production of piles made of F-concrete after the summer vacation.
Railway-sleepers and hollow-core slabs have been produced with concrete with w/c as low as 0.20 and piles have been casted without vibration with concrete with a w/c 0.27-0.28.
The first building made of F-concrete was erected last autumn in Rauma in Finland. It was a bulk storage building where concrete with a good sulphate resistance was asked for. In the building prefab. wall element, pillars and beams made of F-concrete were used. The floor and the deck was casted in situ. The experiences from the prefabrication was very good. Although the thermal curing was very moderate, the elements could be demoulded by a maturity of ab. 500°C x h and brought directly to the building site and erected. The floor was casted by pumping without vibration, and 2 men were able to cast ab. 500 m^2 floor in one shift.
The experiences from the practical applications of F-cement and concrete are until now very promising.

PRELIMINARY INVESTIGATION OF ALKALI-SILICA REACTIVITY OF DENSITY SEPARATED COARSE AGGREGATE

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1. ABSTRACT

Danish flint is a mixture of two basically different rock types:

- calcedony containing flint
- opal containing flint.

Both types can be calcareous.

The opaline flint types are in general lighter than the calcedony carrying flint types, and can to some extent be separated by heavy media separation. Opaline flint occurs as individual particles, but also as crusts on calcedonic flint. The opaline flint is strongly alkali-silica reactive, besides giving a risk of creating frost damage.

To test what advantages could be gained by heavy media separation, samples of stones were separated into narrow density-fractions as follows:

> 2500 kg/m^3, 2500-2400, 2400-2300, 2300-2200, > 2200 kg/m^3.

In addition the heavy fractions were handpicked into:

"granitic" rocks
limestone
calcedonic flint (pure)
calcedonic flint with opaline crust.

Both the heavy media separated and the handpicked stones were divided into 8/16 and 16/32 mm fractions.

The reactivity of the individual stone fractions were tested by casting concrete test cylinders with a non reactive sand, and storing them in a saturated NaCl-solution at 50°C. At regular intervals the samples were inspected for any sign of damage.

The lighter, coarse aggregate fractions, containing mainly opaline flint, developed pop-outs and produced large amounts of gel, but developed no fractures.

The heavier fractions, above 2400 kg/m^3 contained calcedonic flint with opaline crusts. These developed pop-outs, some gel and produced cracks extensively. Samples with pure calcedonic flint did not show any sign of damage in 8 weeks.

Two different size fractions were used, 8/16 mm and 16/32 mm. The results showed more severe damage with the small stones. This might be due to the expansion centers becoming increasingly better distributed the smaller the grain size, and the situation approaches the situation where the reactions are caused by reactions in the sand fraction.

The experiments will be described, and the results will be illustrated.

2. INTRODUCTION

In recent years severe damages have developed in several concrete structures in Denmark. Alkali-silica reactivity, especially of the sand fraction, has played a major role in these breakdowns. As a result, sand for concrete making is carefully selected; even new types of cements are being produced. Further precautions, in the form of the addition of flyash or silica dust to concrete and maintaining a low water/cement ratio and air-entraining are also being introduced.

Attention has now been focused on coarse aggregates. Danish coarse aggregate types are generally mixtures of "granite", limestone and flint. The above terms, as used by the Danish construction industry, need some explanation.

The term "granite" refers to all rock types which have been carried from the Scandinavian bedrock to Denmark during the ice ages. They include gneiss, amphibolite, quartzite, sandstone and volcanic rocks.

The majority of limestone is from the Danish bedrock and consists of white chalk, bryozoan limestone or coral reef limestone. A part of the limestone comes from the Scandinavian bedrock and consists of orthoceras or silurian limestone and occasionally marble.

The flint types can very from calcedonic to calcareous opaline (1). Some of these flint types are difficult to distinguish from limestone. As far as the alkali-silica reaction is concerned, it is the flint content which is of importance.

Beside being alkali-reactive, some of these Danish aggregate types are not stable in a freeze-thaw environment. Recently, a heavy-media-separation technique has been introduced in Denmark to remove low density porous materials from gravel and thereby improve their performance in a freeze-thaw environment.

The main object of the present investigation was to ascertain if the alkali-silica reactivity of Danish gravel types could be reduced by using the heavy-media-separation technique.

3. MATERIALS AND EXPERIMENTAL TECHNIQUES

3.1 Preparation of aggregates and making of test prisms

A large supply of 8/32 mm size aggregates was obtained from a Danish source, which is known to contain all types of rock prevalent in Denmark. This supply was divided into two parts and treated in the following ways:

(a) One of the parts was first separated into narrow density fractions by heavy media separation. The density ranges of each of the fractions are shown in Table 1. A part of each of the density separated fractions was hand separated into different rock types. Thus these hand picked aggregates are homogeneous both in rock type as well as in density range. The rock types and their density ranges are shown in Table 2.

(b) The second part of the raw aggregate was further subdivided into 8 parts. One part was used as received. From each of the other 7 parts, materials below a definite density were removed. The density ranges of these 7 parts are shown in Table 3.

All the above density separations were carried out with a heavy media made up of a mixture of water, ferro-silicon and magnetite. The density of this media was adjusted by varying the proportion of its three constituents.

Each of the fractions of (a) and (b) were further separated into 8/16 mm and 16/32 mm size ranges.

TABLE 1

Reactivity indications / Density	16/32 mm fraction			8/16 mm fraction		
	Cracks	Pop-outs	Gel	Cracks	Pop-outs	Gel
>2500 kg/m^3	0	0	0	1	0	0
2550 - 2500 kg/m^3	1	0	0	2	1	2
2500 - 2450 kg/m^3	1	0	0	2	1	1
2450 - 2400 kg/m^3	1	0	0	3	0	2
2400 - 2350 kg/m^3	1	0	1	2	1	2
2350 - 2300 kg/m^3	1	1	1	3	0	2
2300 - 2200 kg/m^3	1	1	2	1	3	2
<2200 kg/m^3	0	0	2	0	1	3

Degree of damage in a 0-5 scale with 0 indicating no damage. The Table shows the results with the 16/32 mm fraction and the 8/16 mm fraction on concrete samples produced with aggregates in narrow density intervals.

TABLE 2.

Rock Type	Reactivity indications / Density	16/32 mm fraction		
		Cracks	Pop-outs	Gel
Granite	>2550 kg/m^3	0	0	0
Granite	2550 - 2500 kg/m^3	0	0	0
Limestone	>2550 kg/m^3	0	0	0
Limestone	2550 - 2500 kg/m^3	0	0	0
Limestone	2500 - 2450 kg/m^3	1	0	1
Limestone	2450 - 2400 kg/m^3	0	0	0
Calcedonic flint	>2550 kg/m^3	1	0	0
Calcedonic flint	2550 - 2500 kg/m^3	1	0	0
Calcedonic flint with opaline crust	>2500 kg/m^3	1	1	1
	2550 - 2500 kg/m^3	1	0	1
	2500 - 2450 kg/m^3	1	0	1
	2450 - 2400 kg/m^3	1	0	2
Opaline flint with minor calcedonic flint	2400 - 2350 kg/m^3	1	0	1
	2350 - 2300 kg/m^3	1	1	1
	2300 - 2200 kg/m^3	1	1	2
Opaline flint	<2200 kg/m^3	0	0	2

Degree of damage in a 0-5 scale with 0 indicating no damage. The Table shows results with the 16/32 mm fraction on concrete produced with hand-picked rocks from the density intervals shown in the Table.

TABLE 3.

Density \ Reactivity indications	16/32 mm fraction			8/16 mm fraction		
	Cracks	Pop-outs	Gel	Cracks	Pop-outs	Gel
>2550 kg/m^3	1	0	0	1	0	0
>2550 - 2500 kg/m^3	1	0	0	1	0	0
>2550 - 2450 kg/m^3	1	0	1	1	0	1
>2550 - 2400 kg/m^3	1	0	1	1	0	1
>2550 - 2350 kg/m^3	1	0	1	2	0	1
>2550 - 2300 kg/m^3	1	0	1	2	0	1
>2550 - 2200 kg/m^3	1	0	1	1	0	1
Untreated sample	1	0	2	2	0	1

Degree of damage in a 0-5 scale with 0 indicating no damage. The Table shows the results on concrete samples produced with aggregates, where lightweight pieces have been removed at various densities.

3.2 Preparation of prisms for alkali-silica reactivity test

Using ordinary Portland cement and a non-expansive sand, concrete mixes were prepared from each of the aggregate fractions. The cement content of the concrete mixes was 340 kg/m^3 and the water/cement ratio was 0.57. From each of these mixes one 150x300 mm cylinder was cast. The cylinders were humid-cured for the first 24 hours and then in water for 27 days. Each of these cylinders was cut into two halves longitudinally. One of these halves was stored in a saturated NaCl bath at 50°C (2) and another half in water at 50°C. After 8 weeks of storage, the specimens were inspected for alkali-silica reaction and damage. The extent of the damage was visually evaluated in a 0-5 scale; 0 being an undamaged and 5 being a heavily damaged state.

4. RESULTS AND DISCUSSIONS

The results of this investigation are shown in Tables 1 to 3.

The materials in Table 1 are only separated in narrow density fractions and contain more than one rock type. All the fractions contain calcedonic flint with opaline crust. However, the lowest density fraction contains only opaline flint.

All the prisms in these series developed cracks, the exception being those made with aggregates above a density of 2550 and those below 2200 kg/m^3.

Prisms with 8/16 mm size aggregate developed more cracks. Gel formation increased with decreasing density of aggregates.

Table 2 shows the characteristics of prisms made with handpicked rocks of a narrow density range. The prisms made with granite did not show any sign of alkali-silica reaction. The same is almost true of limestone aggregate; only a minor reaction occured in the 2500-2450 kg/m^3 fraction. The later reaction may be due to a minor inadvertent inclusion of opaline flint particles in the limestone. On occasions, it is very difficult to distinguish between limestone and opaline flint.

All prisms made with flint carrying aggregates developed alkali-silica reactions. Even the prisms made with calcedonic flint of density above 2500 kg/m^3 i.e. having only opaline crust, developd signs of reaction. The extent of the reaction increased with the oplaine flint content.

Table 3 shows the characteristics of prisms made with increasing fractions of lightweight aggregates. All the prisms showed damage due to alkali-silica reactions.
Prisms stored in the water bath showed no sign of any reaction.

5. CONCLUSIONS

It is obvious that only limited conclusions can be drawn on the basis of the above experiments. Nevertheless, the following inferences can be made:

1) If the coarse aggregates are reactive their rate of reaction can be accelerated by the saturated NaCl-bath technique, thus enabling their evaluation within a reasonably short period.

2) If a gravel from a given source can be subdivided into fractions of homogeneous rock types, then the reactivity of the individual rock types could be evaluated by the saturated NaCl-bath technique.

3) The use of a non-expanding sand in concrete making will protect a structure if the coarse aggregate is also non-expanding.

4) Not all flint types are equally reactive. The opaline crusts on calcedonic flint particles seem to be capable of causing fractures. Calcedonic flint particles with opaline crusts can not be removed from other rock types present in Danish gravel sources by using heavy media separation technique.

6. REFERENCES

1) Søndergaard, B - Progress Report El. Committee on Alkali Reaction in Concrete. The Danish National Institute of Building Research. Copenhagen 1959.

2) Chatterji, S. - Cement & Conc. Res. 8, 647, 1978.