QUALITY PARAMETERS OF RECYCLED AGGREGATES – CONCLUSIONS UNDER THE ASPECTS OF THE CONCRETE TECHNOLOGY AND PROCESSING TECHNOLOGY

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ABSTRACT

The recycling of CDW is satisfying form the aspect of reused quantities but it is unsatisfying form the aspect of produced kinds, qualities and fields of application. So far only about 1% of the produced recycled aggregates is used for the production of concrete. A progress can be achieved if the specific properties of recycled aggregates are take more in consideration. One the one hand the standards and rules for recycled aggregates have to define the quality more exact and to connect them with the heterogeneity. On the other hand the possibilities of the processing technologies should be used more strictly for the quality improvement. Already today by the introduction of suitable techniques for liberation and sorting such recycled aggregates can be produced which have nearly the same properties like natural aggregates. For such aggregates no separate standards would be necessary.

1. INTRODUCTION

The generation of closed material cycles is one of the most important subjects within a sustainable development. This is true also for the building industry, which needs a considerable amount of mineral raw materials. In Germany the building industry consumes 670 Mio. tons of resources per year. At the same time Construction and Demolition Waste (CDW) is the largest waste stream in Germany. In 2004 72.4 Mio. tons of CDW were generated altogether, devided into the categories mineral waste (50.5 Mio. t), waste from traffic areas and roads (19.7 Mio. t), mixed rubble (1.9 Mio. t) and waste from gypsum materials (0.3 Mio t). Although about two-thirds of the CDW is processed and reused there is a large potential of optimization for the reuse in the structural engineering sector.

2 STATE OF THE ART OF THE RECYCLING OF CDW IN GERMANY

2.1 Rules about quality and application of recycled building materials

On the basis of research results and linked with the introduction of European Standards in Germany the standardization was brought forward step by step. Today it is possible to
produce a concrete for certain exposure classes in which a part of the natural aggregates is replaced by recycled aggregates with a defined composition without changing the rules of design. The recycled aggregates must fulfill certain requirements with regard to the material composition, the density and the water absorption. These parameters are used for classification in the German Standard DIN 4226-100. Additionally the material must meet the thresholds for the chloride content and the sulfate content (table 1). The application of the standardized recycled aggregates is regulated by a Guideline of the German Committee for Reinforced Concrete (DAfStb). Restrictions of the fields of application must be taken into account. Furthermore an objective evidence of the resistance against Alkali-Silica-Reaction must be produced (Table 1).

Compared to natural aggregates the recycled aggregates have to meet environmental thresholds additionally, to avoid the pollution of ground water and ground. These thresholds are valid especially for the reuse of the recycled aggregates in unbound applications. By the reuse in bound applications like concrete the pollution is prevented as far as possible. In this case the thresholds are less strict.

2.2 Technologies of processing

The processing aims in the generation of recycled aggregates with defined properties from the CDW available as raw material. This concerns the particle size distribution as well as the material composition and certain physical properties.

The achieved quality depends on the particular raw material and the used processing technology. If the raw material is rather homogeneous, recycled aggregates with a good quality can be produced with a rather low technological effort. If the raw material is quite heterogeneous and consists of different materials, the processing technology must be much more complex. Therefore, characteristics of the raw material and the needed quality of the product have to be taken in consideration for choosing the processing technology.

The main processing technologies which are used for the treatment of CDW are summarized in Table 2. Furthermore it is necessary to convey and to store the material. If certain mixtures of recycled building material shall be produced, units for dosing and mixing must be available. Further steps of the processing of CDW are the air pollution control, the dewatering of the products and the waste water treatment in case a wet sorting technique is used.
### Table 1. Parameters of recycled aggregates and of concretes with recycled aggregates acc. to DIN 4226-100 and guideline of the German Committee for Reinforced Concrete

<table>
<thead>
<tr>
<th>Classification of recycled aggregates</th>
<th>Type 1: Concrete chippings/Concrete crusher sand</th>
<th>Type 2: Construction chippings / Construction crusher sand</th>
<th>Type 3: Masonry chippings/Masonry crusher sand</th>
<th>Type 4: Mixed chippings/Mixed crusher sand</th>
</tr>
</thead>
<tbody>
<tr>
<td>Requirements on recycled aggregates</td>
<td>Type 1</td>
<td>Type 2</td>
<td>Type 3</td>
<td>Type 4</td>
</tr>
<tr>
<td>Concrete and natural aggregates acc. DIN 4226-1</td>
<td>≥ 90 M.-%</td>
<td>≥ 70 M.-%</td>
<td>≤ 20 M.-%</td>
<td>≥ 80 M.-%</td>
</tr>
<tr>
<td>Clinker, non-pored bricks</td>
<td>≤ 10 M.-%</td>
<td>≤ 30 M.-%</td>
<td>≥ 80 M.-%</td>
<td>≤ 5 M.-%</td>
</tr>
<tr>
<td>Sand-lime bricks</td>
<td>≤ 30 M.-%</td>
<td>≥ 5 M.-%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other mineral materials such as pored brick, lightweight concrete, no-fines concrete, plaster, mortar, porous slag, pumice stone</td>
<td>≤ 2 M.-%</td>
<td>≤ 3 M.-%</td>
<td>≤ 5 M.-%</td>
<td>≤ 20 M.-%</td>
</tr>
<tr>
<td>Asphalt</td>
<td>≤ 1 M.-%</td>
<td>≤ 1 M.-%</td>
<td>≤ 1 M.-%</td>
<td></td>
</tr>
<tr>
<td>Foreign substances such as glass, non ferrous metal slag, lump gypsum, plastic, metal, wood, plant residue, paper, others</td>
<td>≤ 0.2 M.-%</td>
<td>≤ 0.5 M.-%</td>
<td>≤ 0.5 M.-%</td>
<td>≤ 1 M.-%</td>
</tr>
<tr>
<td>OD density (oven dry)</td>
<td>≥ 2000 kg/m³</td>
<td>≥ 2000 kg/m³</td>
<td>≥ 1800 kg/m³</td>
<td>≥ 1500 kg/m³</td>
</tr>
<tr>
<td>Range</td>
<td>± 150 kg/m³</td>
<td></td>
<td></td>
<td>No requirements</td>
</tr>
<tr>
<td>Maximum water absorption after 10 min</td>
<td>10 M.-%</td>
<td>15 M.-%</td>
<td>20 M.-%</td>
<td>No requirements</td>
</tr>
<tr>
<td>Acid soluble chloride</td>
<td>≤ 0.04 M.-%</td>
<td>≤ 0.04 M.-%</td>
<td>≤ 0.04 M.-%</td>
<td>≤ 0.15 M.-%</td>
</tr>
<tr>
<td>Acid soluble sulphate</td>
<td>≤ 0.8 M.-%</td>
<td>≤ 0.8 M.-%</td>
<td>≤ 0.8 M.-%</td>
<td>No requirements</td>
</tr>
</tbody>
</table>

### Requirements on concrete with recycled aggregates

<table>
<thead>
<tr>
<th></th>
<th>Type 1</th>
<th>Type 2</th>
<th>Type 3</th>
<th>Type 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Use of recycled aggregates &gt; 2 mm</td>
<td>up to 45 Vol.-%</td>
<td></td>
<td>Not allowed for structural concrete</td>
<td></td>
</tr>
<tr>
<td>Use of recycled crusher sand &lt; 2 mm</td>
<td></td>
<td>Not allowed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum strength class</td>
<td>C 30/37</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Allowed exposure conditions</td>
<td>Dry environments or environments with low humidity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Design</td>
<td>Acc.DIN 1045/EN 206-1</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The processing of CDW can be carried out in mobile or stationary plants. In mobile plants a simple technological version can be realized only. At first the fed material is divided in a fine and a coarse fraction by prescreening. The coarse material is charged to a crusher and...
comminuted. After crushing the liberated reinforcement and other iron parts are removed by an overhead magnetic belt. With this technological version the so called pre-screen material and the intrinsic recycled aggregates are generated. The pre-screen material consists of constituents of CDW with a rather low strength. Furthermore it contains earth particles. Both constituents are enriched in the fine grained pre-screen material. The composition of the produced recycled building material is similar to that of the input material. With this technological version the particle size distribution can be influenced only. The composition can not be influenced directly.

Table 2. Basic processing steps of the CDW recycling technologies and the objectives

<table>
<thead>
<tr>
<th>Processing step</th>
<th>Objective with regard to the recycling of CDW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crushing</td>
<td>- Reduction of the upper particle size</td>
</tr>
<tr>
<td></td>
<td>- Generation of certain particle size distributions</td>
</tr>
<tr>
<td></td>
<td>- Decomposition of composites, i.e. uncovering of composites’ single components</td>
</tr>
<tr>
<td>Screening</td>
<td>- Limitation of the upper particle size</td>
</tr>
<tr>
<td></td>
<td>- Generation of certain particle size distributions for subsequent recycling</td>
</tr>
<tr>
<td></td>
<td>- Separation of coarse pieces for the protection of downstream crushers and other equipment</td>
</tr>
<tr>
<td></td>
<td>- Separation of fine fractions for release of comminution equipment (reduction of wear, to avoid pluggings)</td>
</tr>
<tr>
<td></td>
<td>- Prearrangement of a sorting, if a narrow particle size distribution is needed</td>
</tr>
<tr>
<td></td>
<td>- If applicable sorting itselfes, if defined fractions are enriched with certain materials.</td>
</tr>
<tr>
<td>Sorting</td>
<td>- Separation of impairing and hazardous substances</td>
</tr>
<tr>
<td></td>
<td>- Separation of mixed recycled aggregates in material groups</td>
</tr>
</tbody>
</table>

In stationary plants more sophisticated technologies can be realized. The following, additional steps of processing can be passed through:

- Two stage crushing: Jaw crushes as pre-crusher and impact crusher as downstream crusher
- Elimination of impairing substances by hand sorting from a picking belt
- Production of particle size groups by vibration screening

In stationary plants the sorting of the crushed CDW can be integrated in the process flow. Light impairing substances can be eliminated by air shifting. A sorting of a mixture of different building materials depending on their densities is possible by wet sorting equipments like jigs or aquamators. So it is possible to influence the material composition of recycled aggregates.
2.3 Range of products and fields of application

The range of recycled building materials which can be produced in a stationary plant is considerably broader than that from mobile plant. The following recycled materials result from crushing and screening processes:

- Pre-screen material 0/x, for instance 0/16 mm
- Recycled aggregates
  - Grain mixture 0/x for instance 0/32, 0/45, 0/56 mm
  - Fine aggregates 0/x for instance 0/2, 0/4, 0/8 mm
  - Coarse aggregates > x for instance > 32, > 45, > 56 mm
  - Delivery grades \(x_{\text{min}}/x_{\text{max}}\) for instance 8/16, 16/32 mm
- Recycled mixtures of different material components.

The grain mixtures are applicable in road construction. Specific fields like concrete production can be served by delivery grades 8/16 or 16/32 mm. Fine aggregates can be used as bedding material for pavement or for backfilling of cable channels. Coarse aggregates are suitable for subgrade improvements.

Producing recycled aggregates which shall be used in concrete production, demands a technical equipment which is available in stationary plants only. In Germany the amount of CDW which is processed in stationary plants decreases since several years. Currently about half of the amount of CDW is treated in mobile plants.

The stagnation of recycling technologies is reflected by the fields of application (Figure 1). The use of recycled aggregates for concrete production occurs very seldom, although the rules are existent for some years and no specific approval is necessary. Examples are very rare for the practice of concrete production with such aggregates. This is also reflected by the statistical data on the fields of application of processed CWD from 1996 till 2004.

![Figure 1. Quantities of reused building materials and fields of application](image)

According to the statistical data the amount of recycled aggregates for concrete production lies between a minimum value of 0 Mio tons in the year 1998 and a maximum value of 2.4 Mio tons in the year 2004. No systematic trends can be recognized that point to the extension of this field of application. The mean portion of recycled aggregates between the years 1996 and 2004 amounts to 1% only.
3 QUALITY PARAMETERS OF RECYCLED AGGREGATES

Recycled aggregates have a certain heterogeneity, even if they origin from a selective demolition and are processed carefully. This heterogeneity can be divided in the constitution heterogeneity and the distribution heterogeneity.

The constitution heterogeneity results from the differences of the composition, the size, the shape etc. of the particles which form the considered recycled aggregate. Example is the heterogeneity of processed concrete. Even if no foreign constituents are contained and the sampling is done correctly, the composition differs from particle to particle, since the particles have different contents of cement paste. The resulting scattering of the properties is shown in Error! Fonte de referência não encontrada., using the example of the distribution of the envelope density. The density ranges from 1.9 g/cm³ to 2.7 g/cm³. The lower limit fits well with the envelope density of cement paste. The upper limit is the density of natural aggregates. The constitution heterogeneity can not be changed by mixing. The only possibly is a comminution.

The distribution heterogeneity depends on the distribution of the particles in the bulk material additionally. It can be influenced by mixing and homogenization. As example the heterogeneity of recycled aggregates from masonry rubble can be named. In this case particles with complete different physical properties coexist like particles of autoclaved aerated concrete and particles of red brick. The distribution of the envelope densities of a sample from this material is broader as shown in Figure 2. The densities range from 1.6 g/cm³ to 2.8 g/cm³.
The heterogeneity of recycled aggregates was scarcely considered so far although it has essential consequences. In the case of the constitution heterogeneity effects on the quality of the produced concretes results. A recycled aggregate acc. type 1 of the German standard which consists of concrete particles and particles of natural aggregates of together 95 % is not defined in its properties by this threshold. In fact the recycled aggregate can consist either almost completely of particles of natural aggregates or almost completely of concrete particles, whose content of cement paste can vary additionally. Differences in the porosity and the mineralogical composition are the result.

A recycled aggregate which consists of concrete particles only can be considered as binary system. The ends of the series are the natural aggregates on the one hand and the recycled aggregates on the other hand. With regard to the physical properties a binary diagram can be developed based on the properties of its endmembers. In the figure 3 the calculated changes of absolute density, envelope density and total porosity are confronted with values measured at three concretes with graded contents of cement paste. The content of cement paste of processed concrete rubble ranges between < 10 and 35 mass-%. Already from these differences a considerable span of the physical properties follows.

The endmembers of the series differ additionally with regard to their chemical and mineralogical composition and their reactivity. Natural aggregates mainly consist of quartz, feldspars or of calcite. They are inert. The cement paste contains C-S-H-phases, portlandite, calciumsulfoaluminate, propably unhydrated constituents of cement and further phases. These constituents can react with water, carbondioxid, sulphate etc.
If concrete with recycled aggregates is produced according to the German Guideline, it must be expected that, because of the variability of the composition of these aggregates, the amount of old cement paste introduced in the secondary concrete differs considerably. For instance, assuming that 45 vol.% recycled aggregates and 55 vol. % natural aggregates are used for concrete production, the following cases depending on the content of cement paste of the recycled aggregates can appear:

- Case 1: The content of cement paste of the recycled aggregates which are processed with a special equipment is 5 % by mass. The introduced amount of old cement paste is only 36 kg/m³ concrete.
- Case 2: The content of cement paste of the recycled aggregates is 25 % by mass. The introduced amount of old cement paste is 178 kg/m³ concrete.

An input of cement paste of 36 kg/m³ results in only little changes of the compressive strength and of the dynamic modulus of elasticity as the results of Weimann 0 show. In contrast a considerable decrease of the strength as well as the dynamic E-modulus occurs if the input of old cement paste is 178 kg/m³.

The distribution heterogeneity plays an important role if the material composition and the content of leachable substances shall be measured. The sample mass which is needed for analyzing depends on the properties of the bulk material like maximum particle size and heterogeneity as well as on the height of the detected content and on the requirements in respect of the reliability of the result. The sample mass is large enough if every particle of the material has the same probability to be selected for the sample. On the basis of this postulate different models concerning the calculation of the needed sample mass were developed. The most well known model was developed for mineral bulk materials and bulk materials from mining by Gy 000. It is the basis for theoretical developments as well as for the development of practical recommendations for the sampling 000. Another model origins from Sommer who answers the question of the sample mass also on the basis of a particle approach 00.

On basis of the models for sampling the dependence between the mass of the sample and content of component which shall be determined can be calculated. As shown in figure 4 the sample mass decreases as higher the content of the component in the sample is. In case of components with a content of 10 mass % a sample mass of 3 kg is necessary. In the case that a component shall determined for which a content of 1 mass % is expected the needed sample mass amounts to 32 kg.
In recycled aggregates of type 1 the acceptable content of foreign components is 0.2 % by mass (see table 1). To detect this low content reliably a sample mass of 159 kg is necessary if the relative deviation shall not be higher than 20 % and the maximum particle size of the material is 45 mm. This mass is clearly more than the sample mass used for particle size analyses. According to DIN EN 932-1 this mass must be calculated from the maximum particle size and the bulk density and amounts to 60 kg in this case.

The sampling from heterogeneous bulk materials plays an important role in different fields of the recycling branch. The content of certain components is often limited strictly to avoid impairments of the properties of the secondary products. By the quality control only then reliable results can be achieved if the sample mass is large enough. This dependence becomes clear form the three examples of the literature 000 concerning the needed sample masses in the field of recycling of glass cullets and in the field of production of secondary fuels in Erro! Fonte de referência não encontrada.. The sample masses calculated for the recycled aggregates form together with the examples from the literature a coherent dependence between the sample mass and the content of the considered foreign component.

4 QUALITY IMPROVEMENT BY NEW TECHNOLOGIES

4.1Preface

The comminution process and the sorting process are the key processes within the technological measures that are able to improve the quality of recycled aggregates which shall be used in the concrete production. The objective of comminution is to generate cement paste free aggregates. The objective with regard to the sorting process is the separation of different mineral materials and the separation of foreign components which must be in the aggregates only in very low portions (see table 1). Furthermore, a separation of the concrete particles in such with high and such with low content of cement paste could be an essential contribution to quality improvement.

4.2 New technologies for comminution

Within the comminution processes two groups can be distinguished:
− Processes that generate compressive and tensile stresses at the boundary between cement paste and aggregate
− Processes that base on abrasion stress at the surface of the crushed concrete.

The electrodynamic and the electrohydraulic comminution are techniques which generate stresses that act directly at the boundary. In both techniques the stress is generated by a disruptive electrical discharge under water. An electrical power flows between two electrodes in a discharge tank filled with water and the concrete fragments (figure 5). That causes an explosive expansion of the discharge channel. In the case of the electrodynamic technique the electrical control parameters are adjusted so that the spark of the discharge goes off directly through the concrete. In the case of the electrohydraulic technique the breakdown occurs through the water. The generated high performance pressure waves act on the concrete. As
shown by Linß 0, the electrohydraulic technique has the ability to produce a large percentage of cement paste free particles.

Processes that base on an abrasion stress are described from Noguchi 0. Other sources report about the application in a technical scale 00. After a pre-crushing the concrete particles are stressed by abrasion. So the cement paste which adheres at the surface is eliminated. In 0 the several devices are presented and described briefly.

Figure 1: Principles of electricodynamic and the electrohydraulic comminution techniques and breakdown voltage for different materials in dependence on the rise time of the impulse 0
Mechanical abrasion treatment in dry state (1)

Concrete

Crushed concrete is processed in a cone crusher-like device. Abrasion stress is applied in the gap between external cylinder and eccentric rotor. Cement paste adhering on surfaces is removed.

Mechanical abrasion treatment in wet state (2)

Crushed concrete is forwarded by a screw conveyer into a cylinder and passes two rotating coned abrasion tools. Cement paste is removed via friction.

Mechanical abrasion treatment in wet state and separation by jig

Crushed concrete is stressed by steel rods in a drum. The following separation of cement paste as well as remaining light-weight particles is done by using a jig.

Abrasion treatment after thermal conditioning

Crushed concrete is passed through by prewarmed air at 300°C in a vertical kiln. Cement paste embrittles, its strength decreases. Subsequent cement paste is removed in tube mills by abrasion.

Figure 2: Overview: Devices for quality improvement of recycled concrete aggregates
The techniques that base on abrasion make it possible to produce high quality aggregates. The physical properties of these aggregates differ only a little from that of natural aggregates. The envelope density of the aggregates after abrasion treatment is between 2.40 and 2.53 g/cm³. It is only 2.7 to 4 % lower as the envelope density of original natural aggregates that ranges between 2.50 and 2.60 g/cm³. The quality of the concretes which were produced with the treated aggregates is nearly the same compared with the quality of reference concretes with natural aggregates.

4.3 Sorting techniques

The conventional sorting techniques which are introduced in the recycling sector since years mainly base on the differences of the densities of the constituents of recycled aggregates. In future more sophisticated techniques based on the identification of the particles by sensors can be expected. By these advanced methods new possibilities for the separation of different materials are opened. The separation in chemical defined material groups seems to be possible.

The density separation can be carried out in air as well as in water as fluid. The sorting criteria is the settling rate. It allows conclusions about the differences in density which are required for the separation. With regard to the separation in air from calculations follow that a concrete particle with a diameter of 8 mm has the same settling velocity like a gypsum particle with a diameter of 16 mm. Both particles are “equifalling”. That means no separation between these both materials is possible in an air stream. Only very light impairing substances like insulation materials, plastics, foils and paper can be separated.

The technical principle and the industrial realisation of a wind shifter for the separation of light particles are shown in figure 7. The material is transported on a broad, horizontal or gently inclined resp. declined conveyer belt to achieve a singling of the particles. At the dropping zone an airstream passes through the material and takes away the light parts. They are transported to an expansion chamber where the air velocity is reduced so that the light particles can settle. The heavy parts drop down on a belt and are transported to a stockpile.

A separation of the different mineral components of recycled aggregates is possible with wet sorting techniques in some degree. Thereby must be noted that the mineral recycling materials show a certain open porosity. The effective density during the separation is not equal to the envelope density in OD state. In fact the density in SSD state will act. For example, particles having an OD density of 1.8 g/cm³ show a SSD density of 2.12 g/cm³ if water can get in all pores. The effectiveness of the sorting process decreases because the acting differences of the densities become smaller. If a mixture of red brick, gypsum and aerated concrete with a particle size of 8/16 mm is considered in a water stream with a velocity of 0.6 m/s then only the aerated concrete can be separated.

The wet separation by density can be carried out with jigs. The principle and the technical realization as pilot plant are shown in figure 8. During the jigging process the material is flown through by a pulsating stream of water. So a stage can be achieved similar to a fluidized bed. The pulsation causes that the particle do not achieve the stationary settling velocity. The upward motion of the light particles with the water current will be enforced compared with stationary conditions as well as the downward motion of the heavy particles. A stratification in dependence on the density occurs. The light particles are discharged over a weir, the heavy
particles are discharged from the lower part of the jigging bed by a rotary feeder. The jigging process is influenced by the properties of the input material like density, particle size and particle shape and by parameters of the process like height of the jigging bed, viscosity of the fluid, frequency of the stroke, height of the stroke etc. The process parameters are applied to control the process.

Figure 7: Principle of an air shifter and an example from a stationary recycling plant (Photos from 0)
Since the middle of the 80s of the last century the development of sensor based sorting techniques can be recognized. They use the same principle like the picking - a method which is used since the middle age for the sorting of ores. The starting point of the sensor based sorting techniques in the field of waste treatment is the sorting of glass cullets. Since that time the application is extended continuously. Currently in the recycling branch devices are used where the material transport is realized with a conveyer belt. They are equipped with different types of sensors to make the process faster, more exact and more economic.

Although the used technical devices are rather different, all sensor based sorting machines consist of a belt, a sensor with a light source and a detector, a computer for the fast processing of the measured signals and air pressure valves for the blow out of identified reject material. The used sensors base on

- the measurement of the radiation intensity in certain wave length ranges,
- the identification of certain shapes and features of the surfaces
- the identification of electromagnetic properties.

The sensor based sorting techniques are used in practice already in the field of sorting of plastics which are used as secondary fuels, in the sorting of waste paper and in the sorting of...
ores or mineral raw materials. In the field of CDW recycling no industrial application is documented so far.

5. RESULTS ON SEPARATION OF GYPSUM FROM CDW BY JIGGING AND SENSOR BASED SORTING

Gypsum is a building material which is used increasingly because of its good workability and its favorable structural-physical properties. In considerations about the material streams in Germany it was detected that the amount of gypsum used in buildings is increased from 1 % in the year 1985 to 3 % in 2000. In the future a further increase of the content of gypsum in the CDW must be expected. By that the reuse of CDW becomes more difficult or even comes to a rest if the gypsum can not be separated by effective methods.

The own experiments were focused on the separation of gypsum particles from concrete CDW which origin from apartment buildings made of precast concrete panels. In these buildings gypsum was used in bathroom elements, as anhydrite floor and as paperboard. Before the reuse of the processed material the gypsum particles must be separated to avoid expansions due to the formation of ettringite which can occur even if the material is used only as filling material.

From the characterisation of the material follows that the mean content of gypsum is 2.3 % by mass. The differences of the density between the concrete (2.4 g/cm³) and the different types of gypsum (bathroom elements 1.55 g/cm³, anhydrite floor 1.9 g/cm³) are rather narrow.

The separation of the gypsum was carried out by jigging at the one hand. By the used jig Triple A of the company AGS (figure 8) asymmetric settling–upstroke-profiles can be realized to improve the separation especially in the case of small differences in density.

At the other hand the separation was carried out with the sensor based device TITECH COMBISENSE® (figure 9). This machine was equipped with a color line camera that allows the identification of color, brightness, shape etc. After the identification the particles of gypsum are blown out by compressed air. They form the rejected material stream in which the gypsum is enriched. The accepted material stream in which the gypsum is reduced is the product.

![Figure 9: Scheme of sensor based grader used for own experiments](image)
In the experiments with the jig mixtures of gypsum and concrete with graded gypsum contents were prepared, which pass through the machine one time or several times. At first the both components were crushed and screened separately. Then the needed masses were weighed in, put on a stock pile and homogenized by the Chevron method. In the experiments with the sensor based sorting machine different types of gypsum-containing building materials were added to a mixture of concrete, mortar and brick. In both experiments material with a particle size between 4 and 32 mm was used.

For the evaluation of the achieved separation the following parameters were measured:

- Content of gypsum in the product, that means in the heavy material in the case of the jigging and in the accepted material in the case of sensor sorting. The content of gypsum was detected by hand sorting.
- Content of gypsum in the light respectively in the reject material, detected also by hand sorting.
- Masses of the wet and dried output materials.

The measured contents of gypsum give information about the quality of the products. From the masses the yield of the product can be calculated. The yield gives informations about the effectiveness of the process.

\[
\nu_p = \frac{M_p}{M_A} \cdot 100 = \frac{M_p}{M_p + M_L} \cdot 100[\%] \\
\text{MP: mass of product} \equiv \text{mass of heavy material} \\
\text{ML: mass of light material}
\]

The content of gypsum in the products and the achieved yield of product in dependence on the content of gypsum in the input material are shown in Error! Fonte de referência não encontrada.. The following conclusions can be drawn:

- With both techniques a reduction of the gypsum content in the product compared with the input material can be achieved. If the content of gypsum in the input is higher than 2 mass %, the reduction is higher after the sensor based sorting process compared with the jigging process. If the content is lower than 2 mass % the jigging process results in lower gypsum contents. The reason could be that a certain portion of gypsum is solved in the process water.
- The required gypsum content acc. to the standard < 0.5 mass % (RC-type 2) can be achieved in a single stage process if the input material contains about 2 % gypsum. A content < 0.2 mass % (RC-type 1) can not be realized in a single step process.
- The yield is considerably higher in the case of sensor sorting compared with the sorting by jig.
Figure 10: Dependence of gypsum amount in the product (above) and dependence of mass output (below) on gypsum content of input material.
On the base of the dependencies in figure 10 the following assessment can be done for an input material with a gypsum content of 2.3 mass % (see above):

After the separation with the sensor based process 96.6 % of the input material forms the product which has a content of gypsum of 0.8 mass %. The rejected material amounts to 3.4 %. Its gypsum content is 44.9 mass %. After the separation by jigging the yield of the product amounts to 81.6 %. The content of gypsum in the product is 0.8 mass % too. The light material amounts to 18.4 %. Its gypsum content is 9 mass %. According to this assessment the sensor based sorting seems to be more effective compared to sorting by jigging. Possibilities for further use of the rejected material with a relatively high gypsum content are thinkable. However these results must be consolidated by further experiments. Besides the comparison of the both techniques, one has to take into account further effects, like the systematic increase of the envelope density of the product of the jigging process compared to the input material.

REFERENCES

