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Sensor-based sorting of mineral construction and demolition wastes by near-infrared

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Abstract Near-infrared based sorting is one possibility to turn recycled mixture of mineral construction and demolition wastes (CDW) into usable materials and has been investigated in a German research and innovation project. The target was to find suitable optical attributes for the identification of aggregates from construction and demolition wastes. The interdependencies between features from the spectrum analysis and the mineralogical composition of unused building materials were analyzed. Within the presented research project was constructed in cooperation with two German companies a sorting system, which allows sorting of mineral construction and demolition waste in industrial scale.

1 Introduction

Construction and Demolition Waste (CDW) is the biggest waste flow in Germany with an amount of 53.1 million tons CDW in the year 2010. Regarding the application of C&DW aggregates, it can be concluded that, independently of the recycling rate, most of them are used in road pavements and earth works, not really substituting the natural aggregate applications. Only a very small amount of recycled aggregates (only 1 wt.-

% in the year 2008) flows back in the production of recycled concrete. CDW from building constructions are heterogeneous mixtures, containing clay brick, mineral bounded building materials (concrete, sand-lime brick, autoclaved aerated concrete, lightweight concrete), mortars, plasters, insulation materials, wood, plastics, etc. In future, as a consequence of modern masonry construction, an increased volume of complex material composites and wider material diversity in mineral construction and demolition waste can be expected. To enable the reuse of recycled aggregates in the production, such material composites must be separated into unmixed material fractions. Main focus is the separation of gypsum attachments and composite particles, which are unavoidable through mechanical crushing. Not only old concrete can be recycled, also other recycled materials like clay or sand-lime bricks can be reused as feedstock in the production, thus closing the cycle. In this case, the heterogeneous C&DW must be turned into homogeneous, recycled material fractions. Otherwise, a cost-intensive landfilling cannot be avoided. The heterogeneity of C&DW aggregates prevents the profitable reuse. Therefore it is necessary to develope appropriate sorting processes. Sensor-based single particle sorting devices are the most promising techniques to sort efficiently usable material fractions and to remove impurities from the recyclable fractions.

2 Sorting of mineral construction and demolition wastes by hyperspectral near-infrared imaging

Figure 15.1 shows the principle of the detection of the reflective of the electromagnetic radiation in near infrared range, which has been applied in the research project. The reflected spectrum is measured by a hyperspectral camera KUSTA2.2MSI from LLA Instruments GmbH allowing the recognition of mineral particles. The spectrograph scans the particles that move on a conveyor. It is possible to scan particles with a minimal particle size of up to 4 mm. The software allows a chemometric evaluation of the spectral information. For this, a statistical method called PLS (Partial Least Squares Regression) is used. The signals from the software control the air pulses, which remove “bad” material from the ”good” fraction.

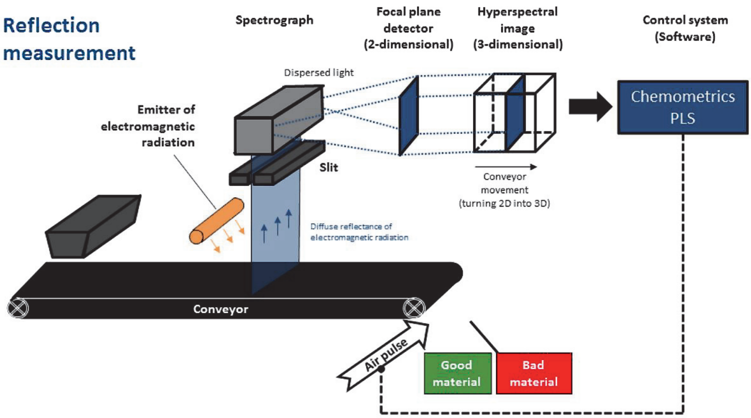

Figure 15.1: Principle of the identification by near-infrared technology [1]

3 Experimental and Results

3.1 Samples for the identification of different components of construction and demolition wastes

In a first step near infrared spectra of different unused building materials were taken and analyzed by chemometric methods for data analysis and classification. The interdependencies between features from the spectrum analysis and the mineralogical composition will be analyzed for the following material classes - conrete, lightweight concrete, autoclaved aerated concrete, clay brick, sand-lime brick, natural aggregates, gypsum, plastics and wood. From each building material class, about ten varieties (sub classes) were investigated regarding their mineralogical composition and their typical near-infrared spectrum. The target was to find suitable optical features for the identification of C&DW aggregates. In Figure 15.2 an overview is given about the evaluated samples and their bulk density. All Particles had a particle size of 8/16 mm. In a second step spectra of real recycled materials were added to the database.

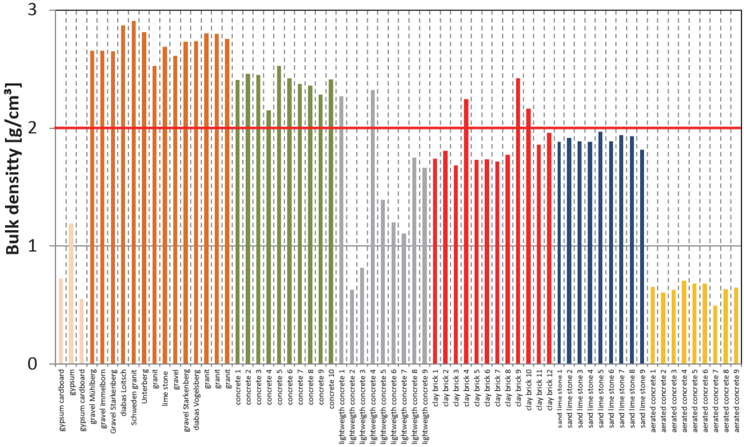

Figure 15.2: Overview of the bulk density of all analyzed unused building materials (grain size 8/16 mm)

3.2 Measurements and Results

A lot of pure minerals have characteristic absorption bands in the near-infrared wavelength range between 1100 – 2500 nm. According to the near-infrared active absorptions, the minerals can be divided into the following groups - Hydrous minerals, Minerals with characteristic hydroxide and Carbonate minerals. The hydroxide groups show absorption bands in the wavelength range from 1350 to 1430 nm which are mineral-specific and therefore ideal for evaluation purposes. The different binding states in the crystal lattice causes small differences in the absorption wavelengths of different hydroxile groups. The wavelength can vary in the range of only a few nanometers, but is sufficient for the identification. The unprocessed spectra are characterized by broad absorption bands in particular in the wavelength range between 1350 - 1450 nm and 1800 - 2100 nm, which are composed of the superposition of the absorption of different minerals and water. In preliminary experiments, building materials forming minerals were measured in pure form with the laboratory spectrometer uniSPEC2.2S and archived. The minerals occurring in construction materials are in particular assigned to the mineral classes: carbonates, silicates (including

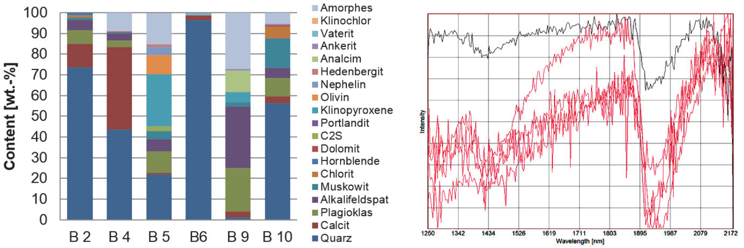

Figure 15.3: Mineralogical composition (left) and spectra (right) of some concrete samples

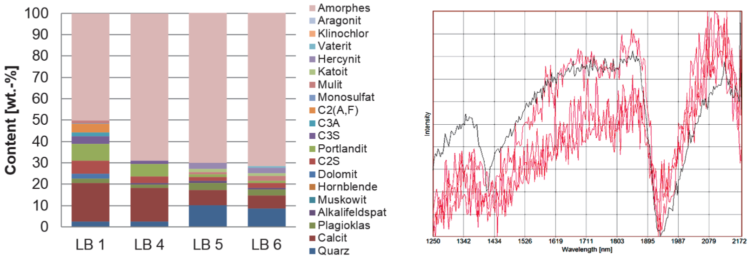

Figure 15.4: Mineralogical composition (left) and spectra (right) of some lightweight concrete samples

layered silicates), sulfates (especially gypsum products) and oxides (e.g. hematite) [2]. Furthermore, at the Bauhaus-University Weimar, the mineralogical composition of selected samples was determined. The X-ray diffractometry was carried out on powdered samples. For this purpose, the material was ground to < 63 µm respectively in the disc mill. The preparation for X-ray diffraction was carried out by front-side preparation ("frontloading"). The measurements were performed with a Siemens D5000 diffractometer. The qualitative phase analysis was performed using Diffrac Plus EVA, Bruker AXS, against the PDF-2 database (NIST) and the ICSD database (FIZ Karlsruhe). In Figures 15.3 to 15.8, the mineralogical compositions and single scan NIR spectra for concrete, lightweight concrete, aerated concrete, clay bricks, sand lime bricks and gypsum are shown separately. The single scan NIR spectra were recorded with a NIR hyperspectra imaging camera

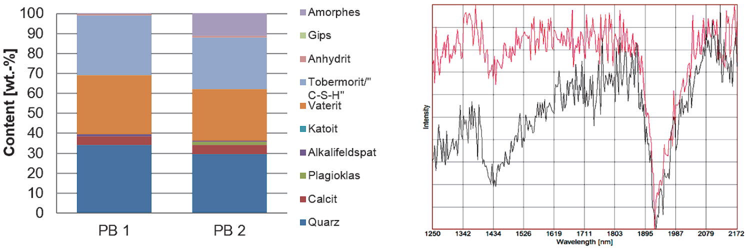

Figure 15.5: Mineralogical composition (left) and spectra (right) of some aerated concrete samples

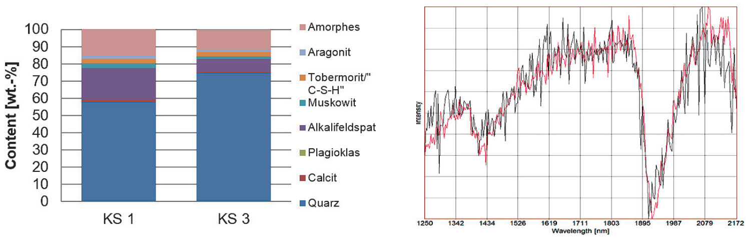

Figure 15.6: Mineralogical composition (left) and spectra (right) of some sand lime brick samples

KUSTA2.2MSI at a belt speed of 2 m/s and a repetition rate of 270 Hz. The mineralogical composition of the concrete is very different, depending on the aggregate (Figure 15.3 left). A differentiation in different types of concrete by NIR is therefore not possible. However, the mineral calcite is detectable and suitable for detection by means of infrared (Figure 15.3 right). Figure 15.4 shows the mineralogical composition and the spectra of the investigated lightweight concrete. Again, the mineral phase composition varies depending on the aggregate used. Also, the X-ray amorphous content is very high. The lightweight aggregates used in lightweight concrete such as expanded glass or expanded clay show in the infrared spectrum no significant bands. A differentiation between normal and lightweight concrete is not possible. Autoclaved aerated concrete can be identified very well on the basis of the tobermorite phase, which was formed during the steam curing in an

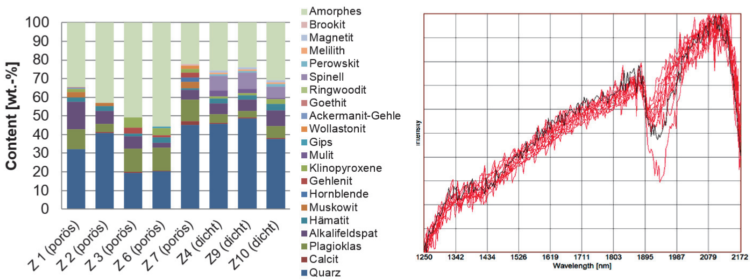

Figure 15.7: Mineralogical composition (left) and spectra (right) of some clay brick samples (porous and dense)

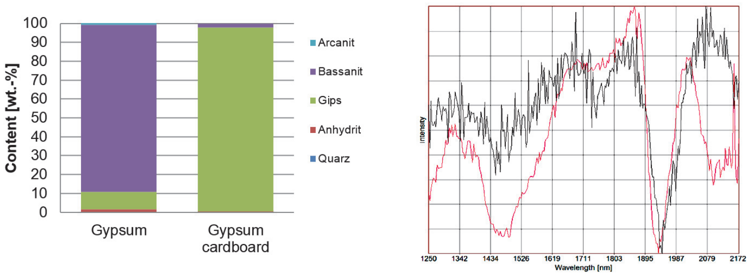

Figure 15.8: Mineralogical composition (left) and spectra (right) of some gypsum samples

autoclave (Figure 15.5). The tobermorite content in aerated concrete is between 30 and 40 wt.-%. The characteristic peak in the spectrum of tobermorit is located at 1426 nm and 1920 nm, as shown in Figure 15.5 right. The investigated sand-lime bricks consist mainly of quartz, which is undetectable in the near infrared spectrum. The calcite content is low. As steam cured material sand lime brick also contains tobermorite, but in smaller quantities (Figure 15.6). The investigated bricks are very inhomogeneous, as shown in Figure 15.7. Depending on the clay used for their preparation, the composition varies in a wide range. The bricks show a typical spectrum, so that it can be identified. But it is not possible to distinguish bricks with lower and higher density by differences in the spectrum. To distinguish the different quality of bricks the evaluation

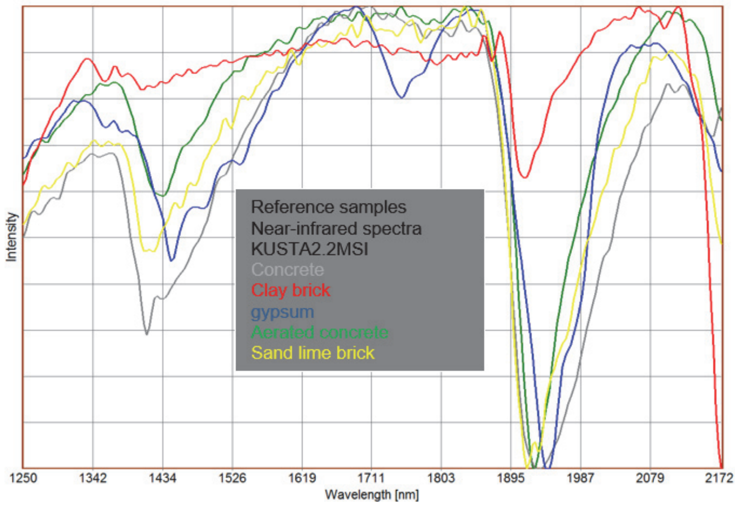

Figure 15.9: Comparison of the spectra of the investigated materials, shown as 2nd derivation of the Intensity

of different features and feature vectors in the visible spectrum is very well suited as found in previous studies of LINSZ and ANDING [3]. In Figure 15.8 the mineralogical compositions of the investigated gypsum are shown. The bands for gypsum and bassanite also referred to as hemihydrate – are very noticeable in the near-infrared spectrum and can be used for identification.
Figure 15.9 compares the object average spectra for representative materials of each type investigated.

3.3 Development of a Prototype

In cooperation with the companies S+S Separation and Sorting Technology GmbH and LLA Instruments GmbH, a sorting system has been developed, which allows the sorting of mineral construction and demolition wastes under real conditions (Figure 15.10). The hyper spectral camera offers a much higher spatial resolution at a very high refresh rate (possible measurement frequency of up to 270 Hz) due to the used

Figure 15.10: Near-infrared sensor based sorting machine for CDW

2D sensor array. Therefore, even small particles can be detected and sorted. By means of the demonstrator, the performance limits are being tested.

3.4 Algorithm for the separation of different material combinations

The procedure for the creation of the sorting file is as following: Before NIR sorting of different building materials is possible, the chemometrical identification have to be developed. For this purpose, a sufficient number of spectra for each material class must be recorded. Spectra containing artifacts or exhibiting a low signal to noise ratio must be removed from the learnset. The learnset includes both spectra of unused building materials and spectra of recycling materials. In the learnset, the identified material groups must be included as different types. The learnset is then utilized for a PLS (Partial Least Squares Regression)analysis. The PLS is a statistical chemometric method for data evaluation based on principal component analysis. The results of the principal component analysis - the score vectors are used for the classification of unknown material. The calculated score vectors can be visualized by a so called scores plot in 2-D or 3-D. The 3-D Scores plot for the separation of gypsum from concrete and also of gypsum from sand lime brick are shown in Figure 15.11.

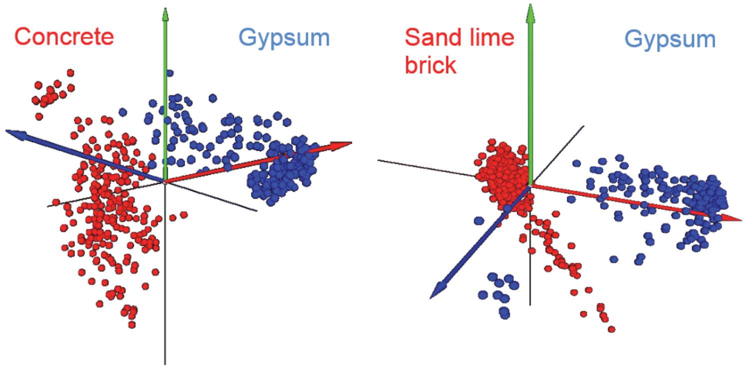

Figure 15.11: PLS Scores Plot for the system gypsum/concrete (left) and gypsum/lightweight concrete (right) (Software "KustaSpec", LLA Instruments GmbH, Germany)

4 Summary

The results can be summarized as follow:

- In principle, concrete and brick are well distinguishable in the infrared spectrum.
- Autoclaved aerated concrete and sand lime brick can also be very well recognized by near-infrared sensors.
- Lightweight and normal concrete cannot be distinguished in the near-infrared spectrum.
- Gypsum as impurity in the waste stream is very well detectable by near-infrared.
- A distinction between dense and porous clay bricks is not possible at the present state of knowledge by means of near-infrared.
- Clay brick material is not always recognizable. To explain the reasons, more research is needed.

Within the presented research project, an optical sorting method based on hyperspectral near-infrared sensors and the necessary recognition software is developed.

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