Influence of Mix Design on Alkali-Silica Reaction in Concrete

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ABSTRACT

The speed of deterioration of Alkali-Silica-Reaction in concrete is mainly influenced by the type of reactive aggregate and the amount of alkalis in the cement. In this test the influence of concrete mix proportion, especially the w/c-ratio, on the degree of deterioration by ASR was analysed for various cement and aggregate combinations.

INTRODUCTION AND AIM OF RESEARCH

In some limitated areas of northern Germany aggregates are found containing opaline sandstone. Under moist environmental conditions concrete, containing a critical amount of that aggregate, could be damaged by ASR.
Use of low alkali cements for concrete production with reactive aggregates is recommended in Germany. These requirements - in combination with the test procedure for aggregates - have been proved within the last 10 years.

The aim of the research-program which is described was to find out whether the mix proportioning of concrete, especially the water-cement ratio and the fineness of cement, have an influence on the degree of damage due to ASR under constant moist curing conditions. The tests were carried out using the pessimum proportion of reactive aggregates.

TEST PROCEDURE

The concretes had a cement content between 300 and 500 kg/m³. Since the low-alkali-cements did not cause any deterioration of the concrete, the influence of mix-proportion is only described for normal and high-alkali Portland-Cements (0.7 to 1.1 % Na_2O-Eq.). The water-cement ratio varied between 0.45 and 0.70.

There were two different curing conditions for the concrete specimens:

a) storage in a fog-room at 40 °C
b) out door exposure (moderate European climate).

The concrete surface was observed and the expansion of the beams in storage a) were measured over a period of 6 years and the degree of deterioration caused by ASR was recorded.

RESULTS AND CONCLUSIONS

The two different curing conditions caused essentially the same degree of deterioration after 6 years of exposure. Therefore, all conclusions were based on the mean deterioration rate of all test specimens in both storage conditions.

Water-cement ratio

Under, otherwise, constant conditions the degree of deterioration of concrete was decreased by lowering the water-cement ratio from 0.65 to 0.45 (figure 1).

The lower water-cement ratio has four different effects on the concrete; first diminish the deterioration:

- the pore structure will become more tight, i. e. the alkalis cannot easily move to the aggregates,
- the concrete strength is increased, therefore, the concrete can tolerate more internal stress, due to ASR,
- the concentration of alkalis in the pore solution of fresh

concrete is higher, thereby the velocity of reaction could be increased and a greater amount of alkalis could react harmlessly in fresh concrete.

and on the other hand

- the development of strength is increased, which leads to a reduction of the time for harmless reaction in fresh concrete, this could increase the possible deterioration.

From the results it can be deduced, that the damaging effects of ASR could be reduced by lowering the water-cement ratio. I want to point out, that this does not mean, that a low water-cement ratio could avoid a deterioration by ASR in every case.

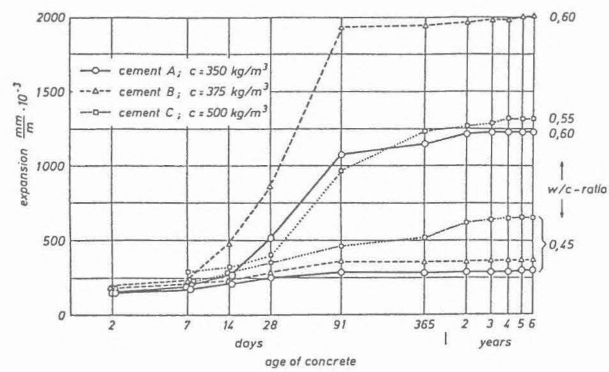

Figure 1: Influence of water-cement ratio on ASR in concrete

There are special concretes with high alkali contents, which show severe damages, even with the very low water-cement ratio of 0.45. But even in that case the damage is increased by increasing the water-cement ratio.

Degree of Hydration

Under, otherwise, constant conditions the degree of damage increased with increased fineness of cement (figure 2). That means, the damage was increased while the concrete strength also was increased. A possible explanation for this "strange" behaviour can be seen in the reduction of the setting period caused by the higher fineness of cement, i.e. the time for a harmless reaction in the fresh concrete is reduced. The test results prove, that in similar concretes the rate of deterioration increases directly with the two-day-strength.

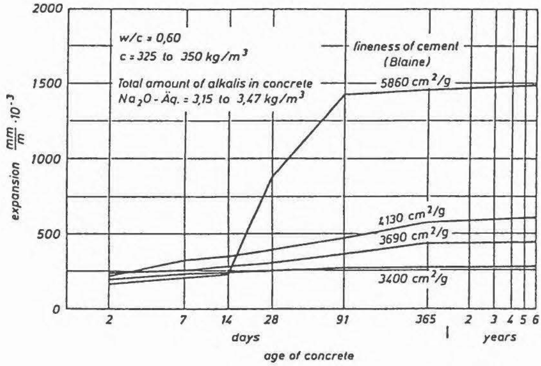

Figure 2: Influence of cement-fineness on ASR in concrete

From previous researches, in various institutes, it's well known, that the ASR is increased by the amount of alkalis in the concrete. Figure 3 shows the combined effect of alkali content and the two-day-strength of concrete on the deterioration due to ASR.

The filling of the circles indicates the degree of deterioration. The concretes without damage are indicated by the empty and the quarter filled circles while those with damage and severe damage are indicated by the half-filled and filled circles. The curves indicate the maximum tolerated alkali-content where no damage by ASR occurs. The different curves characterize the different water-cement ratios.

You easily can see in this figure that the tolerable alkali content in concrete is increased for a given constant

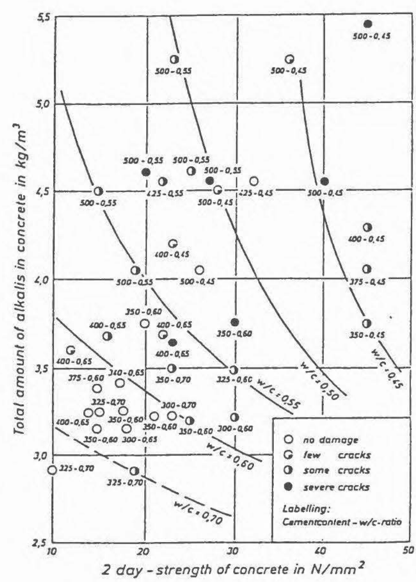

Figure 3: Influence of alkali-amount and strength on ASR in concrete

two-day-strength by lowering the water-cement ratio and is decreased for a constant water-cement ratio by increasing the two-day-strength.

From these results it may be concluded that the alkali-content of 3 kg/m³ is not safe without any further restrictions. The German requirements of limiting the cement content to max. 500 kg/m³ and using low-alkali cement (≤ 0,60 % Na_2O-equivalent) lead indirectly to a total alkali content of 3 kg/m³. Since the relative high cement contents were combined in practice with a low w/c-ratio, this requirements proved to be successful in preventing damage to concrete for the past 10 years.

OUTLOOK

The results show, that the early strength of concrete dramatically influences the effects of ASR. In future research, the effects of blended cements with late strength development, or of retarding agents, on damage to concrete due to ASR should be studied.