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Durability of cement-based grouts and binders

La durabilité des coulis à base de ciment et des liants

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A number of changes have taken place which affect cement-based grouts and binder: (i) they are being used in an increasing variety of contexts, both geotechnical and geoenvironmental; (ii) they are increasingly being used in more aggressive environments e.g. contaminated land; (iii) there is an increased incorporation of industrial by-products, which are continually changing in composition because of cleaner production processes; (iv) there is a need to increase the lifespan of materials because of the drives towards sustainability and (v) there is continued developments of more environmentally acceptable and sustainable cements to reduce the environmental impacts from the production of Portland cement.

One of the main durability problems of Portland cement is the leaching of calcium: firstly the portlandite (which is highly soluble and highly reactive) is dissolved and then the calcium silicate hydrate (C-S-H) is decalcified leading to its degradation. Durability problems include sulfate, chloride and acid attack, freeze-thaw and wet-dry cycling and long-term deterioation.

On-going research by the author is investigating two areas of improving the durability of cement-based grouts and binders. The first is the incorporation of durability improving additives. The example used here is zeolite. The second is the investigation of a more durable cement and the example used here is magnesium oxide cement.

Like clay, zeolites are aluminosilicates. However they have a rigid three-dimensional structure which contains channels and cavities. They have large reaction surfaces and high cation exchange capacity. Zeolites are already widely used in a range of industrial and commercial processes including wastewater treatment, refinery distillation and in commercial detergents. In China they are widely used as a cement blending material.

Some of the advantages of zeolite in cement-based binders are listed here. Firstly, the highly porous structure of zeolite provides large reaction surfaces for the interaction with Portlandite hence consuming it. Secondly, zeolite in a cement matrix produces a hydration phase which contains less Portlandite and less Ca-rich C-S-H reducing leachability. Thirdly, zeolite produces a finer pore matrix in cement paste, reducing the permeability. Zeolite offers much improved durability compared to commonly used additives, which have durability improving properties, such as pulverised fuel ash and blastfurnace slag.

Related experimental work was carried out in which cement-based mixes, not containing zeolite, were immersed in sulphate and acid solutions for up to four days and showed extensive physical deterioration. Similar samples which contained zeolite, survived those two environments for over 200 days without any signs of physical damage.

Magnesium oxide (MgO) cements are a recent invention. Their main ingredient is magnesium oxide, or magnesia, which has to be reactive. This is produced by the calcining of magnesite (calcium carbonate) at a temperature of around 850^{o}C, this being much lower than the temperature used to produce Portland cement. The cement formulations also include a pozzolan, e.g. pulverised fuel ash, and Portland cement. One range of these cements is called Tec-cement which is a modified Portland cement in which a small quantity of reactive magnesia is added to Portland cement. Another range is Eco-cement which mainly consists of a pozzolan and reactive magnesia to which a small quantity of Portland cement is added.

The reason for the good durability performance of MgO cements is the fact that they hydrate to form Brucite (magnesium hydroxide) which is far less soluble and far less reactive than Portlandite. It therefore has much reduced leachability and much reduced reactions with anions. Brucite is also fibrous and has a layerd structure and hence it is additional able to trap sulphate and chloride ions within its structure. In addition, Brucite has a lower water demand leading to a denser paste, lower permeability and reduced freeze-thaw problems.

One technique being employed in the study of this cement is nano-indentation. Nano-indentation involves the formation of an cone-shaped indent on the surface of a material with the application of a force. From the load-displacement profile a number of physical and mechanical properties of the tested material can be obtained. The application of this technique to the study of the microstructure of Portland cement was pioneeded by colleagues at MIT.

At the 10^{-6}m scale, a sample of Portland cement will consist of the two types of C-S-H, high density C-S-H and low density C-S-H. By applying nano-indentation to such a sample, one can map a profile of Young's modulus within the sample. This shows that the low density C-S-H forms around 67-70% of the sample and has an average E value of around 22MPa. The high density C-S-H forms the remaining 30-33% of the sample and has a higher E value at an average of 30MPa. If the same procedure is applied to a sample which is calcium leached, this shows that the E values of the low density and high density C-S-H types drastically reduced to 3 and 12 MPa respectively. This gives a clear indication of the effect of the calcium leaching on the stiffness of the C-S-H. Such observations are being linked to observations of stiffness and other properties carried out at the macro-scale using material blocks.

In summary:

- There has been many changes affecting cement-based grouts and binders – but what is the impact on their durability?
- There are additives which offer vast durability benefits such as zeolite but would cost implications be a hindrance to their use?
- MgO cements are likely to be more durable than Portland cement. However as a new material, it will require extensive testing and validation. Also how long will be take the construction industry to accept alternative cements to Portland cement?

And finally, two more general questions:

- Are there sufficient research efforts being carried out on the durability of cement-based grouts and binders? and
- Where should current and future research efforts be concentrated?