ALKALI AGGREGATE REACTION IN CONCRETE (AAR)

INTRODUCTION

AAR is a chemical reaction of alkali in concrete and certain alkaline reactive minerals in aggregate producing a hygroscopic gel which, when moisture present, absorbs water and expand. Gel expansion causes cracking in the concrete.

The number of structures affected by AAR is relatively small comparing to the total number of concrete structure built, but the problem has been found in many countries around the world. In Hong Kong, occurrence of AAR has been identified for some structures [Stanley, 1992]. See photos in the Teaching Web Page for cases of AAR in Hong Kong and around the world.

Most of the structures severely cracked by AAR are exposed to the weather or underground in contact with damp soil. This is because for significant expansion to occur sufficient presence of moisture is essential. Apart from the moisture, high content of alkali in the concrete is also essential. No case has been found where the alkali content, in terms of equivalent sodium oxide (Na$_2$O$_{equ}$), is below 3-4 kg per cubic meter of concrete.

It is also found that, when there are sufficient moisture and alkali, maximum expansion of concrete due to AAR occurs when the content of reactive minerals in aggregate is within a sensitive region, some refer to this as "pessimum" content. Content of reactive minerals below or greater than the pessimum value, AAR expansion reduces.

From the above, it can be seen that, for a damage AAR expansion to occur, it is necessary to have

- sufficient moisture supply
- high content of alkali in concrete, and
- Pessimum amount of reactive minerals in aggregate.

SOURCES OF ALKALIS IN CONCRETE

a. Cement

All ingredients of concrete may contribute to the total alkali content of the concrete; the major source of alkali is from cement. The chemical composition of cement is usually expressed in terms of oxides. In relation to AAR, alkali content in cement is determined from Na$_2$O and K$_2$O. Alkali content is described as total mass of "equivalent sodium oxide", Na$_2$O$_{equ}$, which is determined from the following expression.

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Na_2O_{equ} = Na_2O + 0.658 K_2O
\]
Alkali content of the cement commonly used in Hong Kong is, in terms of Na$_2$O$_{equ}$, less than 1%. In some regions of China, e.g. in Tianjin and Beijing area, alkali content of local cement is relatively high, above 1.5%, owing to the raw material of cement.

b. Pozzolans

A pozzolan is a siliceous or siliceous and aluminous material which reacts with lime released from cement hydration forming a compound possessing cementitious properties. Pozzolanic materials are used as a cement replacement or as part of cementitious material to modify or improve properties of concrete, sometimes for economical consideration.

Common pozzolanic material used in concrete include PFA (pulverized fuel ash, or fly ash), silica fume, GGBS (ground granulated blast furnace slag). Other pozzolans include volcanic ash (the original pozzolan), opaline shale and chert etc. PFA is the most common pozzolan used in concrete. The use of silica fume in concrete is on the rising.

Pozzolan consumes alkali when reacts with lime. When considering pozzolan contribution of alkali to concrete, a reduction to the alkali content of the pozzolan should be allowed for.

a. Aggregate

Aggregate containing feldspars, some micas, glassy rock and glass may release alkali in concrete. Sea dredged sand, if not properly washed, may contain sodium chloride which can contribute significant alkali to concrete.

b. Admixtures

Admixture in the context of AAR in concrete means chemical agents added to concrete at the mixing stage. These include accelerators, water reducers (plasticizers), retarders, superplasticizers, air entraining, etc. Some of the chemicals contain sodium and potassium compounds which may contribute to the alkali content of concrete.

c. Water

Water may contain certain amount of alkali. PNAP 180 states that acid-soluble alkali content of water be determined in accordance with American Public Health Association (APHA) (17ed. 1989) Sections 3500-K and 3500-Na.
d. Alkalis from outside the concrete

In an area of cold weather, de-icing salt containing sodium compounds may increase alkali content on the surface layer of concrete. Soils containing alkali may also increase alkali content on the surface of concrete.

ALKALI CONTENT AND AAR

Research shows that when the total alkali content, in terms of equivalent sodium oxide, is less than 3 kg/m³, damage expansion due to AAR is unlikely to happen, provided that known highly alkali-reactive minerals, such as opal and glass, are not present in the concrete.

Because of the above research findings, and also because no reliable universal testing method has been established for the determination of reactivity of an aggregate, limiting alkali content in concrete has become the most widely used approach for the control of AAR. In Hong Kong, PNAP 180 specifies that, in the absence of alternative approach for AAR control, the alkali content of concrete expressed as the equivalent sodium oxide shall not exceed 3.0 kg per cubic meter of concrete.