# Concrete Proof

Far more concrete is produced than any other man-made material. Annual production represents one tonne for every person on the planet. It is incredibly versatile, and is used in almost all major construction projects. Professor Peter Claisse reveals that it does, however, have two serious problems which may threaten its use in the future.

The first problem is that cement production is responsible for approximately 5% of all carbon dioxide emissions. This results from chemical reactions in the kiln and cannot be significantly reduced with energy efficiency or alternative fuels.

The second problem is durability. There are some fine examples of Roman concrete which is still in good condition after 2000 years; but there are also many examples of modern structures which have required extensive repairs just a few years after completion.

This paper discusses some possible routes towards solutions to these problems and describes work which has been carried out on them at Coventry University Construction Materials Applied Research Group (CMARG).

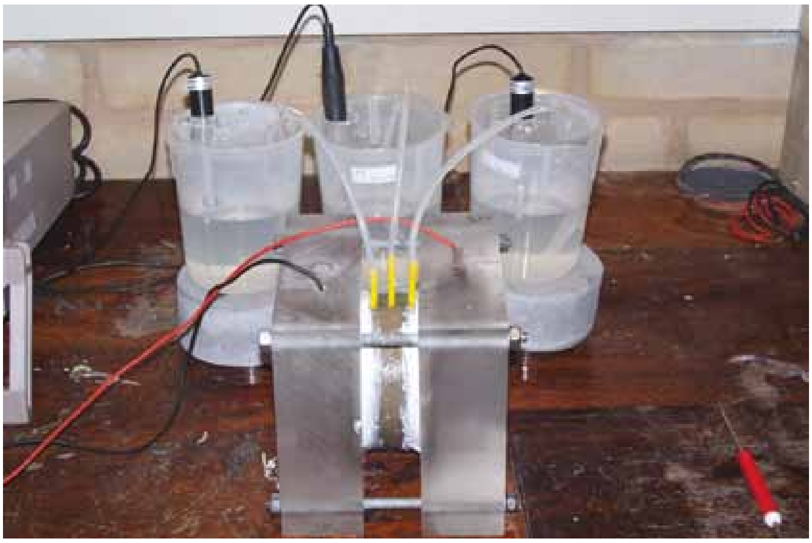
## Reducing the Carbon Footprint

There are three main solutions that are being researched to reduce the environmental impact of concrete:

- Alternative fuel such as shredded tyres or pelletized domestic waste to replace coal and oil in the kilns
- Waste minerals such as ashes or slags to replace the cement in the concrete
- Different cements such as supersulphated cement and magnesia cements

## Alternative Fuels

Fuel efficiency can achieve considerable savings. A traditional cement plant typically emits one tonne of $CO_2$ per tonne of cement produced. The Japanese claim to have reduced this to an average on just 0.7 tonnes of $CO_2$. The problem is that once this figure has been reached it is impossible to make many more reductions because approximately 0.5 tonnes of $CO_2$ are produced by the chemical reactions in the kiln and are unavoidable.



*Top: A sample being tested with the ASTM C1202 rapid chloride test. The red and black wires are applying 60 Volts across it and the Perspex cells contain sodium chloride on the negative side and sodium hydroxide on the positive side. The pipes leading to the top of the sample are for the additional potential readings used for work at Coventry.*

*Right: Cores from the no-cement mix*

## Cement Replacements

There have been some considerable gains in this area with the introduction of the cement classes in EN197. Much of the bagged cement which is sold in the UK is CEMII with either ash, slag or limestone flour in it. Traditional practice for producing concrete in this country is, however, to add cement replacements at the batching plants and there are a number of barriers to achieving more replacement:

- Fly ash is classified as a waste under environmental legislation. This makes it difficult to transport and use.
- Constantly changing sources of coal. The UK now imports much of its coal from areas as diverse as Indonesia and Siberia. These different coals produce very different ashes some of which actually contain so much lime they are self-cementing. This variability makes them very different to use.
- Mercury control on emissions from power stations makes unsuitable ash. This is a particular problem in the USA.
- Limited supplies of ash and slag. During a hot summer most of the coal-fired power stations are often shut down and ash is very difficult to store without adding water to make a slurry. This makes it impossible to process and handle for adding to concrete. Reducing steel production is reducing supplies of slag.
- These materials can only replace part of the cement – up to about 40% for PFA and about 60% for GGBS.

## Alternative Cements

There is considerable interest in these, particularly magnesia cements. A complete change in the basis of worldwide cement production is, however, unlikely in the foreseeable future. Supersulphated cements were withdrawn from the market about 50 years ago due to their poor shelf life.

The CMARG has carried out a number of programmes based on replacing all the cement with waste materials and using waste gypsum and slag to make supersulphated mixes. These mixes have been tested in an extensive series of site trials. The mixes without cement cannot achieve strengths above about 30MPa but there are numerous potential applications including sub-bases for roads. Figure 1 shows a site trial of a section of a car park. The mix contained Basic Oxygen Slag, waste gypsum and kiln dust with no cement.

This work has demonstrated that low strength concrete mixes which are suitable for a wide range of applications may be made using mineral wastes to replace all of the cement.

## Achieving Durability

It is possible to make durable concrete. It is also very easy to make non-durable concrete e.g. by adding too much water. The problem is that there is no reliable


*Above: Site trial of concrete with no cement*

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test to find out if it is durable. For the last 100 years concrete on most sites has only been tested for strength. The consequences of this are that vast numbers of structures are suffering durability problems, primarily corrosion of embedded steel. It has been known for 100 years that the main cause of this is chloride from salt. In the USA the cost of this has been estimated at 2% of GDP.

To reach the steel the salt must move through the concrete. Most durability tests measure how easily salt (and other compounds) can move through it. There are thus three basic types of test to measure the durability of a concrete sample corresponding to the three main transport mechanisms:

- Permeability tests in which a fluid is driven through the sample by a pressure gradient.
- Diffusion tests in which ions are transported by a concentration gradient.
- Electromigration tests in which ions are transported by an electric field.

The most popular durability test in current use is the ASTM C1202 Rapid Chloride Penetration Test. The test works by measuring electromigration as the current through the sample under an applied voltage (figure 2). It is widely used throughout the Americas and Asia as an acceptance test for concrete to be used in parallel with the cube test. The problem with it is that it can be fooled by reducing the current with mixes with high electrical resistivity which are not particularly resistant to salt penetration.

The CMARG has developed a method to overcome the problems with the ASTM C1202 test. The computer model which was used to develop the method is based on a fundamental understanding of the processes that take place during the test. When a chloride ion enters the sample it cannot just stop part way through. This would cause a build up of charge which is contrary to Kirchoff's law – a basic law of physics. The charge must be carried away by a different ion; normally an alkali ion which was already in the sample. Thus the computer model has to simulate the movement of several different types of ion at the same time. A conclusion from the modelling was that if a voltage is applied across a sample the potential at the centre will not be half of the applied voltage. The potential drop is non-linear and by measuring this non-linearity the test results can be corrected to give a true measure of the potential durability of the sample. The photograph shows a sample in which the potential within the concrete is being measured.

This work has demonstrated that the ASTM C1202 test can be modified to overcome its limitations and give an accurate measure of the potential durability of concrete mixes.

## Conclusions

1. There is great potential for using concrete with mineral wastes replacing all of the cement. Using "high strength" cement for low strength applications has a high financial and environmental cost.
2. Durability tests should be routinely applied to concrete in major construction projects in order to reduce the massive problem of reinforcement corrosion. A modified ASTM C1202 test is being developed for this purpose.

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