

Recycled Aggregate

Ceramic recycled aggregate (CRA): It is the aggregate obtained by processing waste with a predominance of ceramic material.

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Recycled aggregates

Said Kenai, in [Waste and Supplementary Cementitious Materials in Concrete](#), 2018

Abstract

Construction industry generates huge amounts of debris that needs to be recycled and reused as recycled aggregates (RAs) for partial or total substitution of natural aggregates. Recycling reduces waste and reduces energy consumption and hence contributes to a more sustainable construction industry. In this chapter the need for recycling and the current situation worldwide are highlighted. RA properties are discussed. RAs have a relative density lower than that of virgin materials and higher water absorption. A state of the art RA concrete performance at the fresh and hardened state is summarized. RA concrete presents lower compressive and flexural strengths as well as lower modulus of elasticity and lower fracture because of the porous nature of the RA and the old adhered cement mortar on the surface of the aggregates. Bond strength and abrasion resistance are little affected. Shrinkage, water permeability and water absorption by capillary increase with increase in RA content. However, the lower performance can be mitigated by a good mix design using supplementary cementitious materials. Successful applications of RA in producing self-compacting and roller-compacted concrete are also discussed.

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Influence of fly ash in physical and mechanical properties of recycled aggregate concrete

Adeyemi Adesina, Paul O. Awoyera, in [The Structural Integrity of Recycled Aggregate Concrete Produced with Fillers and Pozzolans](#), 2022

Abstract

Recycled aggregates have been increasingly considered for use in concrete, owing to the limited supply of natural aggregates coupled with the corresponding carbon footprint. However, despite the sustainability benefits of using recycled aggregates in concrete, its use in concrete is plagued with lower performance due to the physical properties of the recycled aggregates. One of the effective ways to improve the performance of concrete incorporating recycled aggregates is with the incorporation of fly ash (FA) which is also waste material. In this chapter the effect of FA on the mechanical properties of concrete incorporating recycled aggregates has been discussed. With the incorporation of FA in the recycled aggregate concrete mixture, various properties are enhanced, owing to the filler effects and pozzolanic reactivity of FA. Micropores in concrete are filled up with fine particles, and thus ensuring low permeability in the matrix as a result of the improved concrete microstructure.

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Recycled aggregates (RAs) for asphalt materials

Abbaas I. Kareem, Hamid Nikraz, in [Advances in Construction and Demolition Waste Recycling](#), 2020

Abstract

Inclusion of recycled aggregates (RAs) in asphalt mixtures can reduce the depletion of natural aggregates (NAs) by providing an alternative material for hot-mix asphalt (HMA). Given the effects of cement mortar attached to the RA surface and other impurities, the performance of RA-asphalt mixtures was widely documented to be less than that of mixtures containing fresh NA. This chapter summarizes the research

results in the field of RA-asphalt mixtures. The chapter also explains why RAs remain unpopular as acceptable materials in HMA production, discussing various treatments previously suggested for RA-mixtures and also identifying current and future trends in the research of RA-asphalt pavements.

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Construction and demolition wastes

Serina Ng, Christian J. Engelsen, in [Waste and Supplementary Cementitious Materials in Concrete](#), 2018

8.2.2 General user scenarios

RAs can be employed for both bound and unbound applications. In general, unbound application is much more common than bound applications due to the less stringent criteria.

Road, both subbase and surface applications, parking lots, trenches, and backfills are common, profitable venues for using unbound aggregates. One of the first usage of RA in Norway was the building of new tramline in Gaustadbekkdalen in Oslo, 1999. 4000 m³ of RA (38–120 mm) were employed as base materials (0.4–1.4 m depth) on top of a lightweight filling (Myhre et al., 2003). In the same demonstration project, 100 m³ of shotcrete containing up to 20% 0–4 mm recycled sand was placed on the vertical sides of an EPS lightweight filling (Lahus et al., 2002). In 2011, road construction with RA commenced in Estonia and similar results were obtained (Talvik, 2014). Early full-scale laboratory tests showed that RA may have even better drainage characteristics and lower bulk density than NA, and thus are also suitable as backfill material for utility trenches (Mehus et al., 2002).

Bound application of RA refers to those embedded in some type of matrix such as building blocks and concrete. It is more challenging to use RA in concrete production compared to most of the unbound user applications, since the mechanical and durability properties of the final concrete must not be compromised when applying RA in the production. The criteria for bound RA are therefore more stringent than for unbound RA. The largest volume and bulk usage of RA in bound application is still concrete. Properly processed RA can be employed as aggregates in a wide variety of applications to create recycled concrete. In nonstructural concretes, this includes applications in pavements, shoulders, barriers, embankments, sidewalks, curbs, gutters, and bridge foundations. In structural grade concrete, bituminous concrete and soil–cement pavement bases can be constructed (Etxeberria et al., 2007, Safiuddin et al., 2013).

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Use of Recycled Aggregates in Geotechnical Applications

Ravindra K. Dhir OBE, ... Chao Qun Lye, in [Sustainable Construction Materials](#), 2019

11.3.1 Classification of Recycled Aggregates

RA is a generic term, which generally implies aggregates derived from construction, demolition and excavated waste (CDEW). Silva et al. (2014) suggested three main types of materials derived from CDEW, namely, crushed concrete, crushed masonry and mixed demolition debris, and based on composition, have classified RA into four main categories (Silva et al., 2014). These are described as follows:

- Recycled concrete aggregate (RCA): aggregate derived from crushed concrete made with NA.
- Recycled masonry aggregate (RMA): aggregate derived from masonry rubble such as ceramics bricks and sand–lime bricks.
- Mixed recycled aggregate (MRA): aggregate consisting mainly of RCA and RMA.
- Construction and demolition recycled aggregate (CDRA): aggregate which has not been properly processed from construction and demolition waste, or RA that is unrecognisable due to a lack of information on its composition.

In addition, there is another stream of aggregate waste, reclaimed asphalt pavement (RAP) aggregate resulting from crushed bituminous bound mixes, which is also a common alternative material used in geotechnical applications. Although not the focus of this chapter, the relevant data, whenever available, are presented as a parallel comparison with RA and NA.

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Upcycling CO₂ for enhanced performance of recycled aggregate concrete and modeling of properties

Paul O. Awoyera, ... Iman Mansouri, in [The Structural Integrity of Recycled Aggregate Concrete Produced with Fillers and Pozzolans](#), 2022

15.2.2.1 Fresh properties

Generally RAs have higher water adsorption than natural aggregates due to the adhered old mortar on their surface. This leads to reduced workability of RAC. However, as the carbonation of RA increases the density of adhered old mortar, the water absorption of the carbonated RA (CRA) is lower, and the workability is improved. There are only a few studies about fresh properties of RAC utilizing carbonated RA's (Liang et al., 2019). A typical test is the slump test, and there are no studies about more detailed rheological properties for instance. Kou et al. (2014) found that the initial slump of the concretes prepared with RA or CRA increased. Their study also showed that the rate of slump loss was quicker for the RA concretes within the first hour after mixing but was slower afterward. To reach zero-slump, the concrete mixture they prepared without RA's took about 150 minutes, while the mixtures they prepared with RA's took over 3 hours (Zhang et al., 2015) also found that the flowability of natural sand mortar was better than that of the RAs mortar due to the attached cement paste in RCA and that the flowability of CRA mortar was better than that of the uncarbonated RAs mortar (Zhang et al., 2015). Tam et al. (2016) found that the entrainment of CO₂ into RA is directly affecting slump results, dependent upon the CRA replacement percentages applied to the concrete (Tam et al., 2016). Their experimental results did not generate a pattern established around carbonation chamber pressure and duration for the recycled concrete with various CRA replacement percentages. They found that the process of CO₂ conditioning reduced the water absorption of RA, resulting in an increased amount of free water within the rest of the mixture. Also, Abhishek et al. (2017) found that the slump value of uncarbonated RA is lower than that of CRA due to a reduction in water absorption on carbonation.

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Epilogue

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Turning to RA use in mortar and concrete, whilst fine RA may be seen as an appropriate potential development, the use of RA is very much limited to coarse RA in the form of recycled concrete aggregate (RCA). However, the information available on the performance of mortar made with fine RA and analysis of the data suggest that depending upon the specific conditions under which the fine RA is produced, mortar can develop comparable or even enhanced performance, compared with normal mortar mixes. This implies that there could be a scope for cost savings with the use of mortar produced with fine RA and therefore it may very much be

an alternative to natural sand. The properties studied for such information are, for the fresh state, rheology characteristics, consistence, water retention, density and air content and, for the hardened state, strength, deformation, permeation and durability properties.

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Recycled materials in concrete

Carlo Pellegrino, ... Christian Meyer, in [Developments in the Formulation and Reinforcement of Concrete \(Second Edition\)](#), 2019

2.3 Recycled aggregates

The second method to improve concrete sustainability relates to replace natural aggregates with recycled components. Such a strategy might seem not as effective as replacing cement with SCMs, due to the lower impact that aggregates have on the carbon footprint of concrete. However, it is worth recalling that indicators for land use are rarely applied in LCA, thus resulting in underestimating environmental problems linked to soil depletion and topography alteration, which are directly correlated to aggregate consumption. In addition, typically aggregates account for about 70% of the overall concrete volume, hence representing a nonnegligible amount of material, which can be potentially saved through appropriate recycling policies.

Recycled aggregates are produced by transforming C&DW in treatment plants that can be stationary or mobile, and equipped with screens, crushers, and magnetic separators, aimed at reducing debris dimensions, separating ferrous elements and other contaminants, and lastly achieving the required grading. From the technical point of view, a huge amount of research has been carried out to establish how the use of recycled aggregates impacts on concrete performance. First, it is necessary to clarify which kind of recycled aggregates can be produced, on the basis of their composition and grading:

- recycled concrete aggregate (RCA), mainly composed of coarse particles of concrete;
- recycled masonry aggregate, mainly composed of coarse particles of brick; and
- mixed aggregates (MA), composed of a mix of coarse particles of concrete and brick; fine aggregate (FA), made up of fine particles only (maximum size less than 4 mm).

Such a distinction is necessary because the composition of recycled aggregate and its grading have a great effect on recycled concrete properties. A number of standards exist to regulate the use of recycled aggregates in concrete, such as EN 12620 (2008) and EN 206 (2016). Table 2.3 lists, as an indicative example, the maximum replacement ratio allowed per EN 206 (2016), depending on the aggregate type and concrete exposure class. It is significant to note that FA is excluded from any applications in structural concrete, regardless of the strength class and exposure of the structure. In Table 2.3, Type A aggregates are made of RCA, containing a very limited quantity of contaminants (e.g., glass, organic floating materials, asphalt), whereas Type B aggregates are made of RCA and MA, with a lower content of concrete particles and low quantities of contaminants. The nomenclature used in Table 2.3 is that of EN 12620 (2008). As one would guess, the maximum allowable replacement ratio decreases as the exposure class becomes more aggressive.

Table 2.3. Maximum percentage of replacement of coarse aggregates (% by mass) according to EN 206 (2016).

Recycled aggregate type		Exposure class		
X0 (%)	XC1, XC2 (%)	XC3, XC4, XF1, XA1, XD1 (%)	All other exposure classes (%)	
Type A: (Rc90, Rcu95, Rb10-, Ra1-, FL2-, XRg1-)	50	30	30	0
Type B: (Rc50, Rcu70, Rb30-, Ra5-, FL2-, XRg2-)	50	20	0	0

Type A recycled aggregates from a known source may be used in exposure classes to which the original concrete was designed with a maximum percentage of replacement of 30%. Type B recycled aggregates should not be used in concrete with compressive strength classes $\geq$ C30/37.

Those limits on the replacement ratio reflect the effects of recycled aggregate on concrete that have been experimentally observed in past research studies. Indeed, the main technical problems evidenced when recycled aggregates are used depend on the quality of the aggregates (e.g., for MA, or when the attached mortar content is high), on the great heterogeneity of recycled aggregates, and on the use of fine recycled sand, which is typically rich in contaminants. Reliable indicators of recycled aggregate quality include aggregate density, water absorption, and the amount of attached mortar, which can be estimated through various methods (chemically, through thermal shock, etc.). The density of recycled aggregates is generally slightly lower than that of virgin materials, and it is lower for lower quality aggregates. Conversely, water absorption increases for lower quality of the aggregates, and for increased amounts of old attached mortar. Fig. 2.2 shows particles of RCA with varying contents of old attached mortars and, accordingly, different qualities.



Figure 2.2. Recycled concrete aggregate (RCA) particles with different content of old attached mortar.

The use of recycled aggregate, in general terms, causes a reduction in concrete strength (Poon, Shui, Lam, Fok, & Kou, 2004) and elastic modulus, larger creep, and shrinkage deformations (Domingo-Cabo et al., 2009), as well as higher permeability of the concrete (Gómez-Soberón, 2002). In sum, concrete produced with RCA is generally of lower quality than natural concrete. However, when replacement ratios are limited and concern only the coarse fraction, and the quality of recycled aggregate is good, such a reduction of concrete performance is acceptable. In addition, there are methods for the design of recycled concrete that allow one to produce concrete with the same target properties of an ordinary mix, containing natural materials only. For instance, a novel method for concrete design, recently introduced by Fathifazl et al. (2009), called equivalent mortar volume (EMV), has been used to prevent the strength losses often reported in the literature when using recycled concrete. The EMV method has been applied for RCA only, and it considers the recycled aggregate as a two-phase material, consisting of the natural aggregate and the mortar attached to it, which must be quantified and included in the proportions of the mix, as a source of cement and sand. This allows the recycled concrete mix to be designed with a similar internal structure to that of the natural concrete used as a reference. The mixing water compensation method (Ferreira, de Brito, & Barra, 2012) for designing concrete is based instead on adding extra water in the mix that will be absorbed by the recycled aggregate, to adjust the effective water/cement ratio of the mix, and hence allow for improved fresh concrete workability. There is also evidence about the practicability of designing high strength concretes containing recycled aggregates, with replacement ratios up to 30%, that do not display any strength loss, just by adjusting the effective water/cement ratio inside the mix (Limbachiya, Leelawat, &

Dhir, 2000). Other techniques to improve RCA quality before their use, and therefore limiting possible deficiencies of the recycled concrete, are currently available, such as the autogenous cleaning procedure (Pepe, Toledo Filho, Koenders, & Martinelli, 2014). This method, that has been applied satisfactorily at the laboratory scale, gives positive results enhancing the properties of crushed concrete particles, especially in terms of a reduction of the attached mortar content and, consequently, on their water absorption.

With regard to concrete durability, generally the reduced properties of recycled aggregates, that is, their lower density and mechanical strength, along with the higher absorption and porosity, make recycled concrete less durable against carbonation, chloride penetration, permeation, and freezing/thawing resistance. However, some contradictory results are also present in the literature. Some research has indicated that carbonation resistance of recycled concrete is slightly inferior to that of natural concrete, due to the increased porosity resulting from the high quantity of attached mortar (Otsuki, Miyazato, & Yodsudjai, 2003). Conversely, other researchers have found that when the recycling rate reaches 100%, carbonation resistance is enhanced (Kou & Poon, 2013).

It is worth recalling that, for a great number of applications, high-performances concrete is not required. Although there are some limitations that may induce practitioners to be suspicious of recycled concrete, there are many cases in which recycled aggregates might be used safely, as the target performances asked of these concretes are within the range of recycled concrete properties. In those cases, the use of recycled aggregates makes strong economic and technical sense. Blends of virgin aggregates and recycled aggregates can be developed, maintaining the replacement ratio below the limits recommended by the standards for the required applications, thus ensuring little impact of recycled aggregate on the concrete mix. One major success story in the United States is the recycling of Denver's former Stapleton International Airport (Yelton, 2004). Instead of hauling the 6.5 million tonnes of concrete and hardscape (enough aggregate to build the Hoover Dam) to landfills, the Recycled Materials Company, Inc., was able to recycle or reuse all of this material. The company claims this project to be the world's largest recycling project and completed it at no cost to the City of Denver within 6 years (Meyer, 2008). There are also some other exemplary cases of efficient use of recycled concrete that are worth mentioning. These are the Allianz Stadium (also known as Juventus Stadium), which at the time of its construction was the first *recycled stadium*, and the ice rink in Torino, both in Italy. For the Allianz Stadium, about 50,000 tonnes of concrete have been recycled, which came from the original bleachers of the previous structure and were then used for the basement of the new facility. The use of recycled materials other than concrete (5000 tonnes of steel, 2000 m² of glass, and 300 metric tonnes of aluminum were saved and recycled) allowed for €2 million savings,

according to Legambiente (2017). The ice rink of Turin, built for the Winter Olympic Games of 2006, was built using 20,000 tonnes of recycled aggregates, again used for constructing the basement.

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Real-scale applications of recycled aggregate concrete

Rui Vasco Silva, ... Jorge de Brito, in [New Trends in Eco-efficient and Recycled Concrete](#), 2019

21.1 Introduction

Recycled aggregates (RAs) from construction and demolition waste (CDW) have been used since World War II. In several countries, mostly in Europe, high recycling ratios have been achieved, such as in the Netherlands, Denmark and Germany, among others. This has been potentiated by those countries' relatively reduced reserve of natural resources and subsequent transformation to construction aggregates or by the promotion of very stringent environmental policies. These factors have allowed the use of RA, albeit with considerable limitations, in real construction applications, mainly in-road pavement layers, embankments and earth-filling operations.

The treatment of CDW in specialised plants started in the 1930s. However, substantial advances in the installation and development of treatment plants has been observed more recently, in order to obtain RA of the highest possible quality (Hu et al., 2010; Nunes et al., 2007). Still, without the application of significant quality control measures during the demolition phase, the considerable variation of mineral components (Brunner and Stämpfli, 1993) as well as the presence of contaminants (e.g., asphalt, ceramic bricks, concrete, dirt, gypsum, glass, metal, plastic, among others) (Stein, 1987) will affect the properties of the output. These commercially available RA, due to their inconsistent characteristics, have instilled low confidence on stakeholders, thereby resulting in few cases that have been reported on the use of RA concrete (RAC). For these reasons, this chapter will further enlighten key individuals in construction that can drive the greater use of the material. The chapter contains an explanation of the difference between that typically observed in laboratory investigations and the limitations that can be observed in practice. It also presents a set of case studies on the use of RAC in structural and non-structural elements in the construction of road pavements and buildings.

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Environmental Impact, Case Studies and Standards and Specifications

Ravindra K. Dhir OBE, ... Chao Qun Lye, in [Sustainable Construction Materials](#), 2019

13.2.1 Chemical Composition of Recycled Aggregates

Although RA is essentially derived from materials which have been used previously in construction applications, the primary environmental concern about RA is related to its chemical constituents and their leaching behaviour, owing to its possible contamination with foreign substances or where the materials might have not been properly processed. The total elemental components, carbon content and inorganic content of different RA types, mainly RCA followed by MRA, from over 100 samples mostly sourced during the 2010s, are given in Table 13.1.

Table 13.1. Total elemental components, carbon content and inorganic content of different types of recycled aggregates

N	RCA					RMA					MRA				
	Min.	Max.	Ave.	SD	N	Min.	Max.	Ave.	SD	N	Min.	Max.	Ave.	SD	N
(a) Major and Minor Elements (g/kg)															
Al	76	3.8	64	40.5	16.9	—	—	—	—	—	21	37	64	53.8	10.9
Ca	81	13.7	<200	96.8	20.1	—	—	—	—	—	23	7.4	110	85.9	22.3
Fe	74	3.2	39	17.9	6.7	—	—	—	—	—	21	11	23.5	18.3	5.3
K	73	0.8	28	11.2	7.3	—	—	—	—	—	23	0.035	28	19.4	8.8
Mg	61	1.8	20	5.5	3.1	—	—	—	—	—	21	3.3	5.95	5.05	0.93
Na	67	0.2	19.5	10.3	5.4	—	—	—	—	—	22	0.031	17	11.6	4.4
Si	56	240	509	383	122.7	—	—	—	—	—	20	250	509	379.5	126.9
(b) Trace Elements (mg/kg)															
As	84	4.5–E–4	33	4.67	4.1	—	—	—	—	—	21	1.9	5.5	4.4	1.2
Ba	72	2	689.2	381.7	244.9	—	—	—	—	—	21	370	640	542.1	119.3
Cd	75	0.005	2.4	0.34	0.30	4	0.005	3.3	1.5	1.7	21	0.15	0.37	0.3	0.08
Co	70	0.201	8.3	5.12	2.5	—	—	—	—	—	23	5.2	9.2	7.1	1.2
Cr	86	0.239	152	29.5	26.3	—	—	—	—	—	21	0.4	64	31.2	15.3
Cu	87	0.016	546	26.4	54.8	3	0.13	29	16.4	15.1	24	9.2	32.8	24.3	9.1
Li	50	8.7	20	15.8	3.9	3	0.05	18	11.1	9.7	21	7.1	19.1	16.1	3.8
Mn	57	180	635	453.2	141.5	—	—	—	—	—	20	330	600	503.3	107.3
Mo	71	0.006	8.7	1.1	1.5	—	—	—	—	—	21	0.55	1.1	0.8	0.2
Ni	71	0.026	182	20.5	25.2	—	—	—	—	—	23	10	25	20.5	5.3
P	50	250	1200	612.5	211.7	—	—	—	—	—	20	350	920	603.1	207.1
Pb	71	0.321	873	51.1	100.2	9	0.001	15.3	4.9	6.3	21	12	210	61.4	43.2

Sb	64	0.001	3.3	0.73	0.6	—	—	—	—	—	21	0.11	1.1	0.6	0.2
Se	61	0.001	17.4	5.9	3.8	—	—	—	—	—	23	5.9	7.4	6.5	0.9
Sr	50	190	510	378.5	117.1	—	—	—	—	—	22	220	510	392.1	123.2
V	51	1.5- E-4	130	44.3	23.1	—	—	—	—	—	21	28	59	45.4	14.2
Zn	74	0.031	553	72.9	67.2	3	0.01	59	34.3	30.5	21	36	150	80.8	24.1

(c) Carbon Content (%)

Or- gan- ic car- bon	31	0.10	1.59	0.5	0.3	—	—	—	—	—	21	0.12	0.6	0.4	0.2
Inor- gan- ic car- bon	23	0.03	10.7	2.7	3.0	—	—	—	—	—	—	—	—	—	—

(d) Organic Content

PAHs ($\mu\text{g/kg}$)	27	0.09	7.05	4.0	3.1	—	—	—	—	—	18	5- E-6	17	3.6	4.8
PCBs ($\mu\text{g/kg}$)	27	1.45	400	18.6	62.9	—	—	—	—	—	18	0.2	69	13.4	19.3

Major elements, ≥ 1 wt%; minor elements, ≥ 0.1 wt% and ≤ 1 wt%; trace elements, ≤ 0.1 wt%. *MRA*, mixed recycled aggregate; *PAH*, polycyclic aromatic hydrocarbon; *PCB*, polychlorinated biphenyl; *RCA*, recycled concrete aggregate; *RMA*, recycled masonry aggregate.

Data taken from Abbaspour et al. (2016), Arulrajah et al. (2013, 2016), Aydilek (2015), Bestgen et al. (2016a,b), Butera et al. (2014, 2015a,c), Chen (2012), Chen and Brown (2012), Chen et al. (2012, 2013), Del Rey et al. (2015), Edil et al. (2012), Engelsens et al. (2006, 2009, 2010), Hu et al. (2010), Lewis et al. (2015), Martins et al. (2015), Mulugeta et al. (2011), Petkovic et al. (2006), Roque et al. (2016), Sani et al. (2005), Sanusi et al. (2011), Wahlström et al. (2000), Wang et al. (2008).

In general, the chemical compositions of RCA and MRA are not too dissimilar, which is to be expected as both aggregates are processed from crushed concrete, although MRA contains an additional component from masonry waste. The most abundant major elements found in RCA and MRA are aluminium, calcium and silicon, with average contents of 40.5, 96.8 and 380 g/kg, respectively, implying that the amount of cement paste residue present in both RAs is appreciable. The contents of iron, potassium and sodium found in RCA and RMA are also significant, ranging between 10 and 20 g/kg on average. The minor element magnesium has an average content less than 6 g/kg.

The concentrations of trace elements in RAs tend to be irregular and vary from one sample to another. They could be affected by several factors, such as the contamination level of the waste before processing and the quality of sorting the waste. Notwithstanding this, the dominant trace elements found in both RCA

and MRA are barium, manganese, phosphorus and strontium, with average values varying between 300 and 650 mg/kg. These are followed by lead, vanadium and zinc, which show average concentrations in the region between 50 and 80 mg/kg, and chromium, copper, lithium and nickel, in the region between 15 and 30 mg/kg. It should be mentioned that chromium metal can appear in a few oxidation states, such as hexavalent chromium (chromium IV, more toxic) and trivalent chromium (chromium III, less toxic), and as no distinction has been made between the two in the reported values, the total chromium is assumed herewith. The remaining trace elements are arsenic, cobalt, molybdenum and selenium, all with an average concentration below about 8 mg/kg. The average concentrations of antimony and cadmium are below 1 mg/kg.

On average, the total organic carbon content and inorganic carbon content present in RA are about 0.5% and 2.7%, respectively. It should be mentioned that RCA which has been stockpiled for a long time could have a higher total inorganic carbon content than freshly crushed RCA, due to the long period of carbon uptake (Chen and Brown, 2012). Organic pollutants such as polychlorinated biphenyls (PCBs) and parent polycyclic aromatic hydrocarbons (PAHs) found in RCA and MRA are about 4 mg/kg and 15 µg/kg, respectively, which is considered low but non-negligible, suggesting that a proper sorting of contaminated RA from non-contaminated RA is still needed.

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