Clinker Burning Kinetics and Mechanism

The industrial cement process is subject to several changes in order to reduce the high energy consumption and thereby increase the profitability of cement production. These changes also affect the core of the entire cement producing process: the clinker formation in the rotary kiln. Thus, in order to maintain or even improve clinker quality (and output), we need a better understanding of the development of clinker properties inside the kiln to react upon the impact of process changes. Clinker formation in industrial rotary kilns is very complex due to a vast number of interacting parameters: kiln dimensions, rotation velocity, temperature, gas composition, heat transfer phenomena, etc. These conditions can only be partly simulated in ordinary lab-scale experiments. Thus, the objectives of this project have been to establish test equipment to simulate the industrial clinker burning process on a laboratory scale and to conduct clinker formation experiments in order to derive knowledge on gradual clinker property development, as a function of different process parameters.

A new lab-scale setup rotary kiln simulator (RKS) was designed and built for this purpose. It is assembled of two parts: an ordinary lab-scale heating furnace and a sample motion system. The motion system consists of a SiC tube, which moves the sample, placed in a Pt/Rh-crucible, at a chosen velocity through the heating furnace. Simultaneously, the sample is rotated around its horizontal axis with a chosen rotation velocity. The heating furnace consists of five individual heating zones, which are set to obtain a temperature ramp from ~900-1540 °C. Furthermore, the atmosphere in the system can be set to any mixture of N2, O2 and CO2. Thus, the rotary kiln simulator features most important parameters of the industrial cement rotary kiln (ICRK): gradual temperature increase, rotation velocity and gas phase composition.

An investigation of clinker formation vs. heating profile and rotational velocity were conducted, and the influence on the clinker phase composition and clinker agglomeration was deduced. Independent of the raw meal used, the different clinker phases were formed in three stages: 1. C2S, C3A and C4AF formation at ~900-1350 °C; 2. Clinker melt formation at ~1350-1400 °C; and 3. C3S formation at >1350 °C. The first temperature of clinker melt occurrence varied slightly depending on the type of raw meal used.

The influence of different heating profiles on clinker formation was studied, and it was observed that C3S formation was more complete, the faster the sample was heated to a temperature >1400 °C. However, only with relative long residence times above this temperature clinker phase compositions similar to industrial clinker, i.e. with high C3S concentration and low CaO concentration, were obtained. It was concluded, that the maximum temperature of 1540 °C in the RKS does not simulate the maximum temperature in the ICRK. Thus, the maximum temperature of 1450 °C, as is often stated in literature, is likely often not applicable.

Agglomeration of the raw meal was observed to start already at 900 °C. The agglomerates formed are first rather weak, but increase in hardness with increasing temperature. The size of the agglomerates as well as the amount formed was found to be dependent on the rotation velocity: the higher the rotation velocity, the higher was the amount of agglomerates < 1mm. The higher rotation velocity also resulted in a decrease of the total amount of agglomerates, whereas the amount of material lining on the reactor walls increased.

The establishment of the RKS setup will allow more realistic clinker formation studies in future and thus potentially an experimental lab-scale access to the understanding of important parameters in the ICRK. The obtained qualitative and quantitative data on clinker phase composition and on agglomerate formation depended on operational parameters are essential for the development/improvement of models for bed material process in the ICRK, and for the development steps to improve the reactor technology.