

# New Dutch guideline on ASR-prevention

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**In 1994, the first Dutch guideline on the prevention of ASR was published. Since, deleterious ASR has been diagnosed in several structures. This diagnosis prompted the revision of preventive guidelines. In the current paper, an overview is given of preventive measures and aggregate testing methods required by the new Dutch guideline on ASR-prevention, CUR-Recommendation 89, which became effective in June 2002.**

*Key words: ASR, preventive measures, regulations, the Netherlands*

## 1 Introduction

In 1992, the first diagnosis of concrete damage due to alkali-silica reaction was made in the Netherlands (Heijnen 1992). Since then, such damage has been diagnosed in about 40 to 50 structures over the country. Most prominent of these is a whole series of bridges in and over motorway A59, built in the late sixties – early seventies of the last century (Bakker 1999). This damage was one of the reasons to revise the Dutch recommendation on prevention of ASR, which came into existence in 1994 (CUR-Recommendation 38). In 2000, CUR regulations commission 62 was installed. This commission has drawn new procedures to determine the risk on deleterious ASR, established preventive measures and outlined methods to assess the alkali-silica reactivity of aggregate. The result, CUR-Recommendation 89, was based on a review of cases of ASR-damage in the Netherlands, international scientific studies and regulations developed since 1994, interviews with foreign experts, as well as new research set out by the commission into the composition and mechanism of ASR-prevention of aggregate and cement supplementary materials such as blast furnace slag and powder coal fly ash common in the Netherlands. The new regulation became effective in June 2002.

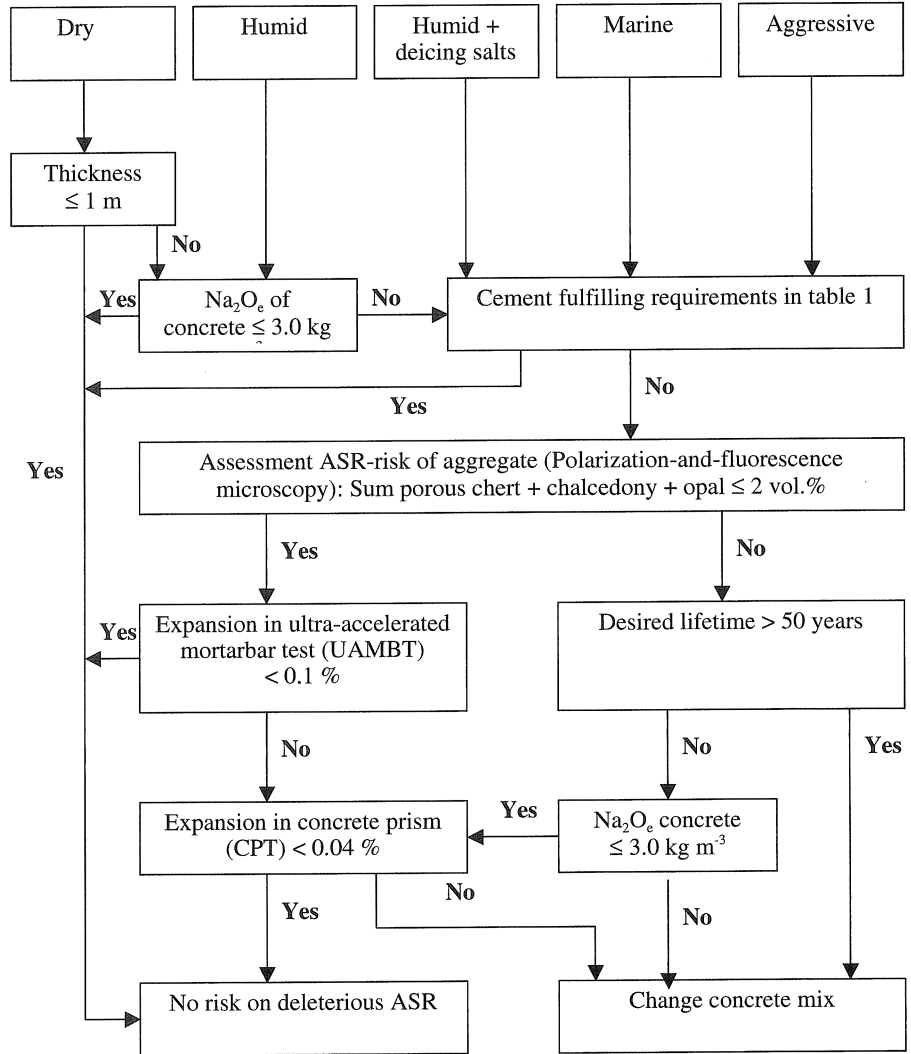
## 2 Preventive measures in the new Dutch guideline

### 2.1 Alkali-silica reaction (ASR)

ASR is a chemical reaction between alkali in a concrete and certain types of aggregate. ASR may result in a decrease in mechanical properties of the concrete and cracking. Deleterious ASR only occurs if at least one of the following conditions is met:

- (periodic) availability of sufficient moisture;
- presence of sufficient alkali in the concrete;
- the aggregate should be alkali-reactive.

Precautions against development of deleterious ASR may involve preventing fulfilment of at least one of these conditions. The new CUR-Recommendation 89 is based on this strategy, which has the additional advantage that it fits with the common practice to specify requirements for concrete according to the environment to which it shall be exposed. These preventive measures will be discussed below. A flow chart of the procedure in the new Dutch guideline is given in figure 1.



Figuur 1. Assessment of the risk on deleterious ASR.

### *2.2 Prevention of moisture availability*

Absence of sufficient moisture does not prevent the development of ASR in all cases. However, concrete damage by ASR is mainly due to swelling of the reaction product by incorporation of water. This swelling induces stresses in the concrete; these may produce cracks. If there is no or insufficient moisture, ASR-gel will not expand, and damage will not occur. Therefore, in a dry environment (environmental class 1 according to Dutch standard NEN 5950), no additional preventive measures are required. Some uncertainty, however, arises from the fact that massive concrete never dries entirely. It is unknown whether this internal moisture may be sufficient to cause deleterious ASR. As a precaution, a limit has been imposed on the thickness of concrete elements for which the absence of external moisture is accepted as a preventive measure (cf. new Canadian guidelines; Fournier et al. 2000). Concrete elements with a thickness over 1 m should be treated as concrete exposed to humid environments (environmental class 2 according to Dutch standard NEN 5950).

### *2.3 Amount of alkali available*

In humid environments as defined in Dutch standard NEN 5950, viz. without de-icing salts, in non-marine conditions, etc., moisture penetrating the concrete will be virtually free of alkali. Under such conditions, swelling of eventual ASR-gel can not be precluded. The formation of ASR-gel itself, however, may be prevented by limiting the amount of alkali in the concrete. The commonly accepted limit of  $3.0 \text{ kg m}^{-3}$  sodium equivalent,  $\text{Na}_2\text{O}_e$  for concrete is maintained in the new Dutch guideline.

For concrete exposed to de-icing salts, under marine or aggressive conditions (foundations exposed to brines, etc.), the amount of alkali available for ASR is not necessarily limited by the amount of alkali present in the concrete. It cannot be precluded that external alkali infiltrate the concrete. Eventual infiltration of external alkali depends on several factors, like the density of the concrete itself. The amount of alkali infiltrated is likely to be higher for concrete made with Portland cement (CEM I) than for concrete made with blast furnace slag cement (CEM III/A or CEM III/B) and (after prolonged hydration) Portland-fly ash cement (CEM II/B-V). In general, infiltration will be rather low for concretes made with the latter cements (Visser & Polder 2001). However, in environmental classes 3 (humid + de-icing salts), 4 (marine) and 5 (aggressive), the possibility of infiltration cannot entirely be excluded. Infiltration could result in the critical limit of  $3.0 \text{ kg m}^{-3} \text{Na}_2\text{O}_e$  to be exceeded. Additional preventive measures are required for these conditions.

Both long term experience in the Netherlands (Nijland & Jansen 2001, Nijland & Siemes, this issue) and experimental studies in, amongst others, Canada (Fournier et al. 2000) and Germany (Smolczyk 1974, Siebel et al. 2001), have made clear that supplementing the Portland clinker in cement by either ground granulated blast furnace slag (GGBS) or powder coal fly ash (PFA) strongly influences the amount of alkali available for ASR. Additional electron microprobe research on hydration rims on slag particles has shown that alkali are incorporated in the crystal lattice of the hydration products. This implies that the effective alkali content, i.e. the amount of alkali available for ASR, in concrete made with blast furnace slag or Portland-fly ash cement is lower than the total

alkali content of that concrete. This was already one of the starting points of the now obsolete Dutch guideline, CUR-Recommendation 38 (1994). New experiments, especially those by Fournier et al. (2000), have provided additional insights in the role of GGBS and PFA in decreasing this effective alkali content

Table 1. Alkali limits for cements considered to prevent development of ASR.

Cement	CEM II/B-V	CEM II/B-V	CEM III/A	CEM III/B
Minimum amount of PFA c.q. GGBS (wt.%)	≥ 25	≥ 25	≥ 50	≥ 66
Max. Na <sub>2</sub> O <sub>e</sub> of PFA (wt.%)	1 ≤ x ≤ 2	2 < x ≤ 3	-	-
Max. alkali content of cement (wt.%)				
- if the amount of alkali contributed by other components ≤ 0.6 kg m <sup>-3</sup>	1.1	1.3	1.1	1.5
- if the amount of alkali contributed by other components ≤ 1.2 kg m <sup>-3</sup>	0.9	1.1	0.9	1.3

In most Anglo-Saxon countries, binders are commonly made by mixing ordinary Portland cement (CEM I) with either GGBS or PFA, whereas in Dutch practice (and most neighbouring countries), factory-produced blast furnace slag (CEM III/A and CEM III/B) or Portland - fly ash cement (CEM II/B-V) are used. Therefore, CUR regulations commission 62 preferred to impose alkali limits on these factory-produced cements, rather than on their individual components. Alkali limits on these components, as derived by Fournier et al. (2000) from their experiments, have been recalculated to limits for cements, based on the amounts by which GGBS and PFA lower the effective alkali content, and (for Dutch practice) for alkali contents of the slag and fly ash themselves. The alkali limits for cements imposed by new Dutch guideline CUR-Recommendation 89 (2002) are given in table 1. Within CUR regulations commission 62, varied opinions were held whether the maximum alkali content of 2 wt.% Na<sub>2</sub>O<sub>e</sub> imposed on cement with a high slag content (CEM III/B) by former Dutch guideline CUR-Recommendation 38 (1994) and German regulations should be maintained. As precaution, a lower value has been agreed (Table 1).

As appears from table 1, the maximum allowable alkali content of the cement depends on the contribution by other components in the concrete, such as aggregate, additives and fillers. For aggregates commonly used in the Netherlands, viz. sands and gravel from the major rivers (Rhine, Meuse, etc.) and their tributaries, as well as those dredged from the North Sea, water soluble alkali

contents are very low, and the alkali contribution by other components will, in most cases, be less than  $0.6 \text{ kg m}^{-3}$ .

Whether aggregates may contribute to the alkali budget available for ASR is heavily disputed. New Canadian guidelines take into account a maximum contribution of  $1.2 \text{ kg m}^{-3} \text{ Na}_2\text{O}_e$  (Fournier et al. 2000). In cases where the alkali content of aggregate is unknown, CUR regulations commission VC 62 has adopted this value (Table 1). One should, however, demonstrate that the alkali contribution by additives and fillers (other than PFA) may be neglected ( $< 0.1 \text{ kg m}^{-3}$ ). If this cannot be demonstrated, evaluation of the alkali content of concrete is necessary, and values in table 1 cannot be applied. Higher alkali contributions by other components than the cement require lower alkali limits for the cements. For example, a total alkali contribution by components other than cement up to  $1.6 \text{ kg m}^{-3} \text{ Na}_2\text{O}_e$  implies that the alkali limits for cement are lowered to 0.8 (CEM II/B-V containing  $\geq 25 \text{ wt.}\% \text{ PFA}$  of  $1 \leq \text{Na}_2\text{O}_e \leq 2 \text{ wt.}\%$ ), 1.0 (CEM II/B-V containing  $\geq 25 \text{ wt.}\% \text{ PFA}$  of  $2 < \text{Na}_2\text{O}_e \leq 3 \text{ wt.}\%$ ), 0.8 (CEM III/A containing  $\geq 50 \text{ wt.}\% \text{ slag}$ ) and  $1.2 \text{ wt.}\% \text{ Na}_2\text{O}_e$  (CEM III/B), respectively.

#### *2.4 Alkali-silica reactivity of aggregate*

If the development of deleterious ASR cannot be prevented by the choice of an appropriate cement or concrete mix, the only remaining option is the use of non-alkali-silica reactive aggregate. CUR-Recommendation 89 specifies methods by which the alkali-silica reactivity of aggregates should be determined, and outlines these in detail in its appendices.

The alkali – silica reactivity of aggregates fundamentally depends on the crystal structure of free silica,  $\text{SiO}_2$ . Several methods have been proposed in literature to assess the crystallinity of quartz and other modifications of  $\text{SiO}_2$  (e.g. Murata & Norman 1976, Shoal et al. 1991) and have been applied in the investigation of Dutch aggregates (Jansen 2002). However, it is both extremely problematic and unpractical to assess the alkali-silica reactivity of bulk aggregates by studies on separate grains. Therefore, it has been decided to adopt methods developed by RILEM Technical Commission 106 (now TC-ARP).

To start with, aggregates have to be investigated by petrography; the procedure essentially corresponds to that developed by RILEM TC 106-1, but has been specified into more detail in order to promote consistency between different laboratories (the same holds for other methods mentioned below). The threshold value between non-alkali-silica reactive and reactive aggregates is 2 vol.% of porous chert plus chalcedony plus opal. However, current knowledge does not enable petrographic discrimination between reactive sandstones, greywackes, etc., and non-reactive ones. Alkali-silica reactive sandstones may, however, be encountered in land based aggregates in the Netherlands (e.g. Broekmans & Jansen 1997, Heijnen & Larbi 1999, Nijland & Siemes, this issue) and surrounding countries (Siebel et al. 1996, Siebel & Reschke 1996-1997). Therefore, aggregates passing petrographic examination should also be subjected to expansion testing.

Aggregates containing  $\leq 2 \text{ vol.}\%$  porous chert, chalcedony and opal may be tested by either the 14-day ultra-accelerated mortar bar expansion test (UAMBT) or the concrete prism test (CPT), as

developed by RILEM TC 106-2 and 106-3, respectively. Maximum expansions allowed by CUR-Recommendation 89 are 0.1 and 0.04 %, respectively.

The UAMBT is not suited to test aggregates containing > 2 vol.% porous chert, chalcedony and opal. In principle, this leaves the CPT as test method for the alkali-silica reactivity of these aggregates. Within the commission that has developed CUR-Recommendation 89, opinions differed whether the CPT is reliably enough as a testing method for aggregates used in the construction of structures with a desired lifetime of over 50 years. For constructions with shorter desired lifetimes than 50 years and alkali contents of concrete of less than  $3.0 \text{ kg m}^{-3} \text{ Na}_2\text{O}_e$ , testing of aggregate by CPT is accepted. For remaining structures, a reformulation of the concrete mix is required.

### 3 Conclusion

For concrete subjected to any exposure condition, adequate preventive measures against damage due to ASR are possibly by precluding the fulfilment of at least one essential prerequisite of the reaction. CUR-Recommendation 89 provides guidelines concerning measures that should be applied. Generally, these fit well with common building practice in the Netherlands, especially with regard to the choice of cement and concrete mixtures: In most cases, cements are already used that prevent the development of deleterious ASR. The abundant use of blast furnace slag cement (CEM III) has limited the number of structures developing concrete damage due to ASR in the Netherlands. Deleterious ASR did not develop in any structure made with either blast furnace slag cement, CEM III, or Portland – fly ash cement, CEM III/B-V (Nijland & Jansen 2001, Nijland & Siemes, this issue).

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