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Research topic:

Optimisation of clinker-efficient cements by means of multi-modal particle size distributions and utilization of energy-efficient products from separate ultra-fine grinding

Background and research objectives

In previous projects on “separate ultrafine grinding” (SFG), it was shown using Portland cements and cements with several main constituents that the particle size distribution (PSD) of high-quality ball mill cements can be redesigned by separate ultra-fine grinding and blending. For the two-staged approach of separate ultra-fine grinding, a lower specific energy demand could also be determined by means of semi-industrial implementation. An optimization of the cement and concrete properties has not yet been pursued. Clinker-efficient cements will be subject to growing demand on the German cement market in the future due to the current climate protection targets. This will lead to a significant reduction of CO_2 emissions through increased clinker substitution in the cement. Therefore, a special focus was placed on separate ultra-fine grinding of clinker, limestone and granulated blast furnace slag for the production of CEM II/C and CEM VI cements in this new project. The focus was on optimization of the cement and concrete properties. The degree of freedom offered by separate ultra-fine grinding makes it possible to blend the main cement constituents to an appropriate fineness based on their hydraulic activity and to influence the properties of the cements. The resulting PSD of the clinker-efficient cement does not necessarily have to follow an RRSB-distribution, so that the hydraulic potential of the individual main constituents can be fully utilized.

In this research project, it was shown that the cement and concrete properties can be optimized with the help of a suitable grinding and blending strategy, such as separate ultra-fine grinding. The optimization was based on the specific electrical energy demand for grinding and a positive development of the compressive strength. A ball mill in a closed circuit with a dynamic classifier was used as a reference for separate ultra-fine grinding.

Scientific approach

Using a previously defined cement composition, reference mortars and concretes made from CEM II/C-M (S-LL) and CEM VI/S-LL cements were produced from the ball mill products, which served as a basis for comparison for separate ultra-fine grinding. The two-staged separate ultra-fine grinding was carried out in the 1st grinding step using a semi-industrial vertical roller mill (VRM), whereby all components were also ground separately here. In the 2nd grinding step, a semi-industrial stirred media mill (SMM) was used for the purpose of ultra-fine grinding of the granulated blast furnace slag (**Figure 1**). Using a suitable mixing strategy for separate ultra-fine grinding, which takes into account both the energy demand of the cement mixture and the strength development, various cement mixtures were produced with a mixing gap within the granulated blast furnace slag (GBFS), resulting in some cases in highly multi-modal particle size distributions. The mixing gap was defined as a blend of both coarse and ultra-fine GBFS, which were added to the corresponding cement in different finenesses and proportions. The mixtures from the separate ultra-fine grinding differed from those from the references only in the mixing strategy of the GBFS. The particle size distributions of the clinker and limestone corresponded to those from the ball mill production.

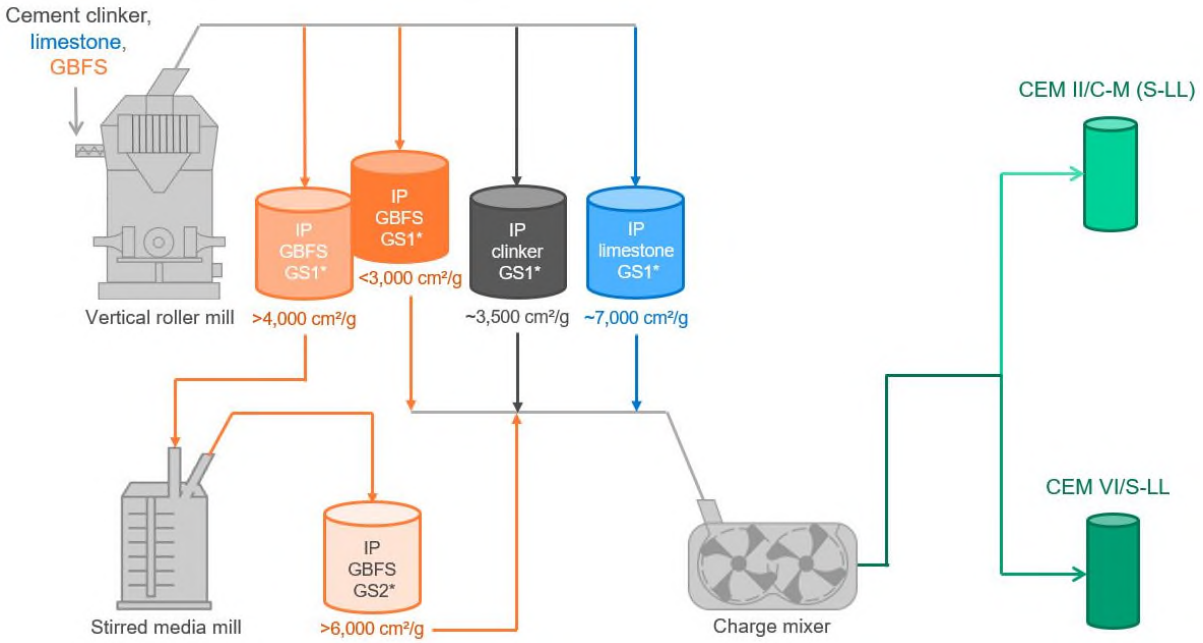

Figure 1 Schematic concept of separate ultra-fine grinding for blending of CEM II/C-M (S-LL) and CEM VI/S-LL.

A total of 28 cement mixtures for CEM II/C-M (S-LL) and CEM VI/S-LL were produced, characterized and tested for their cement properties (water demand, flexural and compressive strengths and setting behaviour). In addition, the cements optimized by separate ultra-fine grinding and mixing as well as the reference cements from the ball mill were further investigated in concrete tests. The compressive and flexural strengths of the concretes were determined and the results were compared with the respective reference concrete of the ball mill. In addition, the durability of the concretes was investigated (cube frost, freeze-thaw resistance and carbonation rate and depth).

Results

The results of the cement properties showed that CEM II/C-M and CEM VI cements can be produced by means of separate ultra-fine grinding and mixing, the strength development of which correspond to those of the reference cements from the ball mill. However, with comparable strengths, an energy saving potential of around 30% could be determined compared to the ball mill. If the energy saving potential is compensated by mixing in higher proportions of ultra-fine GBFS, the compressive strengths of both cement types could be increased on average by ~21% (2 days), ~26% (7 days) and ~19% (28 days). This means that higher compressive strengths could be achieved with the same total energy input, when the grinding strategy of separate ultra-fine grinding and mixing was used instead of using a conventional ball mill. With regard to the frost resistance of the tested concretes, it was found that the concrete test specimens with the optimized cements of the separate ultra-fine grinding consistently exhibited higher durability than the corresponding reference concretes. In contrast to the results of the cube frost tests, the results of the freeze-thaw resistance are less clear. In some cases, the reference concretes showed better or comparable durability compared to the concretes with cements from separate fine grinding (CDF method). The trends from the cement mortar tests, that higher compressive strengths could be achieved through the use of optimized, multi-modally distributed SFG-cements, were also largely reflected in the concrete compressive strengths.

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