

PARAMETERS AFFECTING ALKALI EXPANSION IN ICELANDIC CONCRETES

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We are indebted indeed to researchers in this group, and acknowledge with gratitude the valuable information we have had access to and been able to apply in our fight against premature deterioration of our concrete structures.

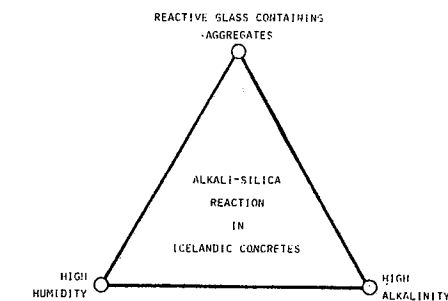
It is difficult for us in our minute community to maintain the contacts that are so essential for our scientific development endeavors; - we have not been able to attend the two latest alkali-silica congresses. Smallness, however is not only an obstacle. It is probably easier for us than for most others to trace back the original compositions of our structures. Because of smallishness the only cement producer in the country was not restricted either to the production of portland cement or pozzolan cement under narrow specifications, but could resort to the production of a special variety of "portland cement". As soon as we had proven that an addition of 5 or 7 1/2% silica fume was a remedy for our alkali malady we started doing so.

We now learn that others are contemplating a revision of their cement specifications to allow for the addition of silica fume, to improve the cement and to safeguard structures.

The harshness of the Icelandic environment calls for extraordinary approaches to solve our problems. Geographically the country is so young that practically no clay deposits or calcareous rocks are to be found, and silicious minerals are rare. We therefore produce cement out of sea shells and perlitic rock. This cement consequently is high in alkalies.

Secondly volcanic formations in contact with water quench fast and produce glassy rocks - which normally are more reactive than chrystalline ones. Thirdly as a consequence of the geographical location in the middle of the N-Atlantic, driving rains are common, the frequency and strenght of wich are not surpassed widely.

FIG. 1 THE MAIN PARAMETERS OF REACTIVITY



The three parameters governing alkali-silica reactions, high alkalies, reactive aggregates and high humidity are therefore plentiful in this environment. Naturally, the speed of reaction is influenced by temperature.

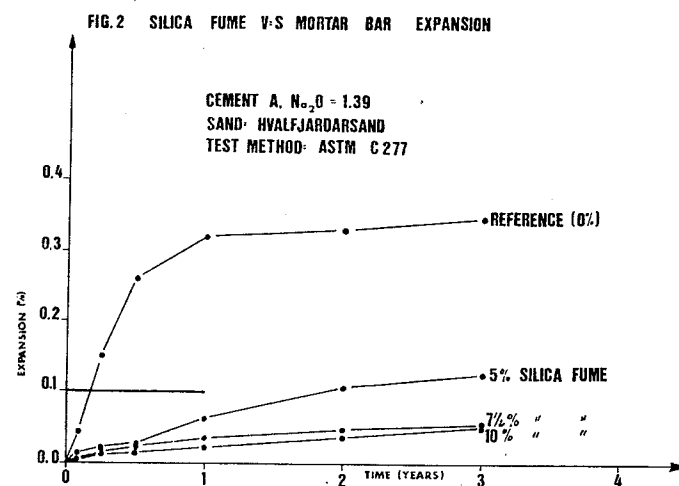
The BRI was early aware of the danger and warned against alkaliaggregate reactions. More than 30 years ago we consulted for the first time, our wise pioneer Bryandt Mather on the matter. Later his disciple and persuer Gunnar Idorn, helped us organize our approach to tackle the problem.

Knowing the early research work of this science we took preventive actions against alkali-expansion in connection with our major structures. Dams, power houses, docks and bridges are therefore now in good conditions. The preventive measures were the use of pozzolanas, and the use of imported low alkali cement. In our housing precincts, however, a risk was taken, and plain concrete was used without such precautions. We are now paying the penalty for taking that risk. Our excuses for the decision however were:

1. No incident of deterioration due to alkali - silica reaction could be cited in housing precincts at that time.
2. Temperature is low in Iceland and temperature variations very small.
3. There is a constant outward temperature gradient in our exterior walls. They should therefore dry out.

We know now that low temperatures and the outward temperature gradient do not prevent the damages.

When the reactivity was detected and the damages became obvious we resorted to general use of pozzolanas, and interground with the clinker various amounts of rhyolite. Soon, after the ferrosilicon plant was erected in Iceland, however, we started replacing 5-7 1/2% of our cement with silica fume. It can be stated that we have harvested excellent results of this addition in all our tests and endeavors.



We cannot avoid altogether the use of reactive aggregates; yet we know that the minerals react differently (fig. 3), and we also observe increased reactivity in our blended aggregates (fig. 4).

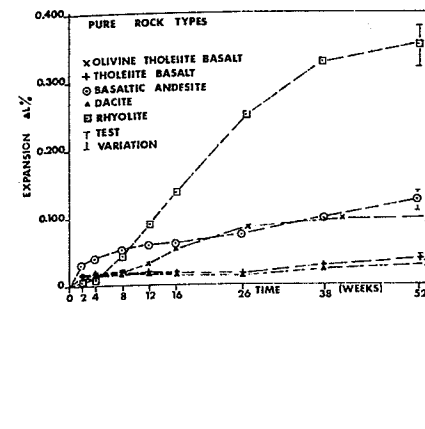


FIG. 3 EXPANSION POTENTIAL OF ROCK TYPES

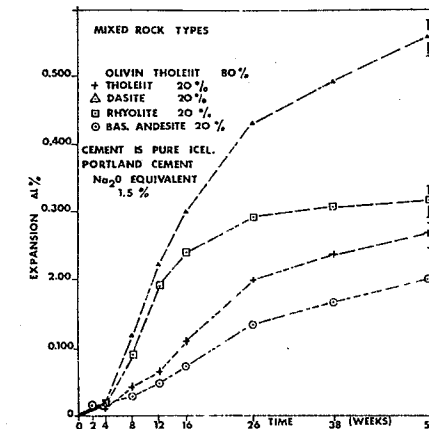
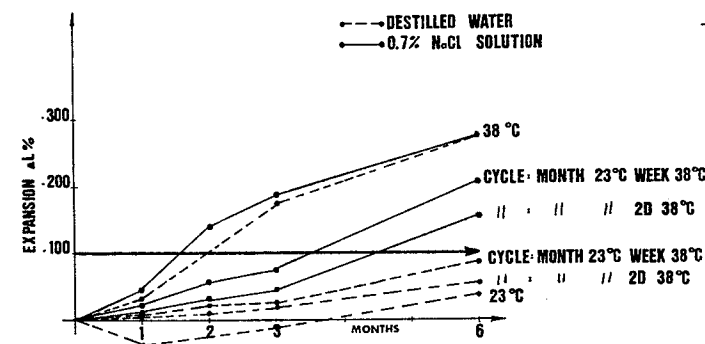


FIG. 4 EXPANSION POTENTIAL OF ROCK TYPES

High alkalinity of our concretes is partly derived from poorly washed seadredged sand and gravel. In our absorbtive aggregates this can bring the sodium salt content 1,3% Na<sub>2</sub>O equivalent or more. Not only does this increase the alkalinity of the fresh concrete. We also firmly believe that the Cl<sup>-</sup> ion has a catalytic effect on the reaction, and we expect this effect to be relatively greater at lower temperatures. Preliminary test results shown in fig. 5 support this even though they can not be considered conclusive.

FIG. 5. INFLUENCE OF TEMPERATURE AND NaCl CONTENT ON EXPANSION CEMENT-PC



When NaCl is added to fresh concrete ionic exchanges take place between the lime freed from the cement hydrolyzes and the sodium salt. CaCl<sub>2</sub> is therefore present in the fresh concrete, and its catalytic effect is well known from empirical tests; but we would like to have the effect better clarified.

Analyzes of cores from damaged concrete with sea-dredged aggregates have shown 0,2-0,5 g NaCl/kg. The average of this content could be introduced in standard mortarbars by using a 0,7% NaCl solution instead of mixing water.

This relatively dilute solution which has only 1/5 of a seawater strenght, has definite influence on mortarbar expansion at lower temperatures. This can be read from the diagrams in fig. 5. In this illustration we have drawn the danger demarkation line which now has been included in our building regulations, e.g. less expansion than 0,1% in one year.

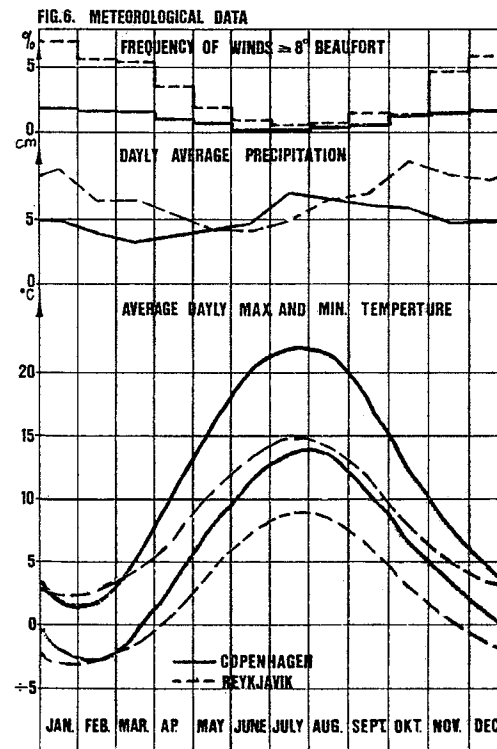
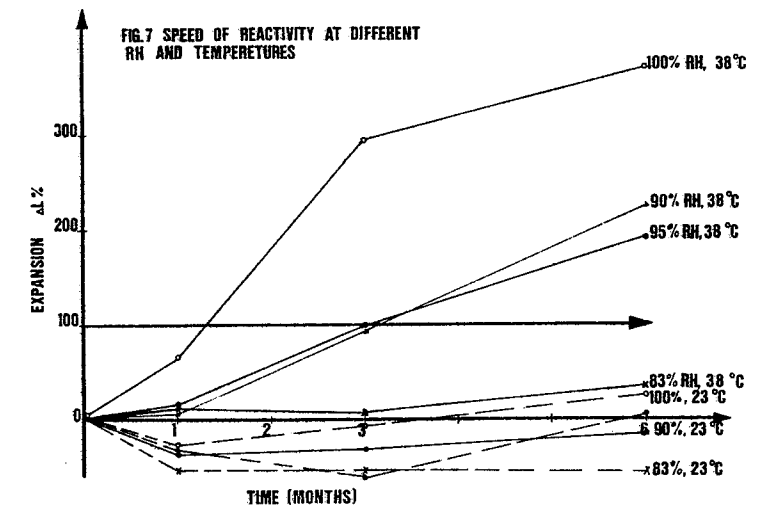


Fig. 6 is shown here as an introduction to the climatic condition we have to cope with. Low temperature, frequent rainfall and strong winds tend to keep our structures wet most of the time. The comparison between Copenhagen and Reykjavik is based on a 35 year data for the years 1930-1965. Note that high winds and much rain coincide in Reykjavik during the winter months.

Bearing the meteorological data above in mind it will not be surprising to anyone that there is sufficient humidity in our housing concrete to maintain wetness for alkali-silica reactions. Moreover 80% relative humidity in the concrete appears sufficient to maintain the reactivity. This can be read from Table I and corresponding diagrams (fig. 7).

Table I - Al vs Mortar Bar Expansion

| Test nr.     | Aggregate      | Cement        | Water     | Water Req. | Date     | L <sub>0</sub>               | ΔL % after (Months) |       |       |     | T °C | RH                        |
|--------------|----------------|---------------|-----------|------------|----------|------------------------------|---------------------|-------|-------|-----|------|---------------------------|
|              |                |               |           |            |          |                              | 1.                  | 3.    | 6.    | 12. |      |                           |
| V-180<br>B-1 | Braifjoss sand | Pure Portland | Agla Det. | 155 ml.    | 15/6 '82 | 3000<br>3265<br>3090<br>2380 | 0,028               | 0,008 | 0,023 |     | 22   | 100<br>(water)            |
| V-180<br>B-3 | "              | "             | "         | "          | "        | 2660<br>2965<br>2470<br>2030 | 0,038               | 0,032 | 0,018 |     | "    | 90<br>(RH <sub>0</sub> )  |
| V-180<br>B-4 | "              | "             | "         | "          | "        | 3160<br>2620<br>3325<br>4160 | 0,054               | 0,059 | 0,059 |     | "    | 83<br>(RH <sub>1</sub> )  |
| V-180<br>A-1 | "              | "             | "         | "          | 21/6 '83 | 2840<br>2890<br>3425<br>2500 | 0,064               | 0,294 | 0,370 |     | 38   | 100<br>(water)            |
| V-180<br>A-2 | "              | "             | "         | "          | "        | 3135<br>2835<br>3435<br>3085 | 0,017               | 0,100 | 0,191 |     | "    | 95<br>(RH <sub>10</sub> ) |
| V-180<br>A-3 | "              | "             | "         | "          | "        | 2594<br>3025<br>3405<br>3110 | 0,003               | 0,096 | 0,221 |     | "    | 90<br>(RH <sub>0</sub> )  |
| V-180<br>A-4 | "              | "             | "         | "          | 22/6     | 3450<br>2955<br>3225<br>3160 | 0,011               | 0,003 | 0,034 |     | "    | 83<br>(RH <sub>1</sub> )  |
| V-180<br>A-5 | "              | "             | "         | "          | "        | 2605<br>3085<br>3130<br>3020 | 0,037               | 0,059 | 0,009 |     | "    | 73<br>(RH <sub>10</sub> ) |



Finally we wish to emphasize that the replacement of silica-fume in relatively small quantities in our alkali-rich cement is simultaneously an improvement of our cement and a strong safeguarding factor against deleterious alkali expansions.