POTENTIALS OF NEW CEMENTS MADE FROM GRANULATED BLAST FURNACE SLAG, FLY ASH AND CLINKER

Andreas EHRENBERG, Volkert FELDRAPPE

FEhS - Institut für Baustoff-Forschung e.V., Bliersheimer Str. 62, 47229 Duisburg, Germany

a.ehrenberg@fehs.de, v.feldrappe@fehs.de

Introduction

The production of cement is energy- and raw material-intensive. In particular, the use of granulated blast furnace slag (GBS) as main cement constituents is of great importance due to its high performance and positive ecological footprint.[1,2] The high performance of GBS also means that the proportion of additional main cement constituents can be increased significantly compared to the simultaneous use without GBS and beyond the compositions previously standardised in DIN EN 197-1.[3,4,5,6] The inclusion of such cements in the revised European cement standard EN 197-1 is expected to take the form of CEM II/C and CEM VI cement.

FEhS – Building Materials Institute (FEhS) together with the Research Institute of the German Cement Industry (VDZ) carried out two large research projects to provide basis information for a potential future standardisation of cements with GBS, fly ash and clinker beyond CEM II/B combination. The structures already corresponded to the two-stage process of CEN technical report CEN/TR 16912 "Guidelines for a procedure to support the European standardisation of cements", published in 2016.

Testing program

In order to determine the performance of cements rich in GBS and fly ash in an extensive but nevertheless feasible manner the utilisation of statistical methods of design of experiments (DoE) was mandatory. In a first step a design with 108 different cements having different compositions and considering different reactive GBS, fly ash and clinker was defined for testing cement strength[3]. The statistical assessment of the results provided general models for the prediction of strength depending on cement composition and reactivity of main constituents with this procedure.

Investigations into the durability of concrete are usually complex and time-consuming. Experience shows that concrete compressive strength is a necessary, but not necessarily a sufficient criterion for adequate durability. As a general rule, however, durability requires a certain minimum strength. Therefore, 7 cement

compositions with sufficient strength development were defined based on the findings of the proven models in a second step[6]. Objective was to determine the resistance to various durability exposures of concretes made with these cements. The cement compositions ranged from already discussed but not yet standardised CEM II/C and CEM VI cements to even lower Portland cement clinker contents. All cements were produced by mixing the finely ground cement constituents – Portland cement, sulphated GBS and fly ash.

Results and discussion

Parameter study for cement development

According to the statistical assessment the cement composition had a significant impact on the mortar strength after 2 and 28 days. Also the reactivity of GBS, fly ash and clinker affected the cement performance significantly. As an example, Figure 1 contains the graphical evaluation of the model for 28 d mortar strength. All models were proven with additional tests which were originally not part of the DoE. As Figure 2 demonstrates, the mortar strength after 28 days is predictable to a good approximation depending on cement composition and raw materials reactivity.

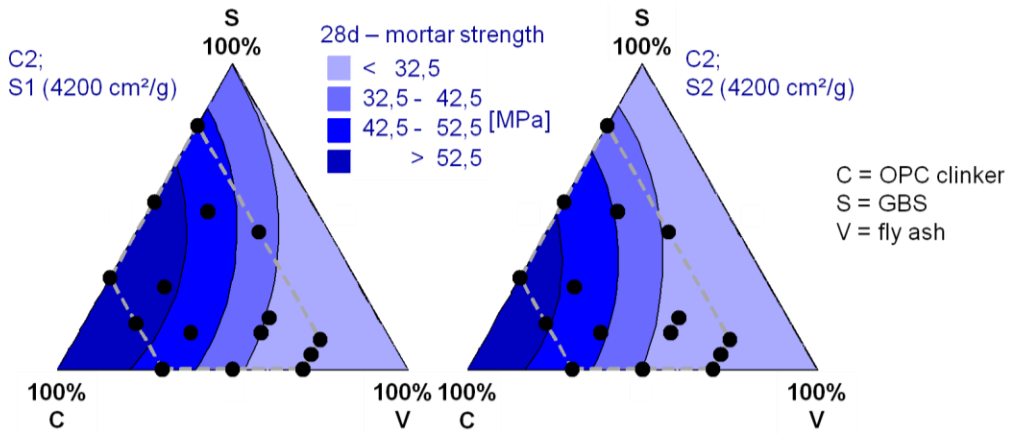

Figure 1: Predicted 28 d mortar strength for cements with clinker C2 and GBS S1 (left) and S2 (right)

Cement mortar strength after 28 days of > 42.5 MPa can be achieved with a wide range of compositions (Figure 1). However, the fly ash content in particular has to be limited to maximum 30 wt% for all cements containing less than 65 wt% OPC clinker. This value can be increased up to 40 wt% if a more reactive GBS is used. The reactivity effect of GBS and fly ash increases continuously with lowering OPC clinker content of the cements. It can be concluded that higher GBS reactivity at simultaneously constant OPC clinker quality allows the use of higher quantities of lower performing cement constituents like fly ash or limestone.

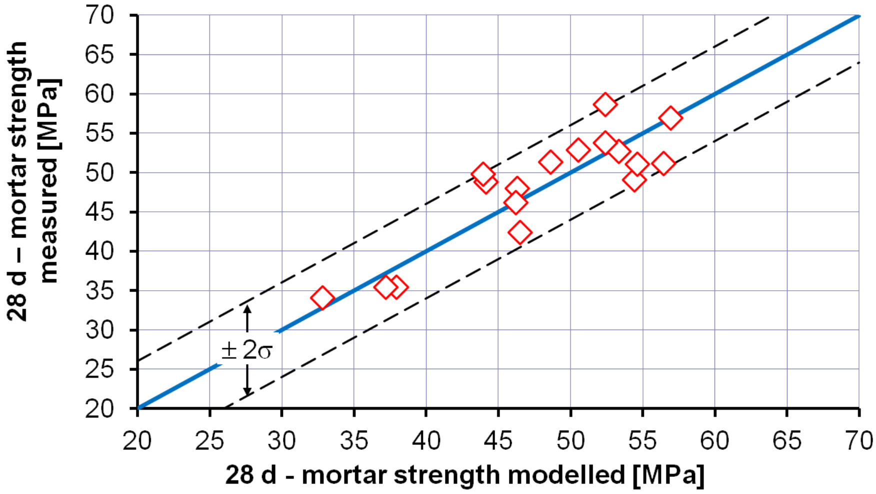

Figure 2: Validation of the model mortar strength after 28 days

Concrete durability

Based on the statistically proven models 7 cements with 5 compositions were defined for the durability tests. The current development for updating EN 197-1 (introduction of CEM II/C and CEM VI cement) was taken into account by 3 cements. Furthermore 4 cements (CEM X) were chosen exceeding the compositions of EN 197 to estimate their potential in concrete. The concrete composition always conformed to the minimum requirements of German concrete standard DIN 1045-2 concerning the different exposure classes. Production and storage were according to DIN EN 12390-2. All tests were carried out in comparison to corresponding mortars and concretes with 2 reference cements (CEM III/A 42.5 N).

For all concretes, flow spread 4 minutes after water addition as well as compressive strength development up to an age of 91 days were determined. The flow spread of the concretes was always higher compared to the reference concretes with CEM III/A cement. Normally it corresponded to a consistency class F3 to F4 according to DIN EN 206-1. Except of concretes with CEM X cements, strength development was in general comparable to the reference concretes.

As durability relevant properties, carbonation, chloride migration, freeze-thaw and freeze-thaw and de-icing salt as well as sulfate resistance were taken into account.

By an example only the results concerning chloride migration resistance are presented although the other durability tests also provided satisfying results.

The rapid method (migration test according to BAW code of practice, which is similar to NT Build 492) was used to determine the resistance to penetrating chlorides on concretes with 320 kg/m³ cement and a w/c ratio of 0.50. The test specimens were

stored in water until the test age of 35 days. Chloride migration coefficient was in a range between 3.1 and 6.3×10^{-12} m²/s which is significantly lower than that to be expected values of app. 9×10^{-12} m²/s for Portland cement concretes. Rather the results were in the order of magnitude of the reference concretes with CEM III/A cements.

Conclusions

According to the verified models obtained from statistical evaluation of the DoE, manufacturing of cements of strength class 42.5 is possible within a wide range of compositions and quality of cement main constituents[3]. If the fly ash content is limited, properties can be achieved comparable to those of commercial cements.

The durability of concretes made with these cements was tested related to various exposures. The investigations clearly show that durable concretes can be produced with all cements if the minimum concrete composition requirements defined in DIN 1045-2 for the corresponding exposure classes are met[6]. The durability behaviour was normally similar to that of the reference concretes made with CEM III/A 42.5 N as illustrated by the example presented here. These findings provided an important basis for including CEM II/C (S-V) and CEM VI (S-V) cements in the current draft EN 197-1 which will define 39 cement types.

The huge potential of using DoE and statistical evaluation tools in the building materials sector could be demonstrated. With comparatively few tests general relations between the different impact parameters and the performance of cements consisting of GBS, clinker and fly ash were developed and statistically safeguarded.

References

1. H.-M. Ludwig, “Entwicklung und Einführung von CEM II-M-Zementen”, in *Proceedings of 15th Internationale Baustofftagung (ibausil)*, Weimar, Germany, 2003.
2. V. Hoenig, M Schneider, “CO_2 Reduction in the Cement Industry, Process Technology of Cement Manufacturing”, VDZ Congress 2002, Edited by Verein Deutscher Zementwerke, Düsseldorf, Germany, 2003.
3. V Feldrappe, S. Schulze, A. Ehrenberg, J. Rickert, “CEM X -Zemente - Möglichkeiten und Grenzen der Leistungsfähigkeit von Zementen mit Hüttensand, Steinkohlenflugasche und Klinker”, in *Proceedings of 18. Internationale Baustofftagung (ibausil)*, Weimar, Germany, 2012.
4. A. Wolter, “Multikompositzemente”, in *Proceedings of 17. Internationale Baustofftagung (ibausil)*, Weimar, Germany, 2009.
5. C. Müller, K. Severins, “Ökologisch und technisch optimierte Zemente mit mehreren Hauptbestandteilen - Laboruntersuchungen und Betriebsversuche”, Final report of BMBF-research project “ÖkotopZement” - funding code 01LK0502, Düsseldorf, Germany, 2009.
6. V. Feldrappe, A. Ehrenberg, “Dauerhaftigkeitseigenschaften von Betonen mit hüttensand- und flugaschereichen Zementen”, Report des FEhS - Instituts für Baustoff-Forschung, 24 (2) 2017.