THE ALKALI-SILICA REACTIVITY OF FLINT AGGREGATES

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ABSTRACT

Flint-bearing deposits are a major source of aggregates for concrete in the UK but flint is a known alkali-silica reactive rock type. The reactivity of flint-rich gravels was investigated, particular attention being paid to the relationship between reactivity and the amount of porous cortex present. The results showed that the reactivity of the gravels was related to the amount of porous cortex present rather than to the total flint content. On the basis of porosity, three gravel types were identified, each type having a different pessimum proportion. Some modifications to the UK specifications are proposed. In particular, in those concrete structures where it is imperative to avoid the risk of ASR damage and where other precautions against ASR are not being taken, low porosity flint-rich gravels should not be used.

Keywords: alkali-silica reaction, flint, pessimum proportion, porous aggregates, specifications.

INTRODUCTION

Flint-bearing deposits are a major source of aggregates for concrete in the UK but flint is a known alkali-silica reactive rock type. Flint is a type of chert and in the UK flint typically consists of very finely crystalline quartz. Flint is often considered to be a uniform material as regards its alkali-silica reactivity but the results we are presenting here show that this is far from true. This variability has important implications as regards ASR testing and the drawing up of specifications.

Previous research at BRE indicated that flint aggregates from different sources do not all possess the same degree of reactivity (1). Results presented at the 9th Conference showed that the most reactive component of the flint fragments within sands and gravels was the porous cortex, which develops around flint as a result of weathering processes (2). A problem which was identified in the work programme concerned the anomalous expansive reactivity shown by a small number of flint-rich mixes. The majority of flint-rich mixes (reactive flint-bearing sand combined with a flint-rich gravel) produced no significant expansion, when tested for alkali-silica reactivity, but a small number of mixes did show expansive reactivity. The work did not identify the reason for the expansive reactivity or how such anomalous reactivity could be predicted and avoided. Current specifications in the UK (3) state that mixes will not be expansive if the total aggregate in the mix contains more than 60% flint by mass and the total flint content of the mix includes at least 5% by mass of flint with particle size less than 5 mm. The results of the work quoted above, therefore, suggest that some mixes complying with these specifications could be expansive, although it should be emphasized that the test conditions are quite severe and there is no evidence from the field of failures from this cause.

This paper describes investigations carried out in order to increase understanding about the differences in reactivity exhibited by flint-rich aggregates with a view to improving current specifications for preventing ASR. Since the main reactive component of flint is the porous cortex, the relationship between reactivity and the amount of porous cortex present within different flint-rich gravel deposits was studied. The investigations were further extended to examine the relationship between the amount of porous cortex in a flint-rich gravel and the proportion of the gravel producing maximum expansion.

EXPERIMENTAL PROGRAMME

Assessment of Reactivity

The reactivity of flint-rich gravels, from different geographical locations and formed by various geological processes, was investigated. Flint-rich gravels are abundant in Southern and Eastern England and also occur offshore in the English Channel and the southern part of the North Sea. Flint-rich gravels were obtained from 57 locations, chosen to cover as wide a geographical area as possible. The gravels were collected from glacial, river, beach (including ancient beach), plateau, Quaternary Head and marine deposits. They included five flint-rich gravels which had previously been associated with the mixes showing anomalous reactivity.

The gravels were tested for reactivity using a method based upon the Concrete Prism Test, which is a draft for development British standard (4). The test method consists of monitoring expansion by measuring the length change of concrete prisms (75 mmx 75 mmx200 mm) stored above water under hot (38 °C) humid conditions. The prisms are made using a high cement content (700 kg/m^3) and a water/cement ratio of 0.325. The method varied from the draft British standard in three ways; a slightly higher alkali level was used (1.11% $Na_2Oeq.$ instead of 1% $Na_2Oeq.$), the prisms were unwrapped, and two prisms were monitored instead of three. A dense limestone (crushed Cheddar Limestone) was used as the fine aggregate so that all the reactive silica came from the flint fragments within the gravel. In all the mixes the flint-rich gravel formed 70% by volume of the total aggregate in the mix and was made up of 40% by volume of the 20 mm-10 mm fraction and 30% by volume of the 10 mm-5 mm fraction. Flint was the dominant constituent of all the gravels and only gravels with flint contents above 85% by volume were included in the testing programme. This meant that the flint content of the total aggregate in the mix was always between 60% to 70% and therefore all the mixes contained similar amounts of flint.

Assessment of Porosity

Unweathered flint has a very low porosity but porosity increases as a result of cortex development. The cortex appears much paler than the unweathered flint but a visual examination gives no indication of cortex depth. Water absorption is an indirect measure of the porosity of an aggregate so water absorption values (24 hr) were used to provide a quick and fairly accurate assessment of the relative amounts of reactive porous cortex present in the gravels. The water absorption values were determined by methods outlined in BS 812 (5). The separate 20 mm-10 mm and 10 mm-5 mm water absorption values were obtained and then used to calculate the water absorption of each gravel as used in the Concrete Prism Test. Flint was the dominant constituent of all the gravels tested and, therefore, the water absorption values were not significantly affected by other aggregate types.

RESULTS

The results from the concrete prism tests showed that, when the flint-rich gravels were tested in the 70% proportion, they exhibited large differences in reactivity, even though all the gravels contained similar amounts of flint. Some gravels showed little reactivity whereas others produced large expansions in excess of 0.2%. At 12 months the expansions ranged from 0.011% to 0.267%.The largest expansions occurred with the gravels previously associated with the mixes showing anomalous reactivity. Figure 1 presents expansion curves for some of the gravels to illustrate the range of expansions encountered. It shows that Thames Valley flint-rich gravels, which are used widely in the construction industry, did not all produce similar expansions.

The flint-rich gravels possessed different porosities since their water absorption values varied from 0.90 wt% to 6.61 wt%. The gravels associated with the mixes showing anomalous reactivity had the lowest water absorptions. Visual examination of the flint-rich gravels showed that the gravels with high water absorption values contained large proportions of porous cortex. The gravels with low water absorption values still contained porous cortex but it was present in much smaller amounts.

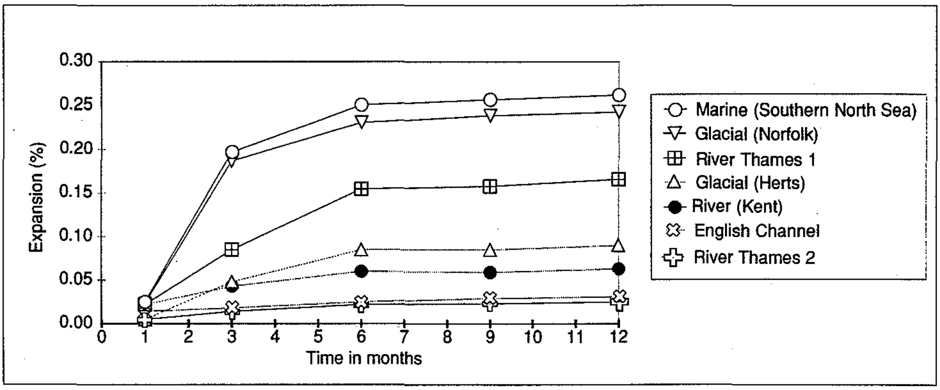

Fig. 1 Expansion curves of concrete prisms containing similar amounts of flint (flint-rich gravel in the 70% proportion).

Figure 2 shows the relationship between the porosity of the flint-rich gravels (as shown by their 24 hr water absorption values) and their alkali-silica reactivity, as determined by the concrete prism test. There is a distinct correlation between the degree of expansion and the overall porosity of the gravel, the highest expansions being associated with those flint-rich gravels having the lowest porosities and, therefore, the smallest amounts of porous cortex. Conversely the lowest expansions occur with those gravels possessing the highest porosities and, thus, the largest

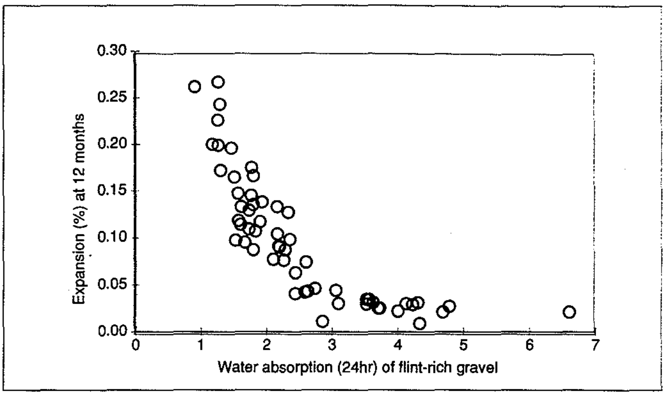

Fig. 2 Relationship between porosity and expansion of concretes containing 60% to 70% flint

amounts of porous cortex. The gravels associated with the mixes showing anomalous reactivity contained the smallest amounts of porous cortex and produced the largest expansions of all the flint-rich gravels. The Thames Valley flint-rich gravels featured in Figure 1 possessed different reactivities because they contained different amounts of porous cortex. The gravel which produced little expansion contained larger amounts of porous cortex (WA=3.71 wt%) than the gravel (WA=1.80 wt%) which expanded above 0.15%.

ADDITIONAL STUDIES

In order to investigate the proportion of flint-rich gravel required to produce maximum expansion 23 of the gravels were also tested in the 10%, 30% and 50% proportions. The results above showed that the amount of porous cortex present in the gravel had an important effect on expansion and gravels were chosen to encompass a wide range of water absorption values (and hence porosities). In all the proportions tested, the ratio of 20 mm-10 mm to 10 mm-5 mm gravel was kept the same as in the 70% proportion. Dense Cheddar Limestone coarse aggregate was added to the 10%, 30% and 50% mixes so that the coarse aggregate (flint-rich gravel + Cheddar Limestone) always formed 70% of the total aggregate in the mix.

Analyses of the results showed that the flint-rich gravels could be divided into three different 'porosity' types: low, intermediate and high porosity gravels. Figure 3 shows the expansions produced by the different proportions of the three porosity types. It can be seen that the largest expansions occur at different proportions dependent upon the porosity of the flint-rich gravel (as measured by water absorption). As the porosity of the gravel and thus the amount of porous cortex increases so the proportion of the gravel required to produce the largest expansion decreases. The amount of reactive aggregate producing maximum expansion is known as the pessimum proportion. Below and above the pessimum proportion expansion is reduced. In the case of the low porosity flint-rich gravels (WA <1.3 wt%) with small amounts of porous cortex, expansion increased as the proportion of gravel in the mix increased, up to the maximum proportion tested (70%). With these gravels the pessimum proportion was not exceeded but may have been reached at the 70% proportion. This proportion

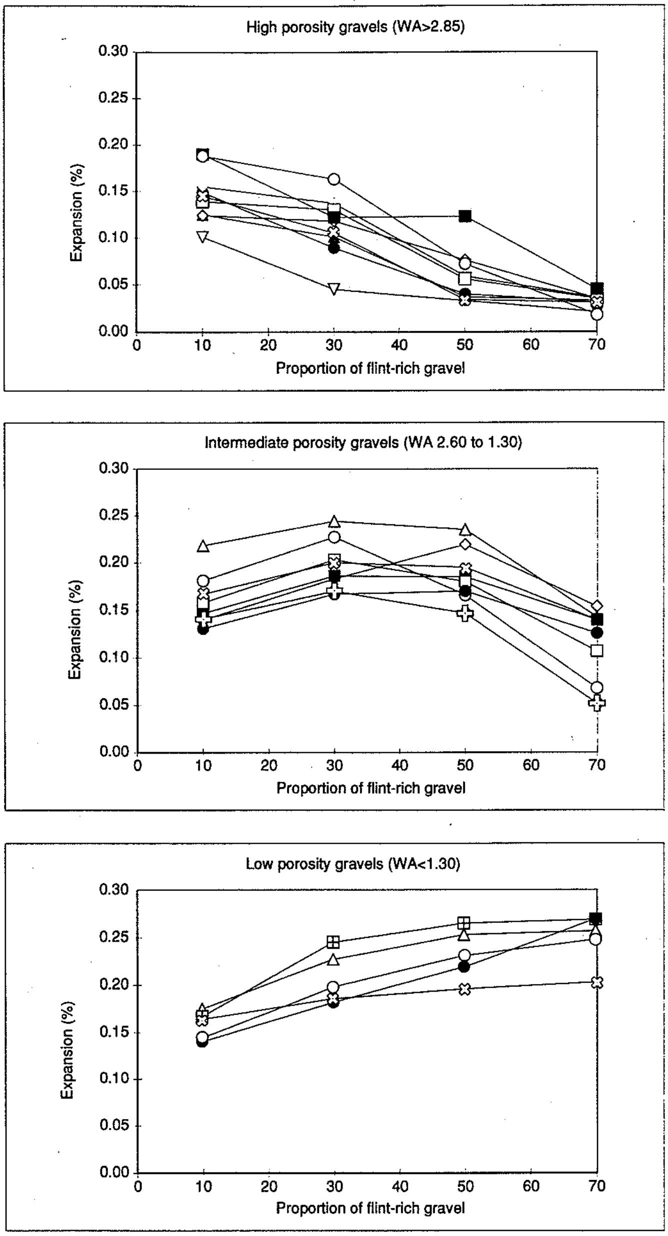

Fig. 3 Variations in expansion with proportion of flint-rich gravel

produced the largest expansion, although expansions above or close to 0.15% occurred with all proportions of the low porosity gravels tested, even with as little as 10% flint-rich gravel. The gravels associated with the mixes showing anomalous reactivity were low porosity gravels. The intermediate porosity gravels (WA between 1.3 and 2.6 wt%) with greater amounts of porous cortex, produced their largest expansions when they constituted either 50% or 30% by volume of the total aggregate in the mix. Thus the intermediate porosity gravels showed evidence of having reached and exceeded a pessimum proportion. Expansions above 0.1% occurred with all the proportions tested, except for a few mixes in the 70% proportion. The high porosity flint-rich gravels (WA >2.6 wt%) contained the greatest amounts of porous cortex and expansion increased as the proportion of flint in the mix decreased, down to the lowest proportion tested (10%). Thus with these gravels the pessimum proportion appears to have been reached or exceeded with as little as 10% gravel in the total aggregate. Far above the pessimum, in the 70% proportion, no significant expansion occurred.

DISCUSSION

The results show that differences in the reactivity of flint-rich gravels occur and can be related to the porosity of the gravels. They also show a relationship between pessimum proportion and porosity. The porosity is determined by the amount of porous cortex present and it is the cortex which is the main reactive component of flint in gravels. Since the cortex is produced by weathering processes, the amount of porous cortex present in flint-bearing aggregates varies according to the geological history of the flint fragments within the deposit. The flint-rich gravels obtained from the plateau gravel deposits of Oxfordshire, Dorset and Hampshire and the Quaternary Head deposits of West Sussex contained large amounts of porous cortex. In contrast some of the glacial gravels from East Anglia had much smaller amounts of cortex. River Thames flint-rich gravels from the London area had intermediate amounts. This variation between the deposits leads to differences in reactivity.

If the results are considered in relation to the amount of reactive cortex present in the flint-rich gravels they can be explained in terms of the pessimum effect. The high porosity gravels contained the greatest amounts of reactive cortex and their largest expansions occurred at the lowest proportion tested (10%). In this respect the high porosity gravels are showing pessimum behaviour similar to a highly reactive material, such as opal. The intermediate porosity gravels had smaller amounts of reactive cortex and their pessimum proportion occurred at correspondingly higher proportions of the gravel (at or close to 30% or 50%). The low porosity gravels contained the smallest amounts of reactive cortex and their largest expansions occurred at the highest proportion tested (70%). However, there are some inconsistencies in the results which suggest that there may be some additional factor affecting expansion. Firstly, the expansions in the 10% proportion were similar for the three gravel types (high, intermediate and low porosity), even though each gravel type contained different amounts of reactive cortex. Secondly, although the expansions occurring with the low porosity gravels increased as the proportion of the gravel increased, the rate of increase in expansion was not uniform. Thus, with one exception, with higher proportions of gravel (>50%) the rate of increase in expansion diminished, almost approaching zero in some cases. The one exception was the flint-rich gravel which had the lowest porosity of all the gravels tested (WA=0.90 wt%, black circle in Figure 3). This gravel showed a more uniform rate of increase in expansion as the proportion of gravel was increased. Thirdly, although the high porosity gravels show pessimum behaviour characteristic of a very reactive material (see above), they do not show the sharply defined peak of expansion at a certain proportion, which is also characteristic of such materials. Figure 3 shows that the high porosity gravels typically showed significant reactivity in the 30% proportion as well as in the 10% proportion. In addition, flint has been shown to have a much lower reactivity than a highly reactive material, such as opal (6). These inconsistencies suggest that there is some factor (or factors), other than the amount of reactive silica present, which affects both the expansions produced and the position of the pessimum proportion. The expansion of reactive aggregates can be reduced by the presence of inert porous aggregates and reasons to explain the effect have been put forward (6, 7). For example, the dilution of the alkalies due to the addition of more water at the mixing stage and the presence of increased numbers of voids in the concrete (both within the cement bordering the porous aggregate and within the porous aggregate itself) to accommodate the gel, are possible reasons. In flint, however, the porous aggregate is, itself, the reactive material. Thus the porosity of flint is acting in two opposing ways: it is both increasing expansion and reducing it. It is possible that the mechanism of the alkali-silica reaction may be affected in some additional way by the presence of aggregates that are both porous and reactive. Recent work is suggesting that this may be the case, at least in some concrete test situations.

In construction, the coarse aggregate typically constitutes about 70% of the total aggregate in a mix. Both the low porosity and intermediate porosity flint-rich gravels produced significant expansions in that proportion. The largest expansions occurred with the low porosity gravels, expansions typically being above 0.2%. The alkali content used in the concrete prism tests was somewhat higher than recommended in the draft British Standard (4), i.e., 7.77 kg/m^3 Na_2Oeq. instead of the recommended 7 kg/m^3. However when two of the low porosity gravels were later tested at the recommended alkali content of 7 kg/m^3 Na_2Oeq. they still produced expansions above 0.2%. In the 70% proportion all the flint occurred in the coarse aggregate and the fine aggregate was an inert limestone. As a result of previous research at BRE, UK specifications have recently been updated to prevent such concrete mixes being used (see introduction). In the case of the high porosity flint-rich gravels, however, no reactivity occurred with the 70% proportion, which suggests that these gravels could be safely used without the proviso that the mix must include at least 5% by mass of flint with particle size less than 5 mm.

The work highlights another area where an improvement in the specifications could be made. One of the main purposes of the work described in this paper was to identify which aggregates could produce anomalous reactivity, since the current specifications do not completely exclude these potentially expansive mixes. Although the number of mixes showing anomalous reactivity was small, recent work at BRE is showing that expansions in excess of 0.2% can occur with these mixes, when tested according to the draft British Standard Concrete Prism Test. The present work has made it possible to identify those aggregates which have the potential to produce anomalous reactivity: they are the low porosity flint-rich gravels. When these gravels are combined with reactive flint-bearing sands significant expansion can still occur, presumably because the amounts of reactive aggregate are still sufficiently close to the pessimum proportion for reactivity to occur. The low porosity gravels are not common and there is no evidence that they have caused a failure of an actual concrete structure. However, it is suggested that low porosity flint-rich gravels should not be used in structures in those cases where it is imperative that ASR damage is avoided and where no other precautions are being taken to prevent ASR occurring.

'Low porosity' flint-rich gravels represented only 1 in 10 of the test gravels. They occurred in East Anglia (Norfolk, Suffolk, Essex), Southern England (Kent and East Sussex) and also in the southern part of the North Sea. The sources from which the low porosity gravels were obtained consisted of glacial, beach and marine deposits.

CONCLUSIONS

The study showed that flint-rich gravel deposits:

- have different reactivities
- contain different amounts of reactive porous cortex
- have reactivities which correlate with the content of porous cortex rather than with the total flint content
- have similar expansions in similar proportions when they contain similar amounts of porous cortex
- have a 'pessimum proportion' which correlates with the amount of porous cortex present
- can be divided into three gravel types, namely low, intermediate and high porosity gravels, each type having a different pessimum proportion and exhibiting a particular pattern of reactivity
- can give rise to anomalous expansive reactivity, if they are of the low porosity type

The results have suggested that some modifications to the specifications are needed. In particular, low porosity flint-rich gravels should not be used in concrete structures in those cases where it is imperative that ASR damage is avoided and where no other precautions are being taken to prevent ASR occurring.

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