COMPARATIVE LABORATORY TESTS ON THE ALKALI-SILICA REACTION

Dennis Lenzner
Institut für Gesteinshüttenkunde der RWTH Aachen, GFR

1. ABSTRACT

Three different reactive aggregates are investigated with the mortar bar test according to the ASTM specifications and the procedure which has been used in the investigations on opaline sandstone in Aachen.

Mineralogical and chemical analysis reveal marked differences of the reactivity of the aggregates.

An acceleration of the alkali-silica reaction (asr) either by a high alkali content of the mortar or by an elevated curing temperature causes a reduction of the deteriorations due to the asr.

Key words: mortar-bar test, alkali - silica ratio

2. INTRODUCTION

The investigations of the asr done in Aachen /1,2/ were carried out mainly with reactive opaline sandstone from Schleswig-Holstein, some also with reactive flint. Thereby, broad experiences were gained about suitable experimental test methods and about influences of different parameters on the asr, such as mortar composition, grain size of the reactive aggregate, different admixtures, curing temperature, and ambient humidity. The test procedure followed the specifications of the German Standard DIN 1164 in order to obtain results which could be compared with other test series.

However in the Anglo-Saxon countries and beyond in most of the other countries who are interested in the asr, the ASTM specifications and especially the mortar bar test C 227 are applied in the investigation of the asr, in spite of several references of the poor applicability of the test results to concrete practice, e.g. /3,4,5/.
Table I shows some of the differences of the test procedures.

The main differences are the mortar composition, the grading of the aggregate, and the curing temperature. The higher cement content of the ASTM mortar results in a greater amount of alkalies per volume, by which the deterioration due to the asr is aggravated /6/.

When comparing the gradings of the aggregate, the main difference is that 10% of the aggregate is admixed to the ASTM mortar in the coarse fraction of 2,36 - 4,76 mm.

Earlier investigations /1/ showed that coarse reactive aggregate reacts very slowly and contributes to the expansion of the mortar not before two or three years time. These same investigations showed that an elevated curing temperature accelerates the asr. However, one result of an acceleration of the asr is a reduced final deterioration as a larger share of the swelling pressures acts upon a younger and more plastic mortar structure and therefore is disassembled without damage through plastic deformation.

One of the intentions of these investigations in progress is to find out whether the differences of the test specifications cause systematical differences of the test results.

Another intention is to investigate whether the test method used in Aachen gives useful results with less reactive aggregates.

Table I		
Some specifications of the mortar bar test:		
	ASTM C 227	carried out in Aachen
mortar mix cement: aggregate	1 : 2,25	1 : 3
water	flow of 105 - 120	W/C = 0,5
aggregate grading	15% 150 - 300 µm 25% 300 - 600 µm 25% 0,6 - 1,18 mm 25% 1,18 - 2,36 mm 10% 2,36 - 4,76 mm	33,3% 80 - 500 µm 33,3% 0,5 - 1,0 mm 33,3% 1,0 - 2,0 mm
specimen dimensions	25 x 25 x 285 mm	10 x 40 x 160 mm
curing temperature	37,8 ± 1,7 °C	18 - 23 °C

3. MATERIALS

3.1 Cements

Five different cements are used: three Portland cements from South Africa, one German Portland cement PZ 45 F, and one slag cement HOZ 35 L, the analysis of which are shown in table 2.

Table II

Compositions of the cements

	PZ %	HOZ %	C(0,62) %	D(0,85) %	J(0,82) %
SiO_2	18,99	27,24	22,40	23,30	20,95
Al_2O_3	5,03	8,82	5,38	5,07	5,08
TiO_2	0,21	0,55	0,32	0,33	0,26
Fe_2O_3	2,55	1,67	2,69	3,50	3,74
MnO	0,17	0,37	0,05	0,17	0,04
CaO	61,85	47,38	64,00	63,10	64,60
MgO	2,51	6,47	1,82	0,85	1,26
SO_3	4,33	3,31	1,88	2,11	2,58
K_2O	1,31	1,06	0,23	0,79	0,98
Na_2O	o,26	0,49	0,38	0,23	0,15
Na_2O - eq.	1,12	1,19	0,53	0,75	0,79

3.2 Reactive Aggregate

Four different reactive aggregates are used in the investigation:

1. Opaline sandstone
2. natural aggregate from the quarry Bültwisch containing opaline sandstone
3. Aggregate from the Malmesbury Group, South Africa
4. Feldspatic greywacke from Malay Falls, Nova Scotia, Canada

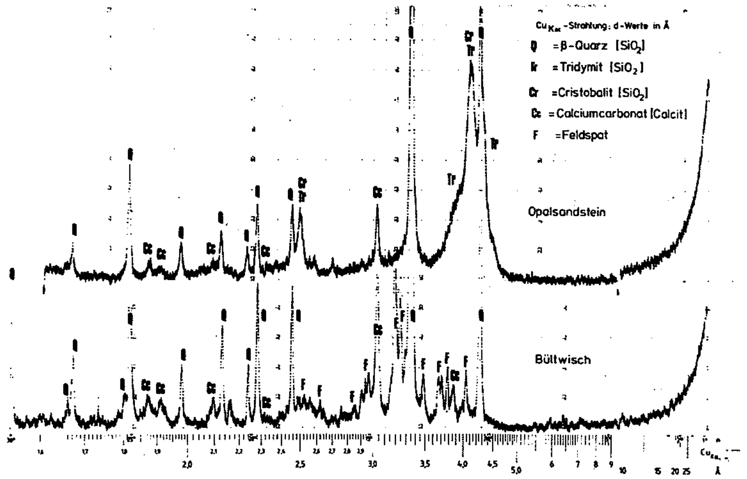


Fig. 1: X-ray diffraction pattern of opaline sandstone and Bültwisch aggregate

The X-ray diffraction analysis of the opaline sandstone clearly shows peaks of cristobalite and tridymite and reveals this material to be highly reactive. These peaks are not found in the diffraction pattern of the Bültwisch aggregate as it contains opaline sandstone only in minor amounts.

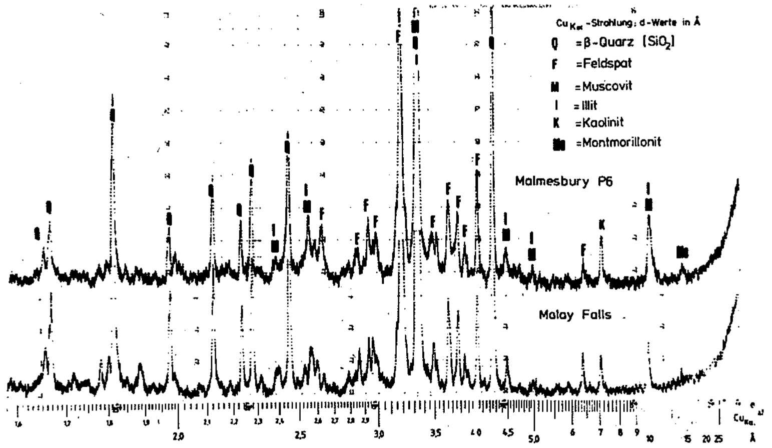


Fig. 2: X-ray diffraction pattern of Malmesbury and Malay Falls aggregate

The aggregates Malmesbury from South Africa and Malay Falls from Canada show the same x ray - diffraction pattern. Besides quartz and feldspar, minor amounts of mica- and clay- minerals are detected.

4. EXPERIMENTAL

According to the specifications ASTM C 227 and the test procedure used in Aachen, mortar bars were prepared using the cements and aggregates named above. Although ASTM C 227 demands a mortar flow of 105 - 120, a uniform water/cement ratio of 0,5 was used as testing with different water/cement ratios was not possible because of the limited quantity of South African cements available. For the cement-rich ASTM mixes, this water/cement ratio was too high whereas it had to be raised to 0,6 for the 1 : 3 mixes which contain the aggregate of ASTM grading.
The amount of water together with the cement content determines the porosity of a mortar. And the deterioration due to the asr highly depends on the porosity of the mortar /8/. This has to be kept in mind when comparing the results of the different test series.
The opaline sandstone with a grain size of 0,08 - 0,5 mm replaced 4% of inert aggregate in the mortar. The other aggregates have been used exclusively, i.e. without addition of inert aggregate.
At varying intervals, the expansion and the resonance frequency of the specimens are measured in order to monitore the effect of the asr. The resonance frequency gives an indication of the strength of the mortar structure as has been explained somewhere else, i.e. /9/.

5. RESULTS

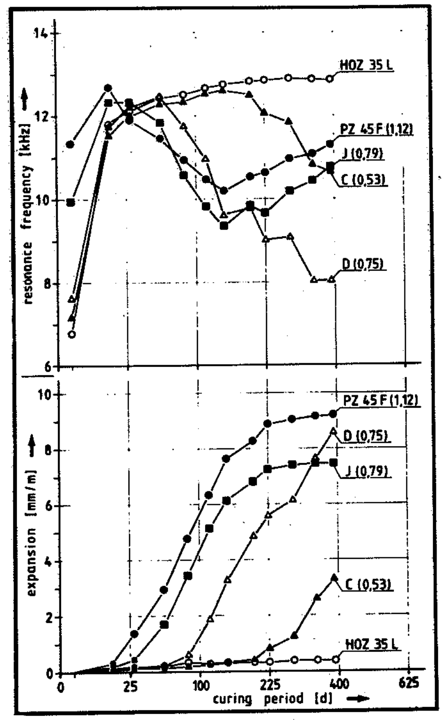


Fig. 3 shows the expansions and the resonance frequencies of the specimens made of mortars with different cements and containing opaline sandstone. It is to be seen that the rate of the deterioration corresponds to the alkali-content of the cement. However, a reaction which starts earlier and progresses more rapidly causes less deterioration at later ages as is shown by the plot of the resonance frequencies. An increase of the resonance frequency indicates the rehealing of the micro-cracks and therewith the strengthening of the structure. The rehealing starts the earlier the higher is the alkali content of the cement. Furthermore, an earlier asr causes less deterioration because the younger, more plastic mortar structure is able to disassemble part of the swelling pressure through plastic deformation.
The mortar with the slag cement does not show any effects of the asr yet.

Fig. 3: ASR with different cements and opaline sandstone

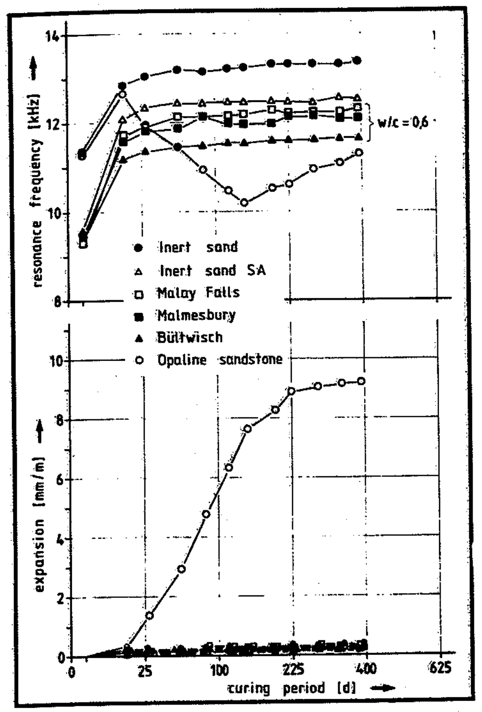
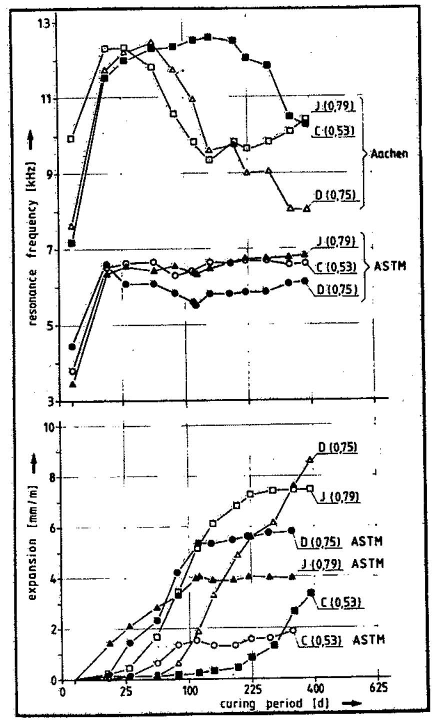


Fig. 4 shows the effects of the asr on mortars with PZ 45 F and different aggregates. The results of two other series with inert aggregates are included in the figure.

Until now, only the specimens containing opaline sandstone show expansion and a drop of the resonance frequency.
The low resonance frequencies of the mortars with Bültwisch-, Malmesbury- and Malay Falls-aggregate clearly show the influence of the elevated water-cement ratio on the strength. The increase of the water content was necessary because of the larger amount of fine particles in the aggregate with ASTM grading.

Fig. 4: ASR with PZ 45 F and different aggregates



The comparison of the two test methods is shown in figure 5.
Here the expansions and the resonance frequencies of the mortars with the South African cements and containing opaline sandstone are shown.

The deterioration of the ASTM-mortars is accelerated because of the higher cement content and the elevated curing temperature. But the deterioration of the specimens of the other series is more pronounced because of the above mentioned reasons.

Fig. 5: ASR with mortars according to ASTM C 227 and to the specifications used in Aachen

6. CONCLUSIONS

Within the hitherto test period of one year, only the mortars containing the highly reactive opaline sandstone are affected by the asr and show sincere expansions and reductions of the resonance frequency.
However, experiences with coarse natural aggregate from the Bültwisch quarry /10/ show that under the chosen test conditions deteriorations can be observed which start even after three years.
The test period is too short to allow an estimation of the mortars with the weakly reactive aggregates Malay Falls, Malmesbury and Bültwisch. The tests are continued.

The comparison of the effects of the asr with the cements of different alkali content shows that a higher alkali content accelerates the reaction if the amount of the reactive opaline sandstone is kept constant. Even though the mortar bars with the highest alkali content show the greatest expansions until now, the later deterioration of the structure is inferior to that of the bars with a medium alkali content. This is to be seen from the graphs of the resonance frequency. The reason is that the rehealing of the microcracks begins at an earlier age in the mortar with the high alkali content.

This finding gives a new approach to the conception of the pessimal alkali content or the pessimal ratio of the alkali content to the quantity of reactive silica.
The decrease of the deterioration with increasing alkali content and constant quantity of reactive silica is explained by Vivian /11/ with the formation of a liquid reaction product which exerts a minor pressure on the structure. This explanation is certainly true for very high alkali contents, i.e. more than 2 % Na_2O equivalent.
However, the given test results with cements containing alkalies up to 1,12 % Na_2O - equivalent already show a pessimum effect which is determined by the relation of the rate of the asr to the hardening of the mortar.

The comparison of the results found with the tests according to ASTM C 227 and according to the specification used in Aachen shows that the higher cement content and the higher curing temperature of the ASTM test accelerates the asr but reduces the deterioration.
Only the continuation of the tests will show whether this acceleration affects the test results with the less reactive aggregates.

7. ACKNOWLEDGEMENTS

The support of these investigations by Mr. M.P. Brandt CSIR, NBRI Pretoria, South Africa and by Dr. P.E. Grattan Bellew, National Research Council, Canada who contributed aggregates and cements is highly appreciated.
The financial support of the investigations by the Deutsche Forschungsgemeinschaft, Bonn is gratefully acknowledged.

8. REFERENCES

/1/ Lenzner, D., Ludwig, U., The alkali aggregate reaction with opaline sandstone from Schleswig-Holstein
Proc. 4th Int. Conf. Alkalies in Concrete, Purdue University, West Lafayette, USA, 1978

/2/ Ludwig, U., Theoretical and practical research on the alkali-silica reaction
Proc. 5th Int. Conf. Alkalies in Concrete, Cape Town, South Africa, 1981

/3/ Grattan-Bellew, P.E., Study of expansity of a suite of quartzwackes, argillites and quartz arenites
Proc. 4th Int. Conf. Alkalies in Concrete, Purdue University, West Lafayette, USA, 1978

/4/ Oberholster, R.E., Brandt, M.P., Weston, A.C., The evaluation of greywacke, hornfels and granite aggregates for potential alkali reactivity
Proc. 4th Int. Conf. Alkalies in Concrete, Purdue University, West Lafayette, USA, 1978

/5/ Stark, D., Alkali silica reactivity in the Rocky Mountain region
Proc. 4th Int. Conf. Alkalies in Concrete, Purdue University, West Lafayette, USA, 1978

/6/ Locher, F.W., Sprung, S., Einflüsse auf die Alkali-Kieselsäure-Reaktion im Beton
ZKG 4 (1975), 162-169

/7/ Keil, F., Mathieu, H., Normenprüfung, Kleinprüfung, Schnellprüfung
ZKG 3 (1958), 83-85

/8/ Lenzner, D., Influence of the amount of mixing water on the alkali-silica reaction
Proc. 5th Int. Conf. Alkalies in Concrete, Cape Town, South Africa, 1981

/9/ Lenzner, D., Ludwig, U., Alkali aggregate reaction with opaline sandstone
Proc. 7th Int. Congr. Chem. Paris 1980
Vol. III, VII - 119

/10/ Lenzner, D., Ludwig, U., Langzeituntersuchungen zur Alkali-Kieselsäure Reaktion in Beton
Proc. 8. Ibausil, Weimar 1982, Vol. 1, 84-89

/11/ Vivian, H.E., The effect of amount of added alkalies on mortar expansion
Council for Scientific and Industrial Res. 23 (1950), 31-47