Clean Technologies and Recycling

Clean Technologies and Recycling, 2(3): 165–169.
DOI: 10.3934/ctr.2022009
Received: 17 May 2022
Revised: 29 July 2022
Accepted: 22 August 2022
Published: 26 August 2022

http://www.aimspress.com/journal/ctr

Opinion paper

Is concrete produced by recycled aggregates from construction and demolition wastes appropriate for use in building industry?

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Abstract: The re-use of construction and demolition wastes (CDW) in concrete production gathers increasing interest in order to minimize the environmental footprint of the building industry. However, although its positive environmental impact seems evident, ambiguous literature data regarding the quality and safety aspects, raise doubts about CDW upcycling. The controversy seems to arise from the different materials and methods of construction and demolition used. Therefore, in order to reach an informed decision on whether concrete made using CDW can be usable, it is necessary to consider its physical, chemical, and mechanical properties and compare its technical and environmental performance to that of conventional concrete, taking into account specific materials and methods of construction.

Keywords: construction and demolition wastes; recycled concrete aggregates; waste management

1. Introduction

Because construction and demolition wastes (CDW) are normally produced in large amounts by the building industry, their recycling by using them as raw materials for concrete production seems to be of high priority. This is also confirmed by the current European legislation that sets a minimum target of 70% of CDW for recycling [1]. Although recycled concrete aggregates (RCA) produced from CDW are normally used in road construction, their use in structural concrete is still not a normal practice due to the market' suspiciousness.

Significant research effort has been spent in comparing conventionally produced concrete to that produced using RCA [2–6]. These studies are normally region-oriented, limiting their aspects of view in the performance of concrete, while chemical and mineralogical characterization of RCA is rarely included [7–10]. In general, the CDW-produced concrete was found to be of lower quality in terms of strength and durability, while, unfortunately, the ultimate environmental dimension of this approach has been neglected by the majority of these reports. Only a few studies are available focusing on the environmental impact of the production of recycled concrete leading to controversial results as far the environmental behavior is concerned [11,12], mainly due to the different regional data and production processes. In this paper, we are trying to evaluate the environmental impact when CDW are used for concrete production, taking into account their relatively lower performance in order to conclude on the exploitation potential of CDW by the Greek concrete industry.

2. State-of-the-art

In order to establish the differences between recycled materials and natural aggregates used in concrete production, we have performed a detailed experimental analysis in terms of chemical, physical and mineralogical properties of the samples that have been collected from recycling plants in Southern as well as Northern Greece. These samples were used as raw materials to produce concrete mixtures under laboratory conditions. The concrete mixtures were tested in terms of compressive strength, water absorption, sorptivity, freezing and thawing and carbonation resistance. The experimental procedure followed has been presented elsewhere [13] and its detailed discussion is out of the scope of the present opinion paper.

To summarize, concrete made by RCA was found to be of lower quality than normal aggregate concrete (NAC) for mixtures of 75%, 50% and 25% RCA, as the following Table 1 indicates. The values given in Table 1 represent the range of the experimental results using CEM IV 32.5N for producing C20/25 concrete. It must be noted that significantly better performance is measured when better quality RCAs are used. For example, up to 4% inferior strength can be overcome as a limiting factor for structural applications as it corresponds to only 1MPa in absolute values for the concrete class examined. Moreover, experience has shown that recycled aggregate concrete can be and has been used in constructions, such as pavements, where strength is not a critical factor [14]. Additionally, the environmental impact of the RCA concrete compared to NAC was studied. Life Cycle Assessment (LCA) was the tool used to perform comparisons. The environmental comparisons were made with Gabi Education Software using Greek manufacturers data for energy requirements. The functional unit (FU) is 1 m^3 of C20/25 concrete. The system boundary used was cradle to grave (from raw materials extraction to concrete waste landfilling). The avoided impact of concrete waste landfilling for recycled aggregate concrete has been taken into consideration. The CML method was used to calculate the specific environmental impact indicators: global warming potential (GWP_{100}; kg CO_2-eq), acidification potential (AP; kgSO_2-eq), eutrophication potential (EP; kg Phosphate-eq), human toxicity potential (HTP; kg DCB-eq). Results indicate a better environmental performance of the recycled aggregate concrete.

Table 1. Conventional vs. RCA-based concrete.

Property	Relative difference of RCA-based concrete with the conventionally produced (%)		
	75% RCA	50% RCA	25% RCA
Compressive strength [13]	−(8–37%)	−(7–26%)	−(4–24%)
Water absorption [13]	+(30–44%)	+(25–34%)	+(14–19%)
Sorptivity [13]	(−57)–(+52)%	(−63)–(+14)%	(−62)–(+12)%
Freezing and thawing resistance (relative dynamic modulus of elasticity)	−(85–90%)	−(86–87%)	−(78–87%)
Carbonation resistance (carbonation depths)	+(38–112%)	+(40–94%)	+(49–82%)
GWP_{100} (kg CO_2-eq)	−(1–8%)	−(1–5%)	−(1–3%)
AP (kgSO_2-eq)	−(1–14%)	−(1–9%)	−(1–5%)
EP (kg Phosphate-eq)	−(1–13%)	−(1–8%)	−(1–4%)
HTP (kg DCB-eq)	−(2–4%)	−(2–3%)	−(1–2%)

3. Discussion

Although literature data regarding the quantitative assessment of environmental indicators may vary the main conclusion is that RCA concrete presents similar or better environmental performance to that of conventional concrete. Comparable environmental improvement was determined when 70% of natural aggregates were replaced with recycled demolition materials from construction waste [15]. They found that GWP decreases by 5%, AP by 9%, and EP by 15% when reducing the transportation distance of materials from 100 to 50 km. Research conducted for France with 100% RCA concrete concluded that recycled concrete is friendlier to the environment [12]. Another study specifically in the Paris area found that 50% replacement of natural aggregates by recycled coarse aggregates had a lower GWP index value than conventional concrete [16]. On the other hand, a study conducted in New York concluded that conventional concrete and concrete with 100% recycled aggregates have the same environmental footprint [17]. Weil et al. compared normal aggregate concrete to 35% and 50% recycled aggregate concrete with different cement contents [18]. Their conclusion was that if the cement content is the same, the global warming potential is similar. Different reasons can be accounted for the observed discrepancies. In the first place the poor quality of some recycled aggregates imposes an increase in cement content to compensate for the quality of the concrete. Also, the different types of aggregates, construction and recycling methods used as well as the variability in scope definitions contribute to the variability of the results. For the same reasons the technical performance of RCA concrete presents similar discrepancy, justifying the doubts about its use. Our data indicate that the main factor for producing concrete with minor negative changes in physical and mechanical properties is the quality of RCA. For example, with high quality RCA the compressive strength decreased by only 8% even with 75% replacement whereas poor quality RCA led to a 37% decrease. In the former case the environmental benefits, as measured by the environmental indicators (reduction 8% in GWP, 14% in AP, 13% in EP) seem significant while in the latter negligible. Other benefits of recycling concrete can also be mentioned, that are not easily quantifiable: landfill saving from waste disposal, limitation of mining (especially in sensitive ecosystems such as riverbeds). To quantify the above-mentioned advantages in terms of the environment, it is necessary to proceed with process analysis tools (such as ANSYS supplied by

LCA data), thus achieving a more complete comparison of recycled concrete to the conventional one, considering different production and transportation scenarios of conventional and recycled aggregates. Moreover, a main issue to be addressed is how to set quality standards for recycled aggregates to minimize the need for increased cement content. On top of the environmental benefits, there are also crucial economic reasons to widely introduce RCA in the concrete industry. For example, the production and transportation costs are expected to be significantly reduced, especially for in-situ CDW recycling. However, the quantification of this remark is out of the scope of this paper.

4. Conclusions

To our opinion, primarily the environmental and secondarily the economic benefits of using RCA in concrete production are significant for the sustainability of the construction industry. The question is if it is significant enough to allow for the acceptance of the relatively lower quality of the product. The key issue is the quality of RCA. When compared with the conventionally produced concrete, the use of high-quality RCA corresponds to a product of comparable or slightly reduced quality (even for mixtures up to 75%), in terms of technical performance. The environmental avails, as estimated through the common environmental indicators, although not spectacular, are in certain cases significant. On top of that, the fact that the use of RCA will reduce the natural mineral resources depletion and the need for landfill areas, enhance the significancy of using RCA in concrete production. Obviously, a detailed analysis of concrete production in terms of environmental load per unit process is necessary, in order to further support this point.

Conflict of interest

The authors declare no conflict of interest.

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