HOW CAN WE EXPLAIN CRACKS ON THE SURFACE OF ASR DAMAGED CONCRETE?

WIE KANN MAN RISSE AN DER OBERFLÄCHE EINES DURCH AKR GESCHÄDIGTEN BETONS ERKLÄREN?

Hans W. Reinhardt[1], Oliver Mielich[2], Hasan Özkan[2]

[1] Institute of Construction Materials, University of Stuttgart

[2] Materials Testing Institute (MPA), University of Stuttgart, Otto-Graf-Institute

SUMMARY

For testing ASR (alkali–silica reaction) two shapes of specimens were used with various sizes. The results showed a great influence on occurrence and magnitude of expansion. The larger the specimen the greater is the maximum expansion and the later it takes place. The paper refers to the papers in [1, 2], the experimental results of which are further analysed. The results were very helpful in explaining the development of (macro) cracks in structural elements which suffer from ASR. Leaching of alkalis appears to play an important role.

ZUSAMMENFASSUNG

Zwei verschiedene Probekörperformen in mehreren Größen wurden für die AKR-Untersuchung verwendet (AKR: Alkali-Kieselsäure-Reaktion). Dabei zeigte sich, dass die maximale Dehnung umso später auftritt je größer die Probe ist. Auch der Betrag hängt von der Größe ab. Der Aufsatz verweist auf die Beiträge in [1, 2], dessen experimentellen Ergebnisse weiter analysiert werden. Das Entstehen von Makrorissen in einem quellfähigen Material wird erklärt. Denn obwohl jedermann auf die weiten Risse hinweist, wird ihr Entstehen nicht thematisiert. Es wird gezeigt, dass das Auslaugen von Alkalien eine wichtige Rolle spielt.

1. INTRODUCTION

Several ASR tests (alkali–silica reaction) are used worldwide, but the test conditions e.g. pre-curing, temperature, alkali-content, humidity, prism size cross-section or shape differ from one test method to another [3-5]. Thus, the results and conclusions from different test methods may vary widely. One main problem is that alkalis are leached out of the prisms during exposure in the humid environment and hence reduce the final prism expansion [6]. This finding was first reported by Blanks and Meissner [7]. One effective measure to reduce the amount of alkali leaching during ASR testing is to increase the prism cross-section [e.g. 8, 9]. If we assumed that the alkalis on the surface leached first, it is not obvious that in a swelling material a large macrocrack can develop on the surface. Therefore the question is “How can we explain such a phenomenon?”

2. RESULTS OF PREVIOUS INVESTIGATION

The results of a limited research program have been reported first by Özkan [1] and later in [2]. Two specimen geometries will further be analyzed, prisms and cylinders. Table 1 shows the relevant data.

Table 1: Relevant data of specimens

Specimen	Dimensions [cm]	Surface A [cm²]	Volume V [cm³]	A/V ratio [1/cm]
Prism	[5 x 5 x 20]	450	500	0.90
	[7.5 x 7.5 x 28]	953	1575	0.60
	[10 x 10 x 40]	1800	4000	0.45
	[15 x 15 x 30]	2250	6750	0.33
Cylinder	[Ø 5 x 20]	353	393	0.90
	[Ø 10 x 40]	1414	3142	0.45
	[Ø 15 x 30]	1767	5301	0.33

The dimensions were chosen such that a great variety of the A/V ratio came out. The prims had dimensions between 5 x 5 x 20 cm^3 and 15 x 15 x 30 cm^3, the cylinders varied between Ø 5 cm x 20 cm and Ø 15 cm x 30 cm.

The specimens were manufactured and stored in a climate room at 20°C and 95% RH for 28 days and thereafter in a 40°C fog chamber for 365 days. The length changes were measured at regular intervals. The expansion of the specimens is shown in Figs. 1 and 2 and the results will be discussed in the following.

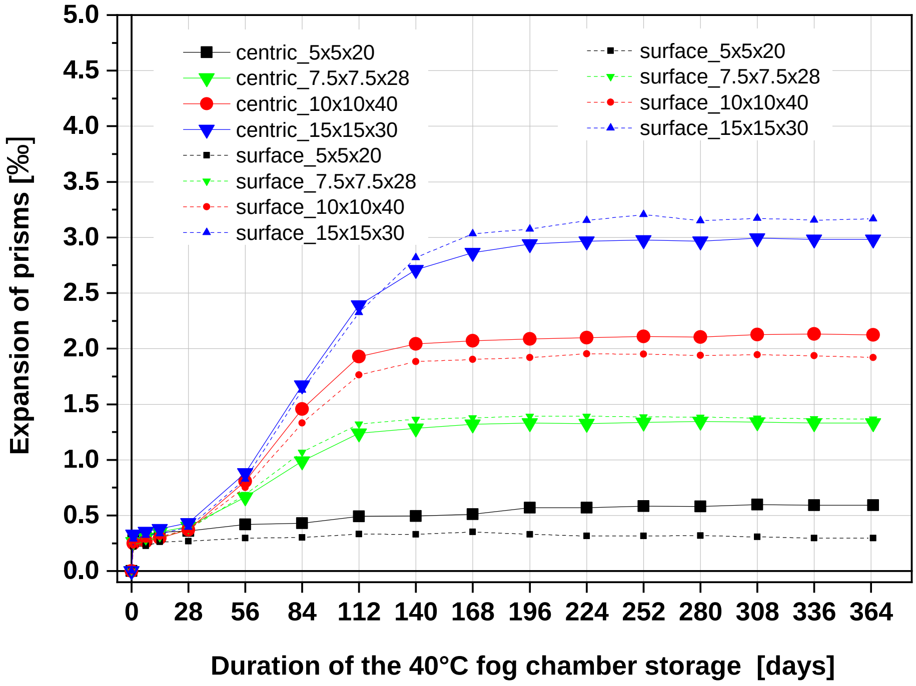


Fig. 1: Expansion of prisms with different dimensions

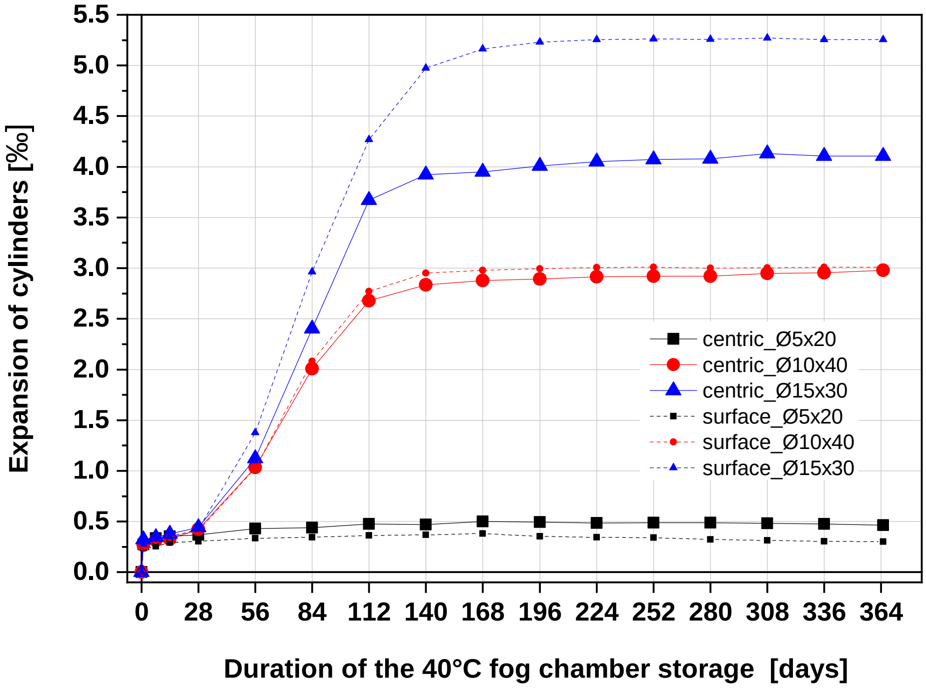


Fig. 2: Expansion of cylinders with different dimensions

3. DISCUSSION

3.1 Influence of A/V ratio on maximum expansion

The surface A to volume V ratio is an important factor assessing penetration of water and leaching of alkalis in concrete. Both processes are diffusion controlled. The larger the surface the more water can penetrate into concrete which is necessary for alkali-silica reaction. Leaching of alkalis depends on water supply, the size of the surface and the volume. The specimens were not stored in water but in water-saturated atmosphere which causes a water film on the surface by condensation. Fig. 3 shows the maximum expansion as function of A/V ratio.

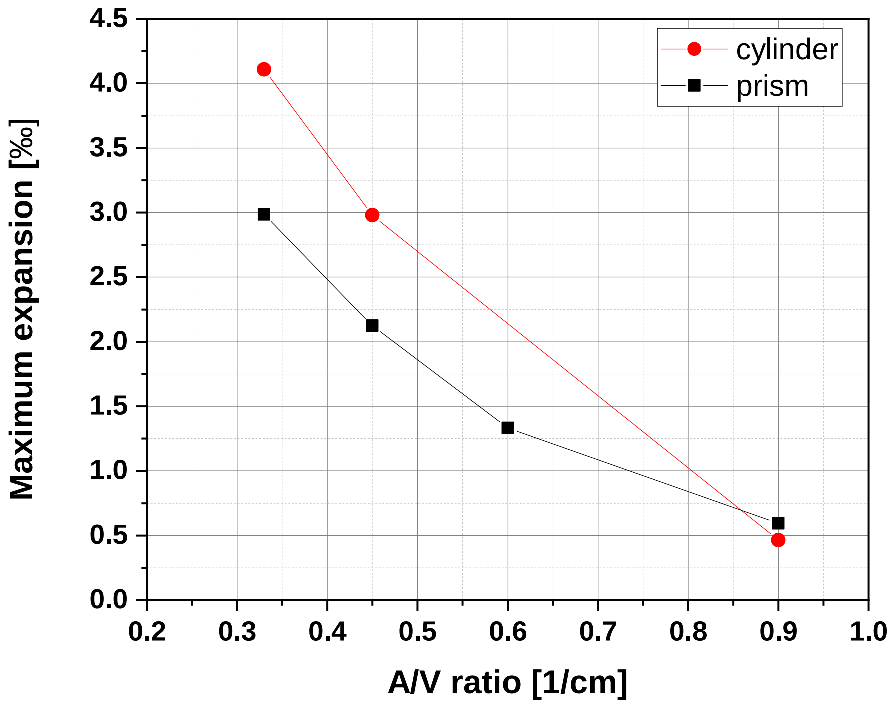
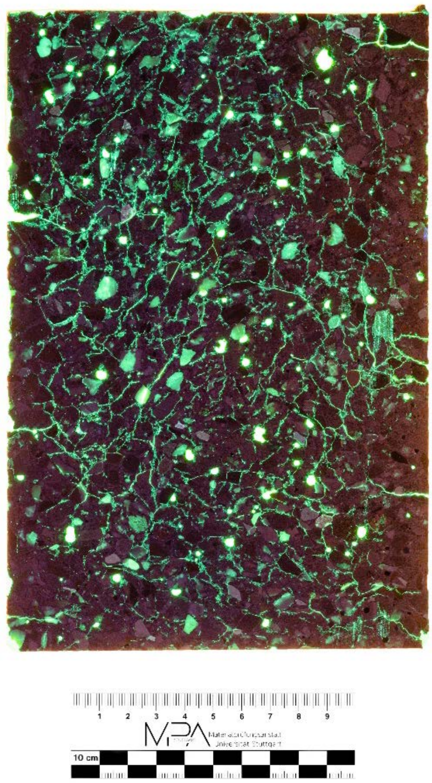


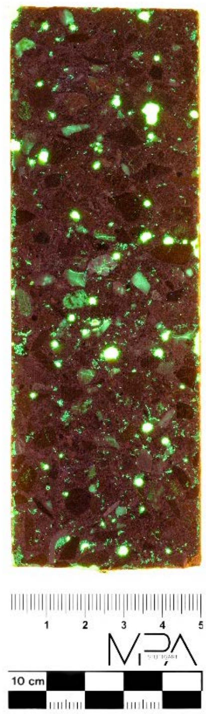
Fig. 3: Maximum expansion as function of A/V

A strong effect can be seen. The larger A/V the smaller is the maximum expansion. The expansion of the largest cylindrical specimen amounts to 4‰ while the smallest specimen showed only 0.5‰. The influence of the prisms is less pronounced. It is assumed that leaching is mainly responsible for maximum expansion or, the other way round, a large volume supplies much more alkalis over a long time. A large volume makes A/V small which causes a large expansion. Opposite to that, a small specimen reaches much faster the end of reaction because all alkalis are leached out.

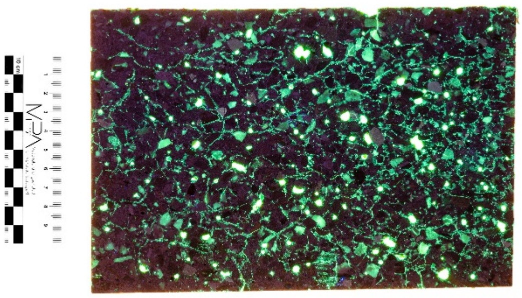
The analyses of seven fluorescence impregnated plane polished sections confirmed the results, that the larger A/V the smaller is the maximum expansion. Four examples of the internal variation of “crack intensity” are presented in Fig. 4, showing UV-photos of cylinders and prisms with A/V of 0.30 and 0.90. With A/V ratio of 0.30 a larger area had a higher “crack intensity” compared with A/V ratio of 0.90 in each case for cylinders and prisms.



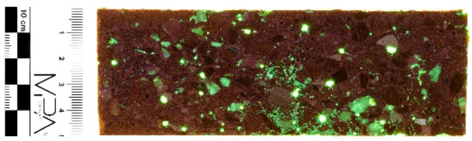
cylinder, A/V ratio = 0.30



cylinder, A/V ratio = 0.90



prism, A/V ratio = 0.30



prism, A/V ratio = 0.90

Fig. 4: Photo in UV-light of the plane polished section prepared from cylinders and prisms with A/V ratio of 0.3 and 0.9

Over the width of the cylinders and the height of the prisms with A/V ratio of 0.30, they show a “cracking gradient”, as in [8] reported. The cracking was somewhat less in the outer 10-20 mm. In this outer layer, only single cracks can be found, compared with craquelé like cracks in the middle. This indicates that less ASR is taking place in this outer layer, probably due to the higher amount of alkali leaching.

3.2 Influence of A/V on the course of ASR

The time necessary to reach the asymptote of expansion must also depend on A/V ratio which can be seen in Fig. 5.

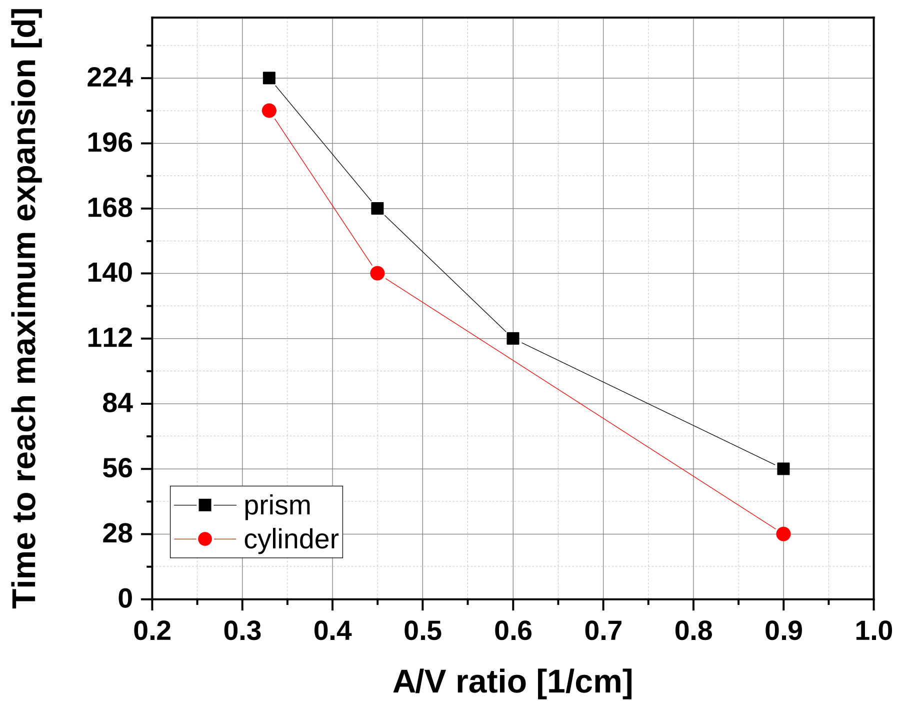


Fig. 5: Time necessary to reach the asymptote of expansion

If the surface is large water can penetrate quickly into concrete and the time necessary to cause maximum expansion is short. The small prism with 5 cm edge length needs only 56 days to reach maximum expansion whereas the 15 cm thick specimen needs 224 days. The corresponding numbers for the cylinder are 28 days and 200 days.

3.3 Influence of specimen volume on maximum expansion

Fig. 6 shows the relationship between maximum expansion and volume of the specimen.

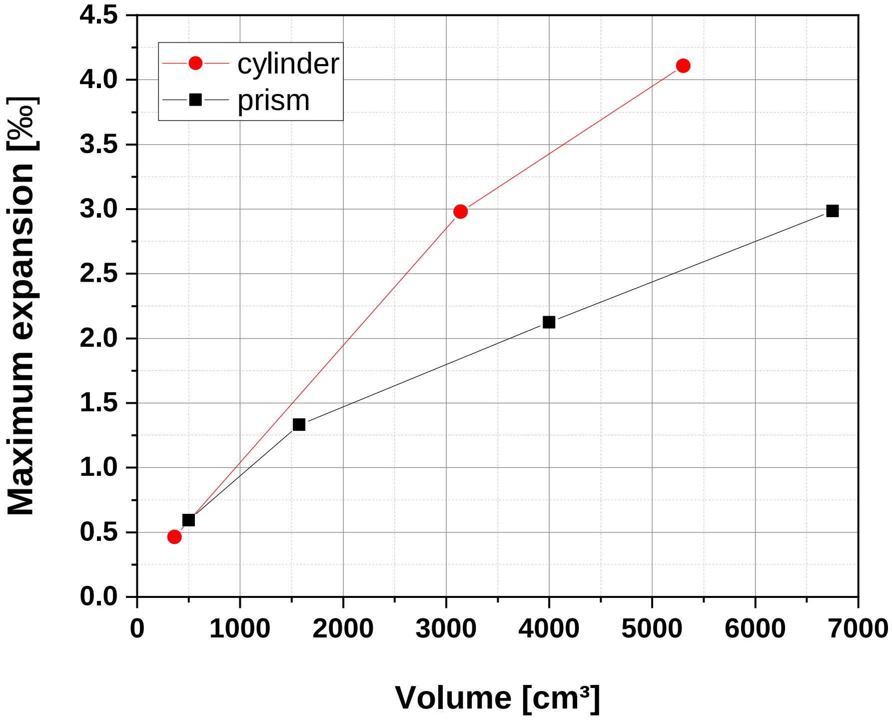


Fig. 6: Maximum expansion vs. volume of specimen.

A cylinder with a volume of about 5,300 cm^3 expands 4‰ while a cylinder of about 400 cm^3 expands only 0.5‰. The prisms show less pronounced results but the trend is the same. The message of Fig. 6 is the same as of Fig. 3.

All results prove that it is essential for interpreting test results that the size and shape of the specimens used are known and taken into consideration. Looking to international standards for testing ASR in concrete there is a great variety. One has also to be prudent in comparing test results published.

3.4 Imposed deformation, eigenstresses and macrocracks in ASR affected structures

It is not obvious that in a swelling material a large macrocrack can develop. However, hundreds of cases have been published. Fig. 7 shows one of them.

Fig. 7: Large cracks caused by ASR

We can see 0.5 to 3 mm wide cracks. How can we explain such a phenomenon? Now, let us consider a structural member in which water can penetrate from outside and ASR can start. ASR causes expansion as has been always measured and agreed upon. If in a solid material expansion develops and the free expansion cannot take place then compressive stresses develop. These stresses must be counteracted by tensile stresses somewhere else in the cross-section. These stresses are called eigenstresses due to imposed deformation. The most probable place for the tensile stress is directly adjacent to the compressive stress. We assumed that ASR develops at the surface of a structural member. It would mean that compressive stresses would exist parallel to the surface which must be equilibrated by tensile stresses directly adjacent. When tensile stresses reach the tensile strength or the tensile strain reaches the ultimate strain of concrete a crack will develop however, not at the surface. Now assume that ASR progresses. Then, new material will expand and the crack will open more and propagate into the interior. This cannot explain the large crack at the surface.

But now the message of figures 1 to 6 come into play saying that the maximum ASR expansion develops faster the smaller the affected volume is. That means that with the progression of ASR into the material the reacting volume becomes larger and the maximum strain and necessary time increases also. With progressing time, the places which were first in compression will become stress-free and a crack can open at the surface. When the crack progresses further and further new material will react while previous material has already ended the reaction. We can see this when we move in Fig. 6 from left to right along the curves. We could also look to Figs. 3 and 5 where we move from right to left because the A/V ratio becomes smaller with every step. Every new material reacts slower but the maximum expansion gets larger. The crack becomes wedge-shaped.

This behavior provides the solution of the enigma of the mysterious crack in a swelling material which was thought to be stressed in compression. So, Figs. 3, 5 and 6 were the necessary key to open this mystery which can only be understood if the history of the crack progression is regarded. In fact, it is the leaching which determines the formation of large cracks.

4. CONCLUSIONS

The experiments lead to the following conclusions:

1) Larger specimens cause greater maximum expansion.
2) Larger specimens reach maximum expansion later.
3) Surface to volume ratio (A/V ratio) is an important indicator.
4) International standards for testing ASR use different specimen sizes and shapes.
5) Cylinders cause greater maximum expansion than prisms with the same A/V.
6) One has to be prudent when published test results are being compared.
7) The leaching of alkalis, beginning from the surface, determines the formation of large cracks.
8) Photos in UV-light of plane polished section prepared from cylinders and prisms confirm these findings.
9) Large surface cracks can be understood only with the history of crack development.

Note: The experiments have been carried out on crushed slow reacting rock of the Upper Rhine Valley. Strictly speaking, the results of the study are only valid for the material tested. But the trend goes for other rocks too.

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