SAVING NATURAL RESOURCES BY MATERIAL RECYCLING

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Summary

Today modern reprocessing techniques lead to materials, which bear the potential to be used as aggregates or additives in mineral building materials. Because of highly sophisticated reprocessing techniques residues with relatively stable composition over a certain range and relatively defined properties can be produced. At the same time, new German and European regulations demand a waste management to decrease waste volume stored at landfills to save natural resources and to enhance sustainable development by recycling of diverse residues. This paper shows the activities of the working group "Saving Resources by Material Recycling".

Keywords: aggregate, cement, concrete, environment, recycling, residue, sustainability

1 Mineral waste materials and their reuse in concrete

Research about the use of residues from industry, incineration processes and deconstruction for the production of high-grade mineral building materials is a positive advance in sustainable development by saving natural resources and decreasing waste volume stored at landfills. Annually about 256 million tonnes of mineral residues are produced in Germany. They are landfilled, recycled in mining and reused in road constructions, embanking, anti-noise barriers and other low-grade applications. Only 5 % are recycled on a high level as aggregate, additive, binder component or raw material for cement and concrete [1, 2]. To reduce the exhaustion of primary resources in terms of sustainability, residues that are not recycled in a closed loop could be evaluated for use in concrete after additional processing. Furthermore, the recycling rate could be increased by reuse of currently deposited residues.

Beside such well approved residues, like fly ash, blast furnace slag, silica fume and crushed concrete or brick, other materials, like waste incineration bottom ash, steel slag, biomass ash, industrial sludge or mixed demolition waste, bear the potential to be used in high-grade mineral building materials [3, 4]. However, sophisticated processing technologies and progressive applications of the waste products are needed. The material efficiency has to be improved by further R&D activities. These comprise technological, methodological, economical and sustainable aspects. The knowledge concerning the longterm behaviour of building materials containing waste products has to be assessed in terms of durability and environmental aspects. The private and public acceptance of secondary materials must be increased. To underline the importance of this working field, the new working group "Saving Resources by Material Recycling" has to be launched in the framework of the BAM division "Building Materials" recently. Its main activities are in the field of

- secondary aggregates from waste materials,
- concrete additives or cement substitutes from residues of industrial and incineration processes,
- holistic assessment of building material cycles and the evaluation of environmental compatibility of building products.

Beside the comprehensive characterisation of the waste materials in terms of chemical composition, technical parameters and environmental safety, our focus is on the reuse of recycled materials in concretes and other cementitious materials. The following chapters show few examples of our research projects.

2 Municipal solid waste incinerator bottom ash as aggregate in concrete

In a series of projects [5-7], processed and aged municipal solid waste incinerator bottom ash (referred to as MSWI bottom ash) has been studied in terms of possible use as aggregate in concrete. Representative fractions of a MSWI bottom ash are shown in Figure 1.

Fig. 1 Municipal solid waste incinerator bottom ash
(fractions 2-8, 8-16 and 16-32 mm from left to right)

Due to the high content of mineral components as well as its chemical and physical characteristics, the MSWI bottom ash should be used as secondary aggregate. However, the bottom ash contains too large quantities of chlorides, sulphates, organics, fines, aluminium metal and waste glass, which cause damages in concrete. Thus, it was necessary to remove or minimise these harmful components. The quality of the bottom ash could be improved by the following additional treatments:

- Fines and organics are effectively removed by an improved sieving and washing process. The content of chlorides and sulphates is also reduced therewith.
- The waste glass is effectively reduced to half by an opto-mechanical separation technique.

- Metal components are further removed by modern sensor technology on the basis of magnetic induction tomography. Alternatively, a lye treatment with sodium hydroxide solution and subsequent washing reduces also the aluminium content below an innocuous level.

To evaluate the effect of MSWI bottom ash on concrete, concrete specimens (CEM I 32.5 R, 310 kg/m³, w/c_{eff} = 0.60, grading curve B32) were produced, in which the coarse aggregates from 2 to 32 mm particle size were replaced by the additional treated MSWI bottom ash. As shown in Figure 2, normal strength concretes can easily be produced with MSWI bottom ash as aggregate. Their properties are similar to concretes made with recycled crushed concrete aggregates.

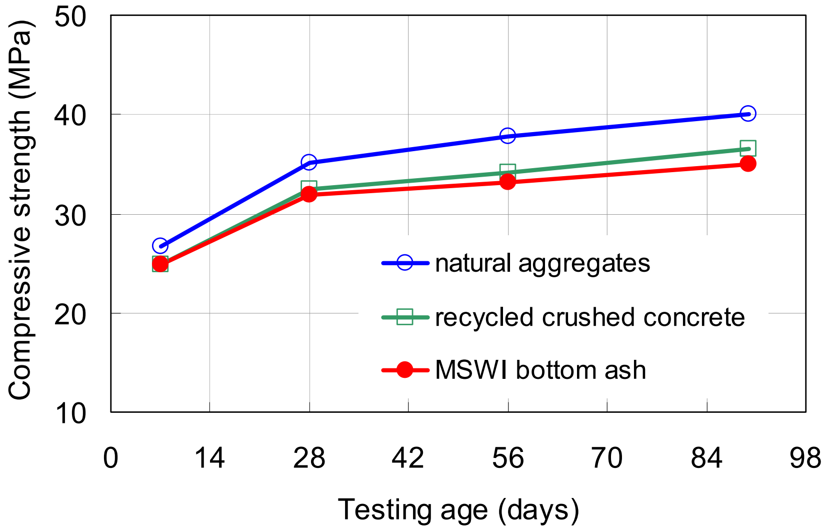

Fig. 2 Development of compressive strength of a concrete with MSWI bottom ash aggregates in comparison to concretes with natural and recycled crushed concrete aggregates

3 Paper ash as cement substitute

Beside other industrial residues, which have been studied as cement replacement [4, 8-10], paper ash shows the best characteristics for use as cement component.

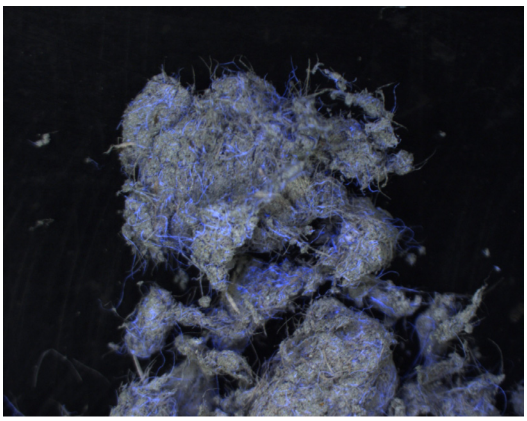

Fig. 3 Paper sludge

In order to energy production, the paper ash is the product of the combustion of paper sludge (Figure 3), which remains from waste paper recycling and deinking processes. The chemical composition of a paper ash, which is shown in Figure 4, is similar to those of an ordinary Portland cement due to its portions on CaO, SiO_2, Al_2O_3 and Fe_2O_3. However, the paper ash is slightly richer in Al_2O_3. The main mineral components are calcite, gehlenite, α-dicalcium silicat, which is a hydraulic active component, lime and quartz. Beside its favourable composition, the paper ash meets the requirements of DIN EN 197-1 [11] for cements with respect to the contents of harmful components. The values of loss on ignition, alkali, sulphate and chloride are below the limits.

To evaluate the engineering properties, composite cements were produced by homogenisation of mixtures of ordinary Portland cement CEM I 42.5 R (OPC) and paper ash (PA). The new composite cements (referred to as PA cements) contain 10 and 20 % PA by mass, respectively. Their strength development was determined using mortar prisms according to DIN EN 196-1 [12]. As shown in Figure 5, the compressive strength of the hardened mortars made with PA cements is only slightly below that of the control mortar made with unblended OPC. In contrast, the compressive strength of the cement, which is blended with 20 % inert quartz-filler, shows a 20 % lower strength as well. Hence, the paper ash contributes probably to the strength development due to its hydraulic active components.

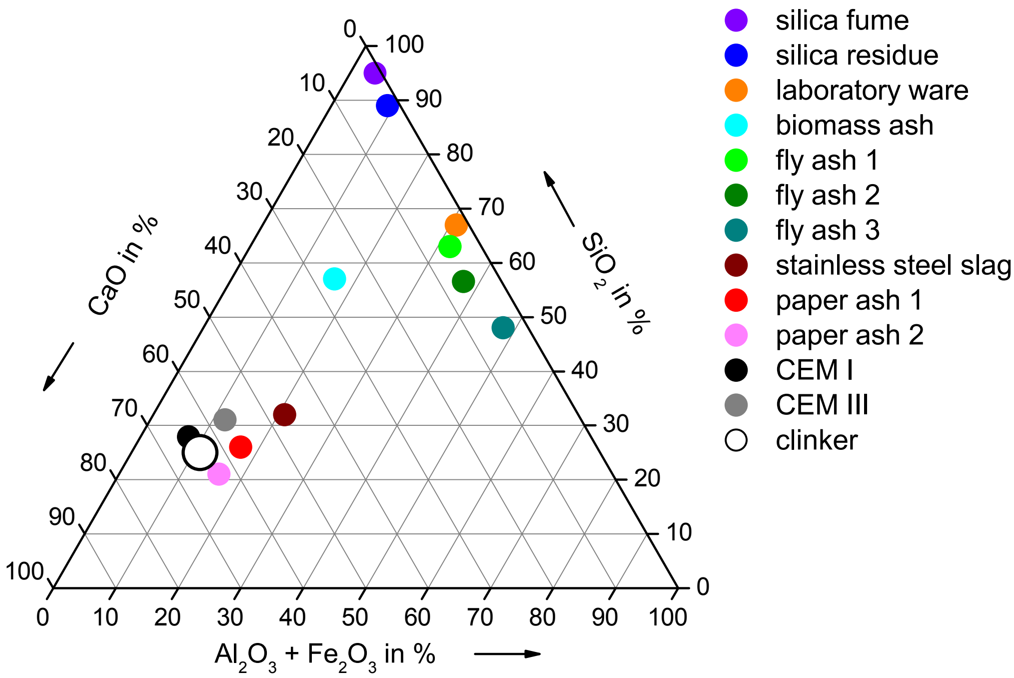

Fig. 4 Position of different industrial residues in the ternary system SiO_2–CaO–Al_2O_3+Fe_2O_3

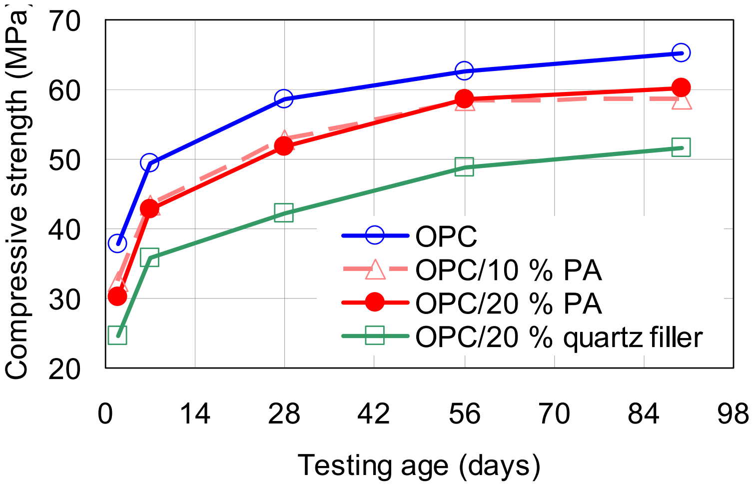

Fig. 5 Development of compressive strength of mortars made with PA cements in comparison to control mortars made with OPC and quartz filler blended OPC

4 Sustainability aspects for use of secondary raw materials in concrete

A concept to assess the applicability of secondary aggregates in concrete has been developed in the framework of the German DAfStb/BMBF research project "Sustainable Building with Concrete" [13-17].

At present an assessment method for the use of secondary raw materials, which considers sustainability aspects, does not exist. The assessment concept was developed on the basis of recycled concrete aggregates, which are already used according to German standards. Afterwards, it was applied and verified by the evaluation of MSWI bottom ashes. The assessment concept is schematically shown in Figure 6. According to this framework, the basic technical and legal demands on the use of secondary aggregates have to be evaluated first (step I). If the materials are basically qualified for the use in concrete the advantages and disadvantages for the sustainable construction can be examined (step II). In doing so, differences between the production costs of primary and secondary raw materials are studied. Furthermore, the influences of the use of secondary aggregates on the production process of concrete must be considered. Parameters, like energy consumption, material resources, emissions and other environmental aspects, are discussed for the complete process chain inclusively the pre-stages. In the next step III, alternative application paths, like road construction, embanking or landfilling e.g., have to be examined. Finally, a sensitivity analysis should be made (step IV). It considers the change of boundary conditions as well as regional differences.

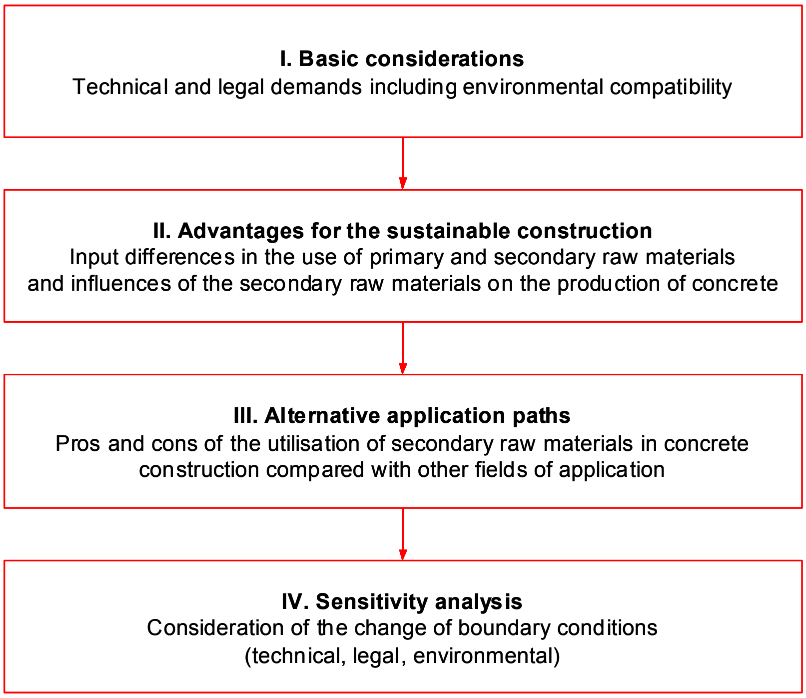

Fig. 6 Schematic concept for the assessment of the applicability of secondary aggregates in concrete

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