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Upgrading the quality of mixed recycled aggregates from construction and demolition waste by using near-infrared sorting technology

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HIGHLIGHTS

- Near Infrared sorting technologies favour selective removal of impurities.
- The quality of mixed recycled aggregates is upgraded by using NIR sorting solutions.
- Advanced sorting solutions can achieve more valuable recycled aggregates.

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ABSTRACT

Recycled aggregates of high-purity, guaranteeing optimal technical and environmental performance, are required for high-grade construction applications such as concrete. The main problem constituents causing a decrease in the quality of recycled aggregates to be used in high grade applications are: organic material, gypsum and autoclaved aerated concrete (AAC). This paper studies the potential of Near Infrared (NIR) sorting technology to improve the quality of mixed recycled aggregates. Tests were carried out by using samples of mixed recycled aggregates collected in different EU countries (Germany, Sweden, Spain and Italy). Constituents, total sulphur content, acid soluble sulphates, total heavy metals and metal leaching were determined before and after the use of the NIR sorting technology. The results clearly indicate that the problematic fractions (organic material, gypsum and AAC) in the mixed recycled aggregates can be significantly reduced or even eliminated during the NIR sorting treatment, boosting a greater use of recycled aggregates in high grade applications such as concrete manufacturing.

1. Introduction

Construction and demolition waste (C&DW) represents one of the European Union's largest waste streams, in quantitative terms by weight and volume. A very large proportion of C&DW can be easily re-used or recycled within the construction sector, be it almost exclusively in low-grade unbound applications such as embarkments, subfoundations and foundations. In this context, the Directive 2008/98/EC on Waste, states that, by 2020, the material recovery of non-hazardous C&DW shall be increased to a minimum of 70% by weight [1]. Eurostat estimates an annual C&DW generation of 970 million tons in EU-27, representing an average value of almost 2.0 ton per inhabitant, with an average recovery rate of 47% [2].

In most countries, the largest part of the C&DW recycled products are recycled aggregates [3] arising from the stony fraction. Some EU countries have achieved high recycling rates for the stony fraction derived from concrete, bricks and tiles (recycled aggregates and sands), but most are traditionally used in certain low-grade applications in civil engineering as unbound applications (embankment, sub-base, levelling of roads). This market for recycled aggregates, however, is getting more and more saturated. Therefore, a shift towards more structural concrete applications (requiring a higher quality of the recycled aggregates than for low-grade applications [4]) is currently investigated and promoted.

Successful cases of production of recycled concrete, the most representative case of high-grade application due to its demanding requirements and its extensive use, based on the use of (C&DW) recycled aggregates, partially or totally substituting conventional aggregates, are widely reported in the literature [5]. Interest has principally focused on the use of coarse concrete aggregates

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[6–8], but also the use of mixed aggregates [9–12] is considered. In addition, some research also addresses the use of fine aggregates [13–15]. The origin, treatment and characteristics of those recycled aggregates are diverse. In the case of mixed recycled aggregates, the sulphate content is systematically [9,11,12] indicated as a restrictive limitation for the use of these aggregates in concrete. Moreover, on the basis of a comprehensive report on C&DW management [16] it was estimated that on average in Europe concrete recycling stands for ca. 44% in low-grade applications and 2% in high-grade applications. In the case of ceramic materials, values would be 46% and 0% respectively.

According to some sources, the most effective way of minimising the amount of contaminants in CDW materials is selective demolition [17,18]. A comprehensive study in Spain [19], for instance, concluded that despite of the fact that the specific production technology at the recycling plant has a bearing on the characteristics of the recycled aggregate obtained (depending e.g. the gypsum content on the number of manual sorting stages), the purity level of the C&DW that is accepted at the plants determines in great measure the impurity content and the gypsum content of the recycled aggregate. Nonetheless, it is quite clear that, on the whole, selective demolition is still a fresh, poorly consolidated idea in the demolition market, of questionable economic appeal (in many cases) and, above all, little practical manifestation [20]. Additionally, space, safety and time might limit the feasibility of this onsite presorting [14].

As a general rule, the content of contaminants such as organic matter (wood, plastics, organic foams), gypsum or AAC in the recycled aggregates must be minimised for high-grade applications. Those constituents give high levels of total sulphur compounds, acid soluble sulphate, high levels of sulphate leaching constituting a known environmental problem [21], and other effects influencing the properties of the final use. The unwanted constituents can lead to expansive compounds in cement-based materials (gypsum) [22,23], induce delays in setting and hardening of cement based materials or cause a lack of bonding strength (organic material) [24]. In addition, particles with lower mechanical strength (e.g. AAC) can cause weak points in the final application.

Currently most C&DW recycling plants employ a variety of treatment processes. A wide number of solutions are adopted in different geographic areas in Europe. However, the technological basis of the treatment systems remains the same in the design of the different processes. C&DW treatment technologies establish two levels of technology according to the degree of waste separation. On the one hand, simple technology based on automated crushing mobile machinery that consists almost exclusively of feed hoppers, crushing systems, magnetic separators, together, eventually, with various screens and conveyor belts. On the other hand, more complex technology can be incorporated to treat highly mixed waste streams. In most cases, it is stationary machinery that might be composed of some of the following equipment: crushing systems, screens and sorting equipment such as manual sorting cabins (mainly for discarding gypsum and organic elements such as wood or plastics), sorting systems based on density differences (gypsum), floating and windshifter separators (light elements like e.g. plastic and wood) or magnetic separators.

In the framework of the use of mixed recycled aggregates from very heterogeneous C&DW (coming from intensive demolitions) in high-grade applications, more rigorous separation and cleaning techniques might be needed to meet the required levels of purity and advanced technologies can contribute to achieving this objective. Furthermore, the ever increasing complexity in the construction environment will lead to more complex C&DW in the forthcoming years, thus requiring adapted advanced treatments for their recycling. The challenge lies in finding the right combination of onsite presorting during demolition processes, inexpensive traditional separation techniques and further advanced automated sorting techniques.

Advanced automated sorting techniques by colour (artificial vision) or chemical composition (spectrometers, lasers, X-ray, Near Infrared, hyperspectral) are successfully researched and developed for high quality sorting of plastics [25–27], in glass recycling [28], or for non-destructive analysis of quality of horticultural products. In the field of C&DW recycling, preliminary tests [29] were carried out, at lab scale, with automatic techniques based on both "Colour Sorting" and "Dual-energy X-ray transmission". However, further research is needed to optimise the separation of heterogeneous C&DW streams. This should result in a guaranteed supply of pure recycled materials that can be used in high-grade construction applications.

Additionally, other novel technologies have been recently developed [30–32], aiming to induce a selective fragmentation and sorting of the diverse constituents of concrete (cement paste and aggregates), which could as well contribute to the improvement of the quality of recycled aggregates for concrete.

The main objective of the current study thereby is to assess and discuss the performance of Near Infrared (NIR) sorting solutions providing mixed recycled aggregates with a substantially higher technical and environmental quality due to lower soluble sulphate contents (mostly related to gypsum and AAC particles) and organic matter contents (wood, plastic and others).

2. Materials and Methods

2.1. Sampling

In the framework of the IRCOW European project [14], 5 samples of recycled aggregates from C&DW were collected in 4 different EU countries (Germany, Sweden, Spain and Italy). The description of each recycled aggregate sample, including information about the recycling process applied for their production, is summarised in Table 1. Two representative big bags of approximately 1 m^3 were collected for each sample. One of the big bags was directly sent to the research facilities of TOMRA Sorting GmbH (Mülheim-Kärlich, Germany) in order to eliminate the problem fractions (i.e. gypsum, AAC particles, wood, plastic...) using NIR sensor-based technologies and produce recycled aggregates of a much better quality. The second big bag remained in the country of origin acting as reserve. A representative subsample was taken from this second big bag and used for characterisation. This subsampling was undertaken in accordance with Standard EN 932-1 [33].

The initial characterisation data were used for identification of the problem fractions to be sorted out. The NIR sensors of TOMRA work optimally with particle sizes over 6 mm, thus guaranteeing both optimal sensor resolution and efficient removal of unwanted fractions through air jets. It must be therefore highlighted that particles smaller than 6 mm were removed from the initial collected samples by sieving. This is in line with many research and regulations, which accept only the coarse fraction of the recycled aggregates for the production of concrete. Subsamples from the samples sorted by TOMRA with the NIR technology were subsequently characterised and compared to the original samples.

2.2. Determination of constituents

The determination of constituents was performed according to EN 933-11:2009 [34]. This European Standard describes a simple method for the examination of coarse recycled aggregates for the purpose of identifying and estimating the relative proportions of constituent materials. The proportion of each constituent in the test portion is determined and expressed as a percentage by mass, except for the proportion of floating particles which is expressed as a volume by mass. This procedure was used in previous works [35,36] to discuss and provide arguments on which to base the regulation of mixed recycled aggregates in unbound road applications and the influence of those constituents on the physical–mechanical properties of hardened concrete.

2.3. Near Infrared-sensor based sorting technology

Advanced automated sensor-based sorting systems use some physical–chemical properties of the different materials such as density, electrical conductivity or magnetic susceptibility, as well as surface and material properties, such as the Near Infrared (NIR) spectrum or the visible colour. This work focused on the use of NIR-sensors aiming to remove problem particles (gypsum, organic particles, AAC) to recover higher quality recycled aggregates.