III- 221 - VALORISATION OF CONSTRUCTION AND DEMOLITION WASTE IN THE CONSTRUCTION SECTOR: CHALLENGES AND OPPORTUNITIES OF THE RECYCLED AGGREGATES IN EUROPEAN COUNTRIES

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ABSTRACT
According to the Waste Framework Directive 2008/98/EC (WFD), the new EU challenge is to recover 70% by weight of Construction and Demolition Waste (CDW) by 2020.
Construction and demolition activities produce large quantities of waste materials, heterogeneous in composition and size, which are classified as *special waste* (Chapter 17 of the European List of Waste – EER code). The disposal of these materials represents an important factor in the costs of construction or demolition operations, in addition to representing a loss of resources that could be valorised and reintroduced into the production cycle of the construction industry, while avoiding a further depletion of natural resources used for the production of new construction aggregates. In this context, the present research work aims to offer a study contribution on the theme of management and recovery/reuse of recycled aggregate (RA) sourced from CDW. The paper presents a literature review of several studies and guidelines that have been developed at national and international scale aimed to providing a global environmental and technical framework on the use of RA in different applications, such as concrete production and geotechnical purpose.
The results demonstrate that RA have mechanical properties similar to natural aggregates (in relation to specific measures taken upstream of the production process, such as selective demolition). The main problems related to the recovery and use of RA refer to the leaching test. As suggested by the guidelines analyzed, the evaluation of the leaching behavior through specific tests able to simulate the "real" recovery conditions and to validate in situ the behavior of the material in real conditions is of utmost importance.

KEYWORDS: construction and demolition waste, recycled aggregates, waste management, leaching behavior, pollution, environmental aspects.

INTRODUCTION
The progressive reduction of non-renewable natural resources has been a constant concern relating to the protection of the environment that, at the same time, encourages the use of alternative materials. In particular, the exploitation of the natural resources for construction activities leads, over time, to a production of

Construction and Demolition Waste (CDW) of million tons every year. For this reason, over the last years environmental sustainability has required a gradual increase of waste valorisation in the construction sector. In 2016, the total waste generated by all economic activities and households (in the 28 countries of the European Union, EU-28) amounted to 2.535 million tonnes; this was the highest amount recorded during the period 2008-2016 (EUROSTAT, 2019). According to Eurostat data, the waste from the construction sector account for around 35% of total waste production, with 923.910.000 tons in 2016.
Italy, with a production of about 54.5 million tonnes is the fourth European country for CDW production after Germany, France and Netherlands (EUROSTAT, 2019); not considering the United Kingdom, recently released from the EU.

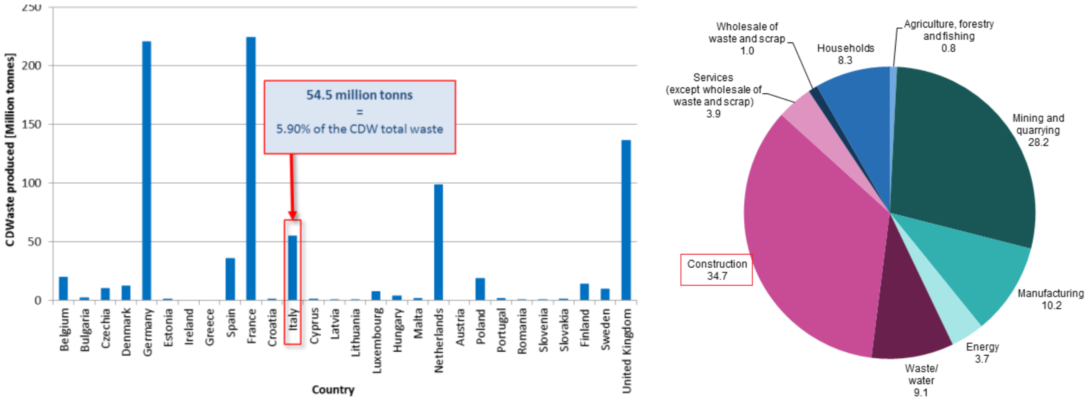

Figure 1. Waste generation by construction and demolition activities EU-28 (2016).

According to ISPRA (2018) and to the UE Waste Framework Directive 2008/98/EC (EUROPEAN PARLIAMENT AND COUNCIL, 2008), that requires a minimum of 70% (by weight) of non-hazardous CDW recovery rate by 2020, 76% of CDW were recycled at national level in 2015. However, the amount of CDW destined to landfill is still important (24%) and this can have serious environmental impacts. Landfills, in fact, in addition to considerable land consumption may cause groundwater and soil pollution. Thus, the valorisation of CDW avoids congesting landfills with inert wastes coming from buildings and other constructions or infrastructures and allows to obtain, after suitable treatment processes, recoverable materials, i.e. recycled aggregates (RA) for the construction sector.
Although there are several encouraging experiences, both research and application, the practice of waste recovery in construction is still limited mainly due to the characteristics of some materials in relation to their environmental compatibility. Therefore, in addition to the study of technical performance that construction products must guarantee, is essential to evaluate their characteristics in relation to the environmental requirements. This work presents and discusses the main regulations and guidelines on CDW correct management and recovery, as well as the results obtained from a literature review that have been developed at national and international scale aimed to providing a global environmental and technical framework on the use of recycled aggregates in different applications, such as concrete production and geotechnical purpose.

OBJECTIVES

The present research work aims to offer a study contribution on the theme of recovery and reuse of recycled aggregates sourced from construction and demolition waste as well as to present strategies for innovation in CDW management in Italy and compare them with the international ones. CDW is one of the most consistent waste flow generated in the European countries. It includes concrete, bricks, asphalt, tiles, plastic, glass, metals, excess dirt, wood, excavated soil and more. These materials are mostly inert and many of these can be recycled. The composition is extremely variable and the main characteristic is the considerable heterogeneity due to the fact that currently the demolition techniques tend to reduce time and cost of the process compromising the debris homogeneity. In view of the above, in order to improve the quality of the final recycled aggregate, a proper waste management is a key element. Therefore, the main objective of this work was to identify new development lines and provide technical-management indications to encourage the recovery of CDW as recycled aggregates for concrete production, roads and other geotechnical works. In addition the purpose was to provide new knowledges on the RA characteristics, with particular reference to the release of pollutants into the surrounding environment. Through the analysis of real case studies, the critical and potential aspects of these materials have been also highlighted. Specifically, with reference to the main forms of recovery applied in Italy, two real case studies have been identified:

- use of the recycled aggregates as a sub-base for industrial flooring;
- use of the recycled aggregates as a base layer in road structure.

METHODOLOGY

The research work has been developed through the collection of data and information both from specialized literature and real case studies. Primarily, the data gathered from the literature experiences were examined and critically evaluated in order to highlight the strengths and weaknesses of these materials (i.e. recycled aggregates). A keywords search was carried out in some search engines (Scopus, Research Gate). In this search, only the papers explicitly discussing environmental and technical recovery of construction and demolition waste were considered.Simultaneously, the regulatory framework was developed through the analysis of regulations issued on the Italian Official Gazette and, specifically for technical standards, through the Italian Technical body (UNI).

The analysis of guidelines was performed in order to identify the main ones of interest: Italian guidelines, EU Construction & Demolition Waste Management Protocol (EC, 2016) and the "End-of-Waste Criteria for Construction & Demolition Waste" of the Nordic Council of Ministers (HJELMAR, *et al.*, 2016). Naturally, there are several countries that are addressing this issue at European level through the definition of their own guidelines, such as Portugal (COUTO, et al., 2010), Germany (EC, 2015) and United Kingdom (EC, 2016). For summary reasons, the guidelines discussed in this article are those mentioned above.

RESULTS OBTAINED AND ANALYSIS OF THE RESULTS

Many guidelines have been developed at national and international level suitable to provide a set of operational indications relating both to the production and the waste management in construction and demolition activities, starting from the place of production (site) up to the treatment activities where they are recovered and turned into new products.

The **Italian guidelines** (2016), gathered in a shared document drawn up by the National System for Environmental Protection (SNPA, 2016), establish several executive expedients for CDW management. The pilot parameter is the selective demolition, i.e. the initial separation of different types of waste from reusable components and their subsequent sending to suitable treatment plants. Moreover, the storage of CDW should be carried out by homogeneous categories (e.g. bricks, iron, wood, etc.) by assigning the respective EER code to avoid mixtures of mixed waste which will subsequently sent to recovery/disposal plants. The EER code is the code used to identify waste as listed in the European List of Waste (EC, 2014). The different types of wastes in the list are fully defined by six-digit code for the waste and the respective two-digit and four-digit chapter headings. In order to allow the greater use degree, recycled materials (RA) must be tested to ensure their environmental compatibility and to evaluate their performance and mechanical characteristics.

The assessment of environmental compatibility must be verified according to M.D. 05/02/1998 through the leaching test established by the Italian regulation UNI EN 12457-2 (2004).

Furthermore, since the aggregates must necessarily report the CE marking, it is necessary to evaluate their geometrical, physical and chemical characteristics and establish a level of conformity attestation according to the type of use (2+ for structural applications or 4 for non-structural) and to the specific applicable reference standards.

Internationally the **EU Construction & Demolition Waste Management Protocol (2016)** has been issued. The savings in environmental impact should be measured in terms of diverting demolition waste from landfill and replacing raw materials; this should be embedded into pre-demolition audits.

A pre-demolition audit is to be carried out before any renovation or demolition project and for any material to be re-used or recycled, as well as for hazardous waste, in order to:

- identify the generated CDW;
- implement a proper deconstruction of the buildings;
- specify dismantling and demolition practices.

This includes providing appropriate timescales for the demolition of a building/structure to ensure full recoverability of the demolition arisings including high value reuse.

Although pre-demolition audit focuses on products ("what"), a process-oriented waste management plan ("how") should be prepared. It must contain all the information about how the different demolition phases will be performed, by whom they will be performed, which materials will be collected selectively at the source, where and how they will be transported, what will be the recycling, reuse or final treatment and what the

follow up. A key aspect of proper waste management is also to keep materials separated. With better separation at the source of waste, the more effective recycling will be, and the quality of aggregates will increase.
Such separation can be challenging: buildings have become increasingly complex and this has implications for demolition works. Furthermore, over the last few decades, an increasing amount of materials have been glued and the use of composite materials has extended as well. The quality of the recycled aggregate (RA) must be guaranteed through an evaluation of the material performance accompanied by a declaration of performance (DoP) and marked with the CE marking. This allows manufacturers to place recycled or reused products on the EU market.
Finally, the **Nordic Council of Ministers** financed the "*End-of-Waste Criteria for Construction & Demolition Waste" (EoW)* (2016). The Nordic countries have a special interest on protecting the quality of groundwater and surface water. In Denmark, in fact, almost all of the drinking water is extracted from groundwater and generally used without treatment. Besides, the relatively high level of precipitation in the northern regions can lead to a high degree of leaching of aggregates in the surrounding environment.
The aim is, therefore, to protect the groundwater, surface water, soil and humans (RECEPTOR) against substances that may be released from the CDW by leaching (SOURCE). The source can be of two types:

1. material placed in direct contact with the potential receptor (e.g. groundwater or surface water). There is not a long path through which the released substances can be retained - *worst case scenario*.
2. material placed in a confined and covered environment at an adequate distance from the receptor (e.g. water well).

The methodology provides, through an inverse procedure (backward), the determination of the maximum admissible pollutant's concentrations in the source compatible with the level of acceptable risk for the exposed receptor. The applied risk analysis must be based on the *source-path-receptor chain* through an evaluation of real scenarios that allow the execution of a less severe risk analysis, without however compromising environmental safety (HJELMAR, *et al.*, 2016). This condition is necessary because a "worst case" scenario calculation clearly indicates that the leaching limit values aimed at the protection of soil, groundwater and surface water will have to be so stringent that very few, if any, waste aggregates can meet them.

Over the last few years, also several literature studies have focused on the use of materials deriving from CDW recovery as resources that can be exploited in the construction sector.
Butera *et al.* (2014) and Galvin *et al.* (2014) studied the environmental and chemical aspects of composition and release of CDW, highlighted that chromium and sulphate are the most critical compounds in the leachates (*Figure 2*). The results showed that the total chromium was released by ceramic materials and partly carbonated samples, indicating that source segregation and management practices may be important. High sulphate levels were detected by the gypsum-based materials, suggesting that segregation of the gypsum source could improve to some extent the leaching properties.

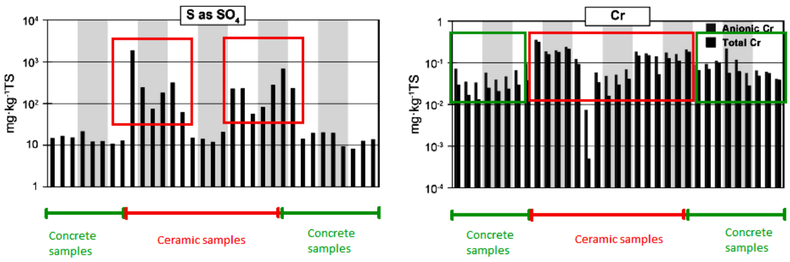

Figure 2. Leaching behaviour of concrete and ceramic samples and relative release of sulphates and chromium (Butera et al., 2014).

The results have been confirmed by Del Rey *et al.* (2015) and Ledesma *et al.* (2014). The authors have shown, additionally, that the detection of high levels of sulphate is due to the presence of other CDW compounds such as mortar particles. High concentrations of chlorides are sometimes recorded. The high release is due both to the presence of cement and to release from ceramic materials. In particular, for the use of RA for concrete production, this parameter must be kept under control, since over time it can lead to corrosion of the reinforcing bars. Possible solutions studied in the literature refer to washing techniques or total immersion of the recycled aggregates in water (MARTÍN-MORALES, *et al.*, 2011). This method is achievable because the chlorides are not bound to the cementitious microstructure and are, therefore, easily removable.
Authors such as Galvin *et al*. (2014) also showed that in geotechnical works the compaction effect represents a considerable variable. By acting on the particle size and on the density of the material, higher levels of pollutants can occur with a potential environmental risk. According to this, it is foundamental that the

environmental behavior of these materials is evaluated in real recovery conditions, as well as on the granular material through laboratory-conducted leaching tests. This is due to the fact that the recycled aggregates under compaction can have serious variations in their physical characteristics that lead to repercussions on the release behavior of the material. In particular, the test developed by the authors showed that after compaction an increase of chromium and sulphate release was recorded in concrete samples due to the percentage of fine fraction.
From a technical point of view, especially for concrete production, it is possible to guarantee good technical and mechanical performances, as demonstrated by Thomas *et al.* (2013). In comparison with the natural aggregates, they obviously still show slight decreases in terms of resistance but this can be compensated by improving the quality of the recycled aggregate and reducing the replacement percentage.

As a further deepening of the developed study, direct analysis of **real case studies**, related to the recovery and use of recycled aggregates in Italy, have been carried out.
The *first case study* concerned a construction/industrial site (on which the construction of sheds was planned) of a company located in Northern Italy that performs both the treatment of CDW and the recovery of RA. In particular, the recycled aggregates were used for the construction of the sub-base layer of the entire site. The quantities of RA used were considerable: around 35000-40000 m^3. The initial CDW has been submitted to a simple treatment process: a rapid phase of coarse screening, followed by a crushing process. The aggregate was very heterogeneous and was transported on site, spread by means of tracked bulldozers and finally compacted by a roller.

Figure 3. Sub-base layer with RA.

In the *second case study* (Interconnection A4-A35 in Northern Italy), the new road base layer of about 15 cm thick was developed through the 100% cold recycling of the pre-existing paving. The milled aggregates were combined with cement, water, bitumen emulsion and any additives, stored in three tanks on three separate trucks, but connected to each other to form the so-called "recycling train". Once installed, the solution was leveled to restore the floors and then compacted by a vibrating roller and a staggered wheeled roller. Above this state, another 6 cm of intermediate filler layer and 4 cm of draining wear layer have been arranged. There are several advantages of this recycling solution: conglomerate with 100% recycled material, energy saving through cold recycling, transportation savings since the RA is already on site.

Figure 4. On-site recycling.

CONCLUSIONS

From the guidelines and literature analysis, the main problems related to the recovery and use of recycled aggregates refer to the leaching test. In particular, the release of contaminants from RA is influenced by several factors that mainly depend on the characteristics of the material, including the:

- heterogeneity in the RA composition (improved through selective demolition upstream of the CDW treatment process);
- low quality of RA obtained by poorly treated CDW;

- non-optimal granulometric size distribution;
- level of carbonation (factor that conditions the pH of the material, extremely important in regulating the mechanisms of release of pollutants).

To overcome these problems, there are considerable technical indications for both the production and use of recycled aggregates. In particular, in order to improve the quality of the recycled aggregate, various measures can be taken both during the demolition phase and during the treatment of CDW such as:

- selective demolition procedures;
- selection and separation of specific fractions;
- double waste crushing operations;
- waste cleaning treatment.

Moreover, as suggested by the Nordic guidelines analyzed, it is necessary to evaluate the leaching behavior through specific tests able to simulate the "real" recovery conditions and to validate in situ the behavior of the material in real conditions. Finally, an approach based on risk analysis would allow an assessment of specific risks on environmental targets, assessed with reference to specific recovery scenarios.

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