.164	0.001
CEMI-2+FF	0.204	0.001	CEMI-2+CF	0.342	0.001
CEMII-2+FF	0.331	**0.37**>0.05	CEMII-2+CF	0.568	0.002
CEMI-3+FF	0.290	0.015	CEMI-3+CF	0.295	0.001
CEMII-3+FF	0.216	0.001	CEMII-3+CF	0.251	0.001
CEMI-4+FF	0.299	0.003	CEMI-4+CF	0.161	0.001
CEMII-4+FF	0.248	0.001	CEMII-4+CF	0.211	0.001

would be limited in these mixtures for the post-7Y-DP period, so the source of such post-7Y-DP expansion rates could not, certainly, be just the formation of a new gel.

As mentioned earlier, a significant amount of the ASR reaction was delayed owing to the ASR-mitigation effect of the S and FF; therefore, it can be assumed that the contribution ratio of the new ASR-gel (post-7Y-DP gel) on the expansion was higher in these mixtures. The reason behind the same increasing rate of the very initial portion of the post-7Y-DP expansions as the very last portion of the pre-7Y-DP expansions can be explained not only by the rapid swelling of the old gel but also by the early formation of new ASR gel—that no longer could be suppressed by the ASR-mitigation effect of SCMs in AMBT (80 °C NaOH solution). It should be remembered that AMBT can be applied to evaluate the ASR-mitigation performance of SCMs as long as the test period is restricted to 14 days [20]. There are vital differences between the ASR mitigation mechanisms of SCMs in the AMBT and those in other test methods. Reduction in the permeability of the matrix due to the pozzolanic reaction of SCMs is the dominant ASR-mitigation mechanism in the AMBT [25] as the solution continually supplies alkali. Therefore, higher impermeability strengthens the cementitious matrix's resistance against the ions' diffusion [25]. Diminution in the alkalinity of the matrix itself is, of course, one of the mechanisms, but it is not the main reason, as in the concrete prism methods [26]. Such a high impermeability was no longer the case beyond 14 days due to the continuous formation of cracks in the very early post-7Y-DP ASR reactions. Thus, the formation of new gel would be almost like that in the mixtures with insufficient SCMs. Although in natural structures and realistic conditions, such high expansion is not likely to occur in the SCM-containing mixtures, these results show that the ASR-mitigation capacity of SCMs would be limited after the repairing work conducted on a structure deteriorates under extreme conditions. But, of course, the primary purpose of using SCMs in this study was to scrutinize the effects of the pre-dormancy expansion levels on the post-dormancy expansions. Beyond 14-day, as mentioned earlier, AMBT is not a suitable test method for analyzing the ASR-mitigation behavior of SCMs; in future studies, the effect of dormancy period on the ASR-mitigation behavior could be investigated in the test methods having more realistic test conditions like concrete prism test.

In addition to assessing the initial increasing rates and the appearance of the curves, a series of statistical analyses were also conducted on each of the 32 mixtures to understand better the overall trends of the pre-7Y-DP and post-7Y-DP expansion curves. The Levene test was applied to measure the homogeneity of variances between the pre-7Y-DP and post-7Y-DP period data. According to the Levene test results, since "p" was less than 0.05 in all mixtures (Table 3), it was proven that the variances of both periods were homogeneous at the 95% significance level. Then, an analysis of covariance (ANCOVA) was applied between both periods.

In the ANCOVA test, the significance of "Period—Time" (P-T) interaction was used to assess whether the effect of time on a dependent variable, ASR expansions, differs across the periods. This interaction term captures any systematic change in the trend or rate between the two periods. If P (significance) is less than 0.05, it suggests that the relationship between time and expansion differed between periods. A significant P-T interaction would indicate that ASR trends changed after the 7Y-DP. In this case, either the dormancy or the pre-7Y-DP expansion/reaction levels —that is more likely to be, as discussed earlier in detail— might have altered the trend of post-7Y-DP expansions relative to that of pre-7Y-DP. On the other hand, no significant P-T interaction ($p \geq 0.05$) suggests that the ASR cumulative expansion curve continued after the 7Y-DP without substantial alteration. In other words, in such mixtures, the ASR reaction was delayed to a great extent —owing to the ASR-mitigation effect of some of the SCMs— so that it could be interpreted that the contribution ratio of the new ASR-gel (post-7Y-DP gel) on the expansion was much higher in these mixtures.

The P-T interaction's Sig. (p) values obtained from ANCOVA analysis of each mixture's data are presented in Table 3. The SCM-containing mixtures highlighted by the black color in the table have no significant P-T interaction ($p>0.05$), implying no statistically meaningful difference in slopes between the periods. In other words, the ASR reaction was delayed to a great extent, so the contribution ratio of the new ASR-gel (post-7Y-DP gel) to the expansion was much higher in these mixtures than in the other SCM-containing mixtures. As can be seen, this phenomenon was dominant only in the GGBFS-containing mixtures.

4. CONCLUSIONS

It can be interpreted from the test results that rapid swelling of old (and dry due to an extended drying/or dormancy period) ASR gel and formation of new gel can cause remarkable expansions again—no matter the mixture type or pre-dormancy period—in an ASR-suffered concrete (in which reactions were halted by dryness) whenever water can continually ingress into it for a long time. The post-dormancy expansion behavior of the mixtures without or with insufficient SCM revealed that the swelling of old gel was the dominant mechanism behind the expansions. On the other hand, the formation of new gel was the dominant reason in the specimens with sufficient SCM, which had lower pre-dormancy expansions due to the ASR-mitigation effect of the SCMs. The mechanisms above should be considered in the repair works of ASR-suffered structures. It can be concluded that an ASR-dormancy period established by water drainage or sealing of concrete, probably accompanied by repair work, will end if water can again ingress into the concrete. The level and rate of the post-dormancy expansions will be highly dependent on the extent of the pre-dormancy reactions, the gel formed, and the post-dormancy conditions. The other important parameters, such as the chemical compositions of old gel and post-dormancy moisture content, should be assessed in future studies.

ETHICS

There are no ethical issues with the publication of this manuscript.

DATA AVAILABILITY STATEMENT

The author confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declare that they have no conflict of interest.

FINANCIAL DISCLOSURE

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USE OF AI FOR WRITING ASSISTANCE

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PEER-REVIEW

Externally peer-reviewed.

REFERENCES

[1] Stanton, T. E. (1942). Expansion of concrete through reaction between cement and aggregate. *Trans Am Soc Civ Eng, 107*(1), 54-84. [CrossRef]

[2] Daidai, T., Torii, K. (2008). *A proposal for rehabilitation of ASR-affected bridge piers with fractured steel bars*. Proc. of 13th Inter. Conf. on Alkali-aggregate Reaction in Concrete.

[3] Daidai, T., Andrade, O., Torii, K. (2012). *The maintenance and rehabilitation techniques for ASR-affected bridge piers with fracture of steel bars*. Proc. 14th Inter. Conf. on Alkali-aggregate Reaction in Concrete, Austin, Texas.

[4] Torii, K., Prasetia, I., Minato, T., Ishii, K. (2012). *The feature of cracking in prestressed concrete bridge girders deteriorated by alkali-silica reaction*. Proc. 14th Inter. Conf. on Alkali-aggregate Reaction in Concrete, Austin, Texas.

[5] Nomura, M., Komastubara, A., Fujimoto, K., Torii, K. (2013). *Evaluation of maintenance methods for ASR-damaged structures in Hokuriku district, Japan*. Proceedings, Third International Conference on Sustainable Construction Materials and Technologies, Kyoto, Japan.

[6] Luan, Y., Arasawa, T., Mutsuyoshi, H., & Kawana, R. (2021). Repair of alkali-silica reaction-induced cracks using bacteria: Crack recovery and other properties. *ACI Mater J, 118*(4), 133-142. [CrossRef]

[7] Bakker, J. D. (2008). Control of ASR related risks in the Netherlands. In *Proceedings of the 13th International Conference on Alkali-Aggregate Reaction in Concrete, Trondheim, Norway*, (pp. 16-20).

[8] Multon, S., & Toutlemonde, F. (2010). Effect of moisture conditions and transfers on alkali silica reaction damaged structures. *Cement Concr Res, 40*(6), 924-934. [CrossRef]

[9] ASTM International. (2019). *Standard specification for coal fly ash and raw or calcined natural pozzolan for use in concrete*. ASTM-C618.

[10] Yüksel, C., Mardani-Aghabaglou, A., Beglarigale, A., Yazıcı, H., Ramyar, K., & Andiç-Çakır, Ö. (2017). Alkali-silica reaction expansions and the extent of alkali leaching in concretes containing basalt and waste glass as aggregate. *Teknik Derg, 28*(2), 7865-7882. [CrossRef]

[11] Yüksel, C., Mardani-Aghabaglou, A., Beglarigale, A., Yazıcı, H., Ramyar, K., & Andiç-Çakır, Ö. (2016). Influence of water/powder ratio and powder type on alkali-silica reactivity and transport properties of self-consolidating concrete. *Mater Struct, 49*, 289-299. [CrossRef]

[12] Andiç-Çakır, Ö. (2007). *Investigation of test methods on alkali aggregate reaction*, [Doctoral dissertation], Ege University.

[13] Beglarigale, A., Yazıcı, H. (2013). The effect of alkali-silica reaction on steel fiber-matrix bond characteristics of cement based mortars. *Constr Build Mater, 47*, 845-860. [CrossRef]

[14] Beglarigale, A., & Yazici, H. (2014). Mitigation of detrimental effects of alkali-silica reaction in cement-based composites by combination of steel microfibers and ground-granulated blast-furnace slag. *J Mater Civ Engin, 26*(12), 04014091. [CrossRef]

[15] Çopuroğlu, O., Andiç-Çakir, Ö., Broekmans, M. A., & Kühnel, R. (2009). Mineralogy, geochemistry and expansion testing of an alkali-reactive basalt from western Anatolia, Turkey. *Mater Charact, 60*(7), 756-766. [CrossRef]

[16] ASTM International. (2007). *1260 Standard test method for potential alkali reactivity of aggregates (Mortar-Bar Method)*. ASTM C1260-07

[17] ASTM International. (2007). *Standard test method for determining the potential alkali-silica reactivity of combinations of cementitious materials and aggregate (Accelerated Mortar-Bar Method)*. ASTM International. ASTM C1567-07.

[18] Turkish Standards Institution. (2012). *Complementary Turkish Standard for the implementation of TS EN 206*. TS 13515.

[19] ASTM International. (2020). *Standard guide for reducing the risk of deleterious alkali-aggregate reaction in concrete*. ASTM International. ASTM C1778-20.

[20] Bérubé, M. A., Duchesne, J., & Chouinard, D. (1995). Why the accelerated mortar bar method ASTM C 1260 is reliable for evaluating the effectiveness of supplementary cementing materials in suppressing expansion due to alkali-silica reactivity. *Cement Concrete Aggregates, 17*(1), 26-34. [CrossRef]

[21] Shon, C. S., Sarkar, S. L., & Zollinger, D. G. (2004). Testing the effectiveness of Class C and Class F fly ash in controlling expansion due to alkali-silica reaction using modified ASTM C 1260 test method. *J Mater Civ Eng, 16*(1), 20-27. [CrossRef]

[22] Johnson, R., & Shehata, M. H. (2016). The efficacy of accelerated test methods to evaluate alkali silica reactivity of recycled concrete aggregates. *Constr Build Mater, 112*, 518-528. [CrossRef]

[23] Piersanti, M., & Shehata, M. H. (2022). A study into the alkali-silica reactivity of recycled concrete aggregates and the role of the extent of damage in the source structures: Evaluation, accelerated testing, and preventive measures. *Cem Concr Compos, 129*, 104512. [CrossRef]

[24] Piersanti, M. (2015). *Testing recycled concrete aggregate suffering different levels of alkali-silica reaction for use in new structures* [Doctoral dissertation], Toronto Metropolitan University.

[25] Xu, G. J., Watt, D. F., & Hudec, P. P. (1995). Effectiveness of mineral admixtures in reducing ASR expansion. *Cem Concr Res, 25*(6), 1225-1236. [CrossRef]

[26] Kawabata, Y., & Yamada, K. (2015). Evaluation of alkalinity of pore solution based on the phase composition of cement hydrates with supplementary cementitious materials and its relation to suppressing ASR expansion. *J Adv Concr Technol, 13*(11), 538-553. [CrossRef]