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Sustainability Improvements in the Concrete Industry

Use of Recycled Materials for Structural Concrete Production

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Introduction

1.1 Objectives of the Book

The recycling of building materials has relatively ancient origins, since when Romans used construction waste such as ceramics in the so-called opus caementicium, the roman concrete, or when they used crushed slag from the crude iron production for roads building. However, from long time ago, recycling of mineral fraction of demolition wastes and a great part of industrial waste has been not considered as a real, effective alternative of waste disposal. Additionally, for centuries, the construction industry has consumed raw materials, causing also great stream of wastes, which needed to be landfilled. An enormous amount of space was dedicated to the disposal of those materials, leading to the increase of the ecological footprint of construction market.

In the last decades however the research community was pushed to study new fields of application for the wastes coming from construction and demolition operations, driven both by the arise of an environmental consciousness in the society, and also by the realization of the possible depletion of non-renewable natural resources, at least at local scale. From many years also iron and more generally steelmaking slag have been employed as compounds of cement-based materials: for instance the use of ground granulated blast furnace slag in cement manufacture as a partial substitute of Portland cement clinker has become a very well-known practice, currently standardized in EN 197-1. The use of other kinds of slag as artificial aggregates in concrete for civil engineering applications is also commonly diffused.

Accordingly many research works have been developed in the last years, aiming to explore the possibility to substitute, at high percentages, natural aggregates or traditional binders with recycled materials, e.g. recycled aggregates coming from construction and demolition waste (C&DW), metallurgical industry, and supplementary cementing materials. Promising results have been obtained with the production of "green concretes", which can be potentially ready-applied into the

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market, as in the case of concretes including coarse recycled aggregates from C&DW. Their use for structural purposes is also accepted by the current design codes, but generally aggregates origin and the strength class of the structure where they will be placed limit their maximum content. Most of the mechanical and durability properties of recycled aggregate concrete have been widely studied, and currently we are able to properly design this material, for the intended target during structure service life. However few aspects are still not sufficiently explored: this is the case of the workability and rheology of fresh recycled concrete mixtures. Very few data are currently available to predict how this material will flow during casting conditions.

Less research works have been carried out about the use of metallurgical slag use in cement-based materials. Over recent decades the steelmaking industry in Europe has been radically transformed; electric arc furnace technology has largely replaced blast furnaces and Linz-Donawitz converters, leading to the appearance of a new by-product: Electric Arc Furnace (EAF) oxidizing slag. Promising results have been obtained when using this material for producing structural concrete, however still few data exist about its durability and long-term behavior.

Benefits obtained through the use of recycled components in construction materials should be however quantified: often the term “green-concrete” is used, but few proofs of the real embodied energy of the product are given.

The book is structured as follows: Chap. 2 provides the state-of-the-art about the current uses of recycled aggregates, coming from construction and demolition waste and from by-products, in cement-based materials; also supplementary cementing materials are covered by this review. The existing Codes and Guidelines regulating their application for structural concrete in several Countries are described.

Chapter 3 deals with a particular property of recycled aggregate concrete: its workability and rheology in the fresh state. The most diffused experimental methods for evaluating workability, consistency, flowability and passing ability are reviewed. Rheology of fresh cement-based materials, i.e. cement pastes, mortar and fresh concrete, is discussed, particularly with respect to fresh recycled concrete. Some experimental data collected from literature have been used, aiming to highlighting the influence of some design parameters on the overall behavior of the mixtures in the fresh state.

The design of concretes with recycled aggregate coming from metallurgical slag is covered by Chap. 4: some results collected from experimental campaign have been used to assess the influence of aggregates properties on the overall mechanical strength and durability of the concrete. The use of electric arc furnace slag for both replacing coarse and fine aggregates has been discussed.

Chapter 5 analyzes the environmental problems related to the use of recycled materials in concrete. Here a procedure for evaluating the environmental impacts of recycled aggregates and recycled concretes is described. Some examples about how performing a comparative estimation between two different recycled concretes are provided. Additionally some other environmental indicators, useful to capture environmental problems at local and regional scale, are described.

Lastly Chap. 6 provides a database about the available experimental results about electric arc furnace slag characterization and possible application in civil engineering applications. This original database can be used for comparing the properties of different slag, and to assess how they influence the properties of the material where they have been placed.

Chapter 2
Recycled Aggregates for Concrete Production: State-of-the-Art

2.1 Construction and Demolition Waste

All the waste materials coming from construction and demolition operations are known as C&DWs. These materials represent one of the most voluminous stream of waste generated in the world, accounting for about 25–30 % of the whole waste produced in the EU. As an indicative data, approximately 3 billion tons of waste are generated in EU 27 each year. Of this, around one third (1 billion tons) comes from construction and demolition activities [1]. C&DW typically comprises large quantities of inert mineral materials, with smaller amounts of a range of other components, depending on the source and separation techniques. The Waste Framework Directive 2008/98/EC [2] excludes from its definition the uncontaminated soil and other naturally occurring material, which are excavated during construction activities, when the material is used, and remains on site. However C&DW definition and composition may vary from state to state (e.g. with respect to the inclusion of excavated soil), and hence some caution is needed when reviewing statistics about its production in Europe and, more generally speaking, around the world. In the US total C&DW was estimated to be 170 million tons in 2003 [3]: a large fraction of this amount ends up in C&D landfills, and barriers to materials recovery still exist. Several reasons can explain the still low valorization of C&DW, including that buildings are not designed to be nor reused nor recycled, there is a lack of recovery facilities in some areas, and for some materials, the demand is too low due to the unwillingness to use recycled materials in place of virgin ones principally for some regulatory preventions. The competitiveness of C&DW recycling could be improved with several operations, i.e. raising the price of raw materials, through taxation, and setting End-of-Waste criteria for certain C&DW fractions [4].

Concerning C&DW composition, generally it is divided into five main fractions: metal, concrete and mineral, wood, miscellaneous and unsorted mixed fraction. More precisely, it may contain:

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- concrete;
- bricks, tiles and ceramics;
- wood;
- glass;
- plastic;
- bituminous mixtures and tars;
- metals (ferrous and non-ferrous);
- soils and stones;
- insulation materials (including asbestos);
- gypsum-based materials (including plasterboards);
- chemicals;
- waste electronic and electrical equipment (WEEE);
- packaging materials;
- hazardous substances.

In this list several hazardous substances appear, which are generally present in building materials because they are used, together with concrete, for completing the structure and for realizing the finishes. These substances are asbestos (found in insulation, roofs and tiles and fire-resistant sealing), lead based paints (found on roofs, tiles and electrical cables), phenols (in resin-based coatings, adhesives and other materials), polychlorinated biphenyls (PCBs) (which can be found in joint sealing and flame-retardant paints/coats, as well as electrical items) and polycyclic aromatic hydrocarbons (PAHs) (frequently present in roofing felt and floorings). The composition of C&DW generally varies highly in relation to the site, because of the local typology and construction technique, climate conditions, economic activities and technologic development of an area, and hence it is difficult to define univocally a composition representative for a large region. The composition of C&DW is also changing during time, due to ageing of the existing buildings and to the low-quality structures, especially build between 1960s and 70s, which are coming to the end of their lifetimes and needing demolishing [5]. Selective demolition of existing structures can determine clear benefits in this context: it would not only reduce the amount of waste destined to landfill, but also increases the quality of the recycled aggregates, minimizing the quantity of impurities and contaminant in the C&DW [6]. However this approach is still under debate, mainly because of the slight practical value and economic benefit, even though some Countries are encouraging this practice [7]. Additionally, in the next future, waste management will be more controlled by the waste treatment BAT reference document (WT BREF) currently under preparation, including when dealing with C&DW management [8].

Concerning C&DW composition, as an indicative data, also inside a single State, it can be very different: for instance in Northern Italy, soils and stone represent the 17 % of the whole waste, but in Central Italy this datum decreases until the 4 % [9]. In average, Italian composition of C&DW is constituted by about 32 % of mixed construction and demolition waste, 27 % of a mixture of concrete, bricks, tiles and ceramics, 14 % of iron and steel, and 11 % of bituminous mixtures. In the typical Finnish C&DW, wood and mineral materials constitute the predominant fraction (respectively about 36 and 35 %), followed by metal (nearly to 14 %) and the rest is other materials e.g. glass, plastic, gypsum and mixed waste [10]. In Germany 72.4 million tons of building waste were produced in 2007, corresponding to a recycling rate of about 68%: around 70 % is constituted by mineral debris from buildings, concrete and asphalt together represent about 25 %, and construction site waste is about 3 %, including gypsum-based waste [9]. In Greece, C&DW exceeded 3.9 million tons in 2000, representing about 656 kg per capita [11]. In Great Britain the production of recycled aggregate follows a WRAP Quality Protocol, and about 60 % of the recycled C&DW is used as aggregate, general fill or land reclamation. Around 17 % of UK aggregate needs are already met from recycled material [12]. Japan is one of the country where recycling of C&DW is more advanced: by 2000, demolished concrete was recycled up to 96 %, exceeding the target (90 %) proposed by the Japanese Ministry of Construction in the "recycled 21" program in 1992. RCA is applied almost at all as sub-base material for road carriageways [13]. Norwegian C&DW comes both from residential and non residential sources: in 2003 it was estimated that 1.256 million tons were generated, being principally constituted by concrete and bricks (about 67 %) [14]. In the US, 170 million tons of C&DW were produced in 2003: 39 % came from residential and 61 % from nonresidential sources. Cochran et al. [15] estimated that about 3.75 million tons of C&D waste were generated in 2000 in Florida, constituted mainly by concrete, representing the 56 % of all the waste. In Asia various studies have been done separately in some cities: in Shangai C&D waste generation estimate was 13.71 million tons in 2012, and waste concrete, bricks and blocks represented more than 80 % of the whole [16].

The official data regarding the non-hazardous inert wastes' recycling in Italy indicate that there are about 52 million tons of C&DWs produced per year [9], even though this number is poorly reliable. Between these, a relevant number of this waste is constituted by contaminated soils, which are generally also sent to inert waste treatment plants. Technology for separating and recovering C&DWs is well established, readily accessible and in general inexpensive. During the process of recycled aggregate production, the undesirable fractions are eliminated, and through grading and sorting, recycled aggregates are obtained. Also at the European level, the statistical significance of figures about C&DWs production is quite poor, and the different available sources are reporting fragmented data and several discrepancies. Currently the level of recycling and material recovery of C&DW varies greatly (between less than 10 % and over 90 %) across the Union, even though this number should increase and be homogenized in the next future, according to Article 11.2 of Waste Framework Directive [2], which states that "*Member States shall take the necessary measures designed to achieve that by 2020 a minimum of 70 % (by weight) of non-hazardous construction and demolition waste excluding naturally occurring material defined in category 17 05 04 in the List of Wastes shall be prepared for re-use, recycled or undergo other material recovery*" (including