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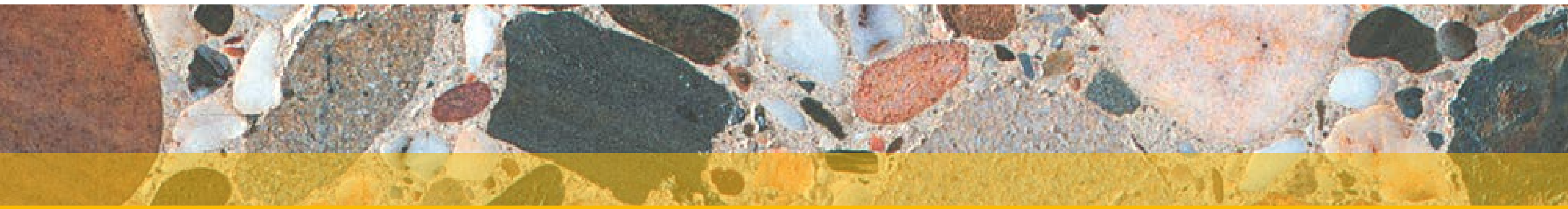

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# NEWSLETTER

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  8 May 2019
- Digitalisation and its Application in the Concrete Sector
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# Cement testing indispensable for the safety of construction works

## Modern online and inline methods enable optimised quality control in cement plants

**The safety and durability of construction works has always been of the highest importance in order to protect lives and assets. Usually we take it for granted that concrete maintains its stability, but the considerable efforts taken to achieve this are largely unknown to those outside the construction industry. The performance of concrete depends on many parameters such as the manufacturing process, the concrete composition and of course the quality of the cement used. Therefore, the requirements related to cement are high, and cement is amongst the best-controlled industrial products beside food and medicines. In view of the large number of tests prescribed, modern methods such as online and inline analysis have become more and more established in cement plants.**

The importance of common criteria for a comparable determination of cement quality was realised already in the 19th century. National standards and surveillance systems were steps on the way to a European system. In 2000, the "cement standards" EN 197-1 and EN 197-2 for conformity evaluation were published as the first harmonised European standards for a construction product.

### High effort for cement testing

Due to its importance for the safety of construction works, the assessment and verification of constancy of performance (AVCP) of cement follows the most rigorous AVCP system 1+. Notified certification bodies have to be involved to control cement and its production. It is worth mentioning that typically more than 500 tests per year are performed on each cement type produced in a cement plant, mainly by the manufacturer (autocontrol testing) but also by the certification body (audit testing).

The laboratory of the certification body usually has to apply reference test methods as described in the European standard family EN 196. These traditional methods, for example wet chemistry, require a lot of working time. They are therefore often replaced by other techniques in cement plants which need to be automatable and fast in order to enable real-time production control. Their equivalence to the reference methods must of course be demonstrated in each case.

### X-ray methods for quality control of cement

Typical examples for automatable test methods used in cement plants are X-ray fluorescence analysis (XRF) and X-ray diffraction (XRD) combined with the Rietveld method. They have become common in most cement plants worldwide. XRF is a method for the chemical analysis of cement, its constituents and other substances relevant for the manufacturing process. The chemical results obtained on clinker can be used for the calculation of the "theoretical" phase composition and thus for the control of the clinker burning process. However, this method according to Bogue postulates completed chemical reactions in the kiln and does not for instance take into account the influence of burning conditions.

As an alternative to the Bogue method, X-ray diffraction and the Rietveld analysis have become established. The method was developed already in 1967 by Hugo M. Rietveld for crystal structure refinement using neutron scattering data. The improvement of X-ray detectors and computers needed for the calculation of the complex algorithms enabled the use of the method for quantitative phase analysis, for example, of clinker and cement. **Fig. 1** shows an example of a Rietveld analysis of a cement sample. Hugo Rietveld himself was surprised by the fact that his method, developed for pure academic application, had become so useful for the industry.

### Isothermal conduction calorimetry has been standardised

The release of heat is an important property of the cement hydration reaction that in different ways has been used since the early 20th century to characterise cements. The so-called "solution method" and semi-adiabatic calorimetry are standardised in EN 196-8 and EN 196-9 and have been applied for many years to determine the heat of hydration and to classify low heat cements which are required for massive concrete structures.

Isothermal conduction calorimetry (ICC) as a third option was recently standardised in EN 196-11. This method allows not only the determination of the heat of hydration but also a continuous measurement of the heat release. The shape of the heat curves obtained can be used as an indicator for the performance of different cements (see **Fig. 2**) and provides information on potential interactions between, for example, cement constituents and additives. The method is currently not automatable but offers many fields of application such as sulfate optimisation,

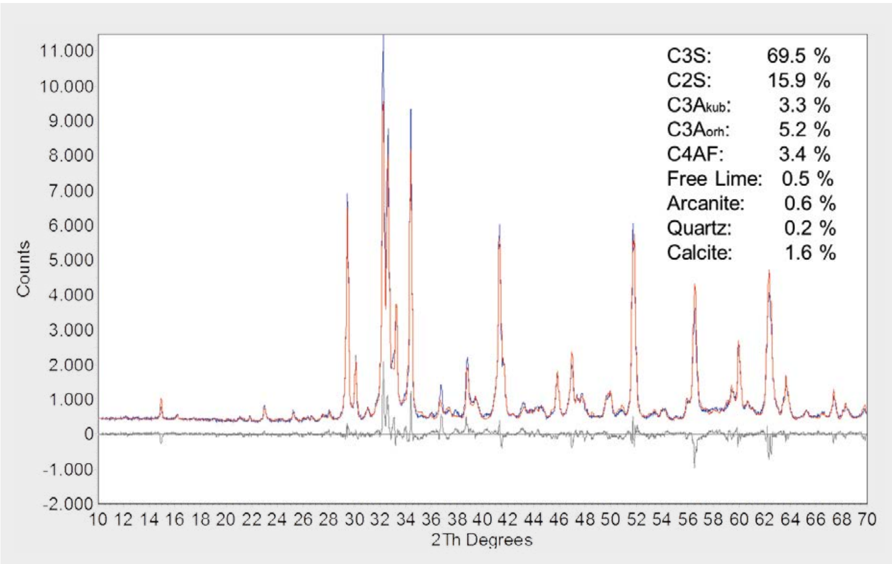


**Figure 1: Rietveld analysis of a cement sample**

strength prediction and setting time estimation. Last but not least, the method requires less working time and is not dangerous, whereas the solution method requires the use of the highly toxic hydrofluoric acid.

### Inline testing offers further advantages

XRF and XRD can both be implemented as classical online methods in cement plants: Samples are automatically taken in the process and sent to a central laboratory, for example using a pneumatic tube, for further preparation and analysis. The whole procedure is much faster and needs less manpower than, for example, traditional wet chemistry or clinker microscopy. A direct process control is possible although there is still a minor loss of time between the sampling and the availability of the results.

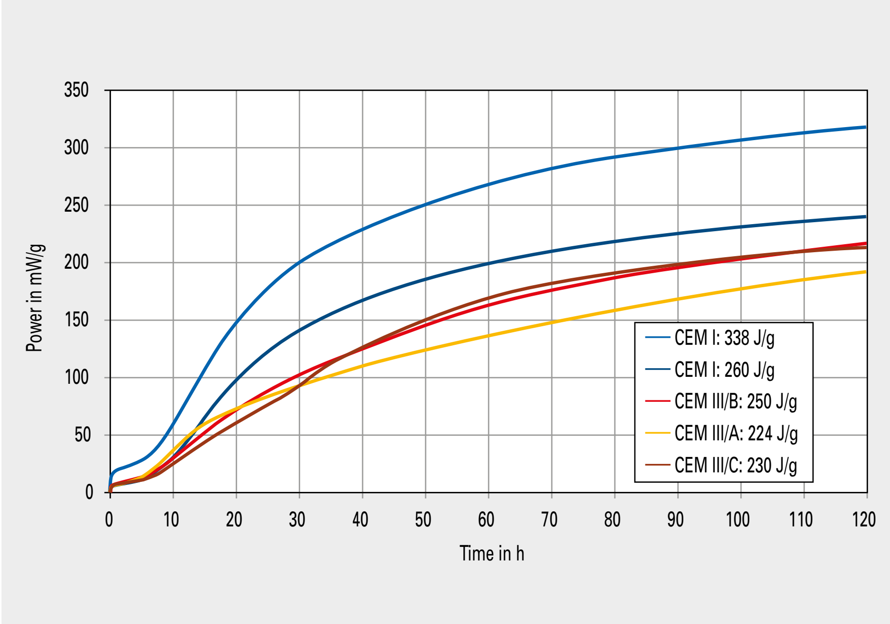


**Figure 2: ICC analyses of different cements**

So-called inline methods go even further as they are directly implemented in the production process. For example, the prompt gamma neutron activation analysis (PGNAA) can be used to determine the chemical composition of raw material. For this purpose the analyser is mounted directly on the belt conveyor where the material is analysed continuously during transport in order to optimise stockpiling. Inline methods are often less precise than online methods, but they have the advantage that no sampling and sample processing is necessary and that a lot of data can be used for continuous process control.

# Digitalisation and its impact on the application of concrete

## How will developments like BIM and 3D printing affect the cement and concrete sector?

**Digitalisation brings new opportunities and challenges for all stakeholders in the construction sector. The main driver towards a digitalised construction industry is Building Information Modelling (BIM). The BIM planning culture is based on cooperation. Data, including material data, is required much earlier in the BIM process than in traditional paper-based 2D planning. BIM certainly presents many advantages. How will this development affect the cement and concrete sector?**

Paper drawings are still widely used on building sites and this will probably not change in the near future, so no revolution is expected here. However, the long-term path towards the drawings and information used on construction sites will be a revolutionary new one. This path or process is called BIM (Building Information Modelling). One of the many advantages of BIM is that drawings are not created in a time-consuming process by engineers or drafters, but automatically by BIM software. The intellectual property of a designer is therefore contained in a 3D model (**Fig. 1**). The core of the BIM method is the digital twin or 3D model of the structure. Therefore, if alterations are necessary, it is always the digital twin which is revised, not the drawing. As in traditional planning, the structure or elements are designed and verified using structural or design software with regards to their:

- serviceability limit states (functioning of the building or element, comfort of people in or around the structure and its appearance)
- ultimate limit states (safety of people in or around the structure)
- durability (resistance of the material against environmental load).

### Advantages of BIM

Construction projects usually begin with an idea of the client or the designer/architect, or the necessity of an infrastructure for a certain purpose. Particularly in the early processes of a construction project, BIM can deliver a good basis for decision making. Using the digital twin to investigate various project solutions usually leads to a feasible and sustainable project. A 3D model is much more accessible to our brains than rough sketches or cross-sections. However, the pre-condition for a successful BIM project is that the client or the architect provides the necessary information early in the process. This can also mean that certain material properties (such as cement types or concrete properties) are defined at a much earlier stage than in traditional planning. Nevertheless, a project carried out correctly by the BIM method will ensure a very smooth construction period due to the minimisation of errors.

### Role of materials manufacturers in the BIM world

The BIM method is not solely based on 3D information. It incorporates a wide array of additional information

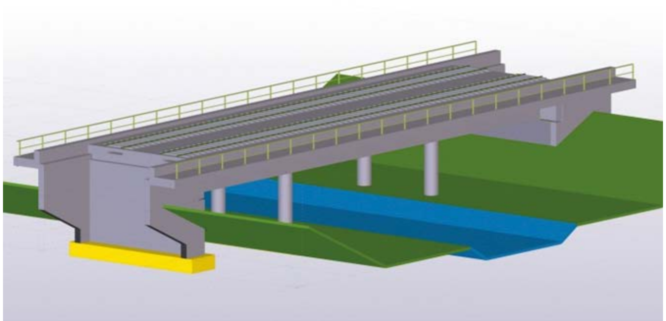

**Figure1: Model of a bridge**

apart from geometry. BIM can also be understood as a database where the 3D model is purely the interface to access data. Behind the 3D model is a huge database with information needed in the planning, construction or operational phases. A typical concrete element in the BIM method contains e. g.:

- its 3D geometry
- its material properties, such as concrete strength class and w/c-ratio
- its exposition classes
- its concrete cover.

Information regarding the exposure conditions, cost or production date of the element can also be included. As concrete is a composite material consisting among other components of cement, it is possible to incorporate the information from the manufacturer's declaration of performance into the BIM database. What is now readily available on cement manufacturer's websites in Declarations of Performance (DOPs) would therefore then become a part of the 3D model.

## Additive manufacturing/3D printing

Once buildings or parts of buildings have been designed and calculated using 3D software, the 3D information about the element or building exists in digital form. The question which then arises is: why not feed this data to a machine and let the machine manufacture the component? The next step towards digital fabrication therefore becomes apparent. Even so, it still seems far away as seen from today's perspective.

In the future, the manufacturing process of building elements will most likely be done using large-scale concrete printers. Depending on the 3D printing process (powder bed or Shotcrete printing), cements will have to fulfill certain criteria. The science of rheology will be a crucial tool to investigate these applications. Shotcrete 3D printing could become a promising 3D printing technology **Fig. 2**). However, independent of the method used, special binders for these applications will have to be developed in some cases.

## Facility management and maintenance

After a structure has been built, the owner receives an "as-built-model". This "as-built-model" is the most accurate digital twin of the structure resulting from the building process. It contains the geometric information, material properties, cost and time information. This model can now be utilised for tasks within facility management and maintenance (cleaning, inspection, concrete repair and improvements). In particular, the digital twin will develop into a valuable asset for inspection and concrete repair. In the future it will then be possible to use the digital twin for documentation and concrete repair planning after a structural investigation. Concrete structures can suffer from various attack mechanisms. Depending upon the exposure, this can be concrete corrosion or reinforcement corrosion. By incorporating the attack mechanisms and damaged areas into the 3D models it is then possible to link the damage to an appropriate concrete repair solution. This could be done by comparing the state of the structure and its mechanical and durability properties with the mechanical and durability properties of the repair solution.

**Figure 2: Layer-by-layer construction of a wall with a Shotcrete 3D printer**

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