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From slag to high performance concrete – Manufacturing FuturBeton[★]

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Abstract

FuturBeton, a high performance concrete, is of great ecological and economical interest and provides high strength and durability due to nano-activated ground granulated blastfurnace slag (GGBS). The application of ground granulated blastfurnace slag instead of clinker in composite cements leads to CO₂-emission saving but normally causes a decrease of reactivity and strength because of its low hydraulicity. For a high performance building material a highly effective cementitious binder with high reactivity is inevitable. FuturZement is such a binder and it contains highly reactive nanostructured GGBS activated by high kinetic processing applying the Simoloyer[®] technology.

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1. Introduction

In 2015 4.6 billion tonnes of cement have been produced worldwide which is 6.3 % more than in 2014 [1]. The cement industry causes 6.5% of all global anthropogenic CO₂ emissions, which is three times the amount emitted by global aviation [2]. CO₂ is emitted during the decalcification of limestone as well as during the clinker burning

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process [3]. Therefore substitution of Portland cement clinker is highly economic and ecologic due to saving energy and CO₂ emissions. Ground granulated blastfurnace slag (GGBS) is a well-known substitute for clinker due to its latent hydraulic behavior and its durability. Although GGBS provides cementitious properties there are still problems regarding its reactivity as far as GGBS needs additional activation. Chemical activation by alkaline solutions or the pore solution from clinker hydration within the cementitious hydration process is a common mode of activation [4]. The processes during this kind of activation have still not been elucidated completely yet but they also bear the inherent risk to cause damage processes such as alkali silica reaction. This would lead to high maintenance costs and higher replacement costs. Therefore another, ideally intrinsic, kind of activation would be highly favorable. High kinetic processing (HKP) leads to highly activated GGBS due to nanoscale activation. This highly reactive HKP-GGBS is an integral part of FuturZement, a high performance Portland-slag cement with enhanced properties. FuturZement is the binder and as such the most important component of FuturBeton, a high to ultrahigh performance concrete with increased strength and durability (Fig. 1).

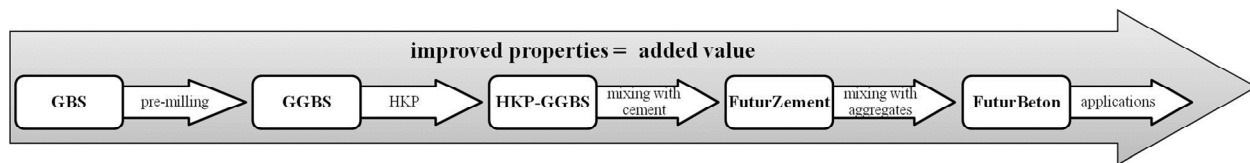


Fig. 1. Process chain: from granulated blastfurnace slag (GBS) to FuturBeton with manifold application possibilities.

All steps lead to added values along the value chain. This shows that a byproduct of the metallurgical process can be transformed into a high performance material with ecological and economical advantages.

1.1. Slag cements

The application of slag cements is economically and ecologically highly efficient. According to the best available technique slag cements can be manufactured with significantly lower costs and energy consumption compared to Portland cement clinker. The decalcification of limestone is a process with high energy consumption and high carbon dioxide emission as well as the subsequent burning of clinker which increases the global warming potential (GWP, Fig 2a). Therefore the substitution of clinker by a material with less calcium oxide content like GGBS is an essential step (see Fig. 2b).

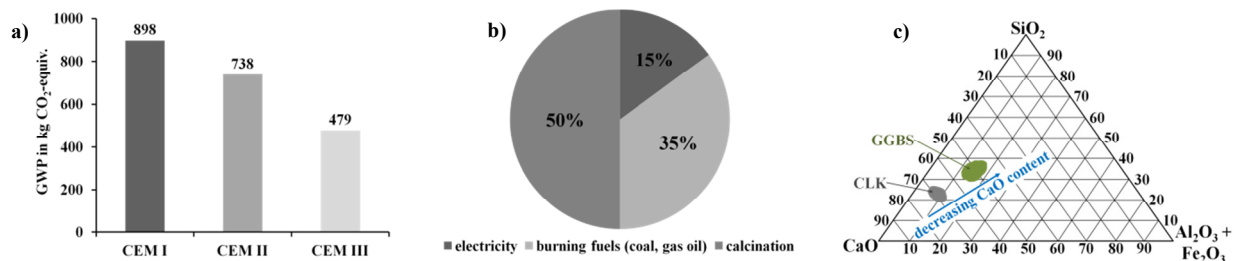


Fig. 2. a) Global warming potential of different kind of cements (CEM I: Ordinary Portland cement, CEM II: Portland-composite cement, CEM III: Blast furnace cement), based upon [5]; b) sources of CO₂ in a cement plant (based upon [6]) and c) ternary diagram of the percentage of CaO, SiO₂ and Al₂O₃ + Fe₂O₃ in binding materials, clk: Portland cement clinker (based upon [7,8]).

In slag cement clinker in cementitious binders is substituted by GGBS in various compositions. GGBS itself shows just low hydraulicity which leads to less application in cementitious binders. Special activation is necessary to increase the reactivity of GGBS. This chemical activation leads on the other hand to a change of the chemical composition of binder systems which is not favorable. Therefore another kind of activation is necessary such as tribochemical activation.

2. High kinetic processing and nanoscale activation

Activation of GGBS is an important step to enable slag cements to have certain reactivity. Chemical activation leads to inadvertent side-reactions which can cause damages and concrete corrosion. Thus nanoscale activation is preferable which can be achieved by high kinetic processing applying the Simoloyer[®] high energy horizontal rotary ball mill (Fig. 3) [9].

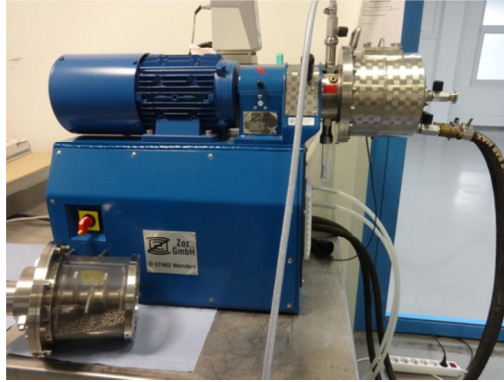


Fig. 3. Simoloyer[®] CM01-2lm high energy ball mill

HKP summarizes the well known processes of mechanical alloying (MA), high energy milling (HEM) and reactive milling (RM). The high kinetic impact is highly efficient ($> 50\%$) given by a maximum relative velocity (MRV) of grinding media up to $18 \text{ m}\cdot\text{s}^{-1}$ compared to conventional ball mills with $\text{MRV} < 6 \text{ m}\cdot\text{s}^{-1}$ [10-12]. The design of the Simoloyer[®] and the high MRV lead to collision of grinding media and powder rather than shear and friction as known from the conventional systems working on cascade and cataract effects. Additionally there is low contamination by the tools and grinding media during the processing. High kinetic processing can be performed under standard conditions as well as under vacuum and inert gas by patented air-lock systems, under elevated and cooling conditions. There are different kinds of operation modes possible such as batch, auto-batch and semi-continuous processes [9].

Application of the Simoloyer[®] HKP technology yields activation at the nanoscale. If there is just physical activation by surface area increase reactivity would rise linearly in relation to the created surface area. As an exponential increase in reactivity has been measured by differential calorimetric analysis (DCA, Fig. 3), activation beyond surface area enlargement has been proven. This can only be explained by additional nano-scale activation of HKP-GGBS.

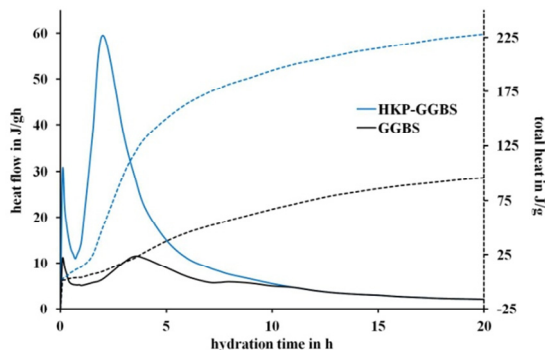


Fig. 3. Hydration process of GGBS and HKP-GGBS with 2 N NaOH-solution.

3. FuturZement

The main powder properties of FuturZement are similar to those of Portland slag cement without nano-activated GGBS beside a slightly higher surface (Tab.1).

Table 1. Cement properties of FuturZement compared to Portland slag cement.

property	FuturZement	Portland slag cement
density [g/cm ³]	3.03	3.09
Blaine surface [cm ² /g]	5,670	5,160
specific surface area (BET) [m ² /g]	2.1	1.5
average particle diameter d ₅₀ [μm]	7.3	8.9

Therefore no special changes have to be considered by application of FuturZement in casting and construction. FuturZement itself is CEM II B/S 52.5 R cement because of its composition and its compressive strength development (Fig 4).

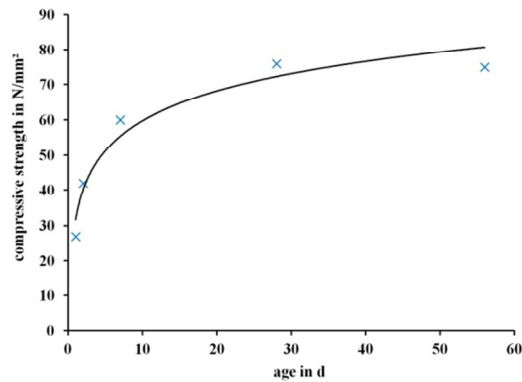


Fig. 4. Strength development of FuturZement according to DIN EN 196-2

In order to obtain cementitious binder with high performance properties, such as high early strength and suitable workability, a certain mixing aggregate with high shear energy is necessary, because of the large surfaces and adhesion forces therein. FuturZement is mixed at a ratio of 30:70 GGBS to cement applying a continuous working Lödige plough-share mixer with internal additional milling heads (Fig. 5). This provides high shear energy.



Fig. 5. Inside plough-share mixer with milling heads.

4. FuturBeton

FuturBeton is a high performance to ultra high performance concrete that is made from FuturZement. It is especially composed (Fig. 6a) and already tested in field tests such as a public bridge in Rosenthal near Olpe (Fig. 6b) and a roof façade in Siegen at the “Villa ZCS” (Fig. 6c), both containing more than 10 tonnes of concrete.



Fig. 6. a) Composition of FuturBeton, b) concrete slab of public bridge “Rosenthal” (est. November 2012) and c) roof façade at “Villa ZCS” (est. June 2013).

FuturBeton provides high compressive strength combined with high durability due to its high density and composition (Fig. 7a). This leads to breakage of the aggregates rather than the cement stone in compressive strength tests (Fig. 7b).

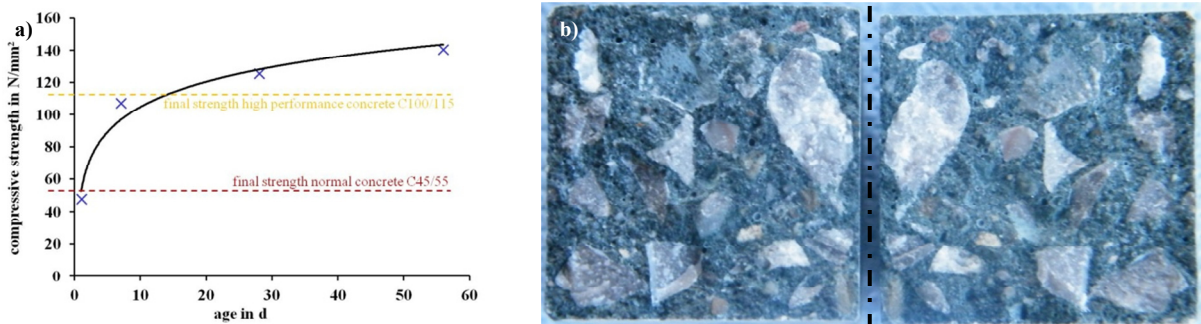


Fig. 7. a) Compressive strength development of FuturBeton and b) fracture face of standard prism FuturBeton.

Due to its provided high durability FuturBeton leads to substantial saving of material. Less maintenance or replacements are necessary and because of the dense structure there is nearly no diffusion of aggressive media possible. Therefore FuturBeton provides a high range of application possibilities such as wind and water power plants, dams, sewage as well as other civil construction projects (Fig. 8).

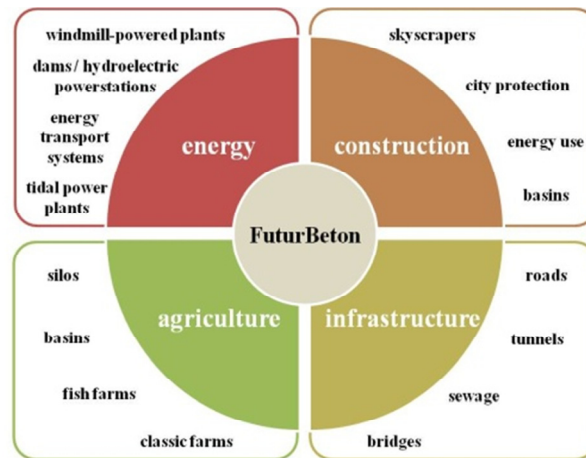


Fig. 8. Fields of application for FuturBeton (based upon [1]).

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