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Concrete based on recycled aggregates – Recycling and environmental analysis: A case study of paris' region

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HIGHLIGHTS

- High grade recycled aggregates affects slightly the compressive strength of concrete.
- Improving the grade of RA, decreases the additional cement.
- The transport of aggregates has a great effect on global warming indicator impact.
- The use of RA in concrete is interesting, when the delivery distance of NA is high.
- The ecological profitability distance depends on RA grade and NA's delivery distance.

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ABSTRACT

The use of recycled concrete aggregates as an alternative source of coarse aggregates for the production of new concrete can help to solve the problem of depleting natural resources and that of growing waste disposal crisis. However, their recycling could decrease the concrete performance, particularly for low grade recycled aggregates (RA). To compensate for this decrease, cement content can be adjusted and hence, the environmental interest of RA has to be assessed. This study aims at assessing the environmental footprint of recycled aggregate concrete (RAC), compared to natural aggregate one (NAC), considering the grade of used RA and the aggregates' delivery distance, at the scale of Paris' region.

From the strength point of view, the use of RA induces a decrease of RAC performance, which is proportional to their content. This decrease can be compensated for by increasing cement content. For 50% of RA dosage, 16% of additional cement is necessary to achieve the compressive strength of NAC, when low-grade-RA are used (RA_1). Recycling high grade RA (RA_2 and RA_3), affects slightly RAC compressive strength and 3% of additional cement are enough to compensate for its decrease. Pre-saturating these RA, reduces by 35% the amount of additional cement.

From an environmental point of view, recycled aggregates can be an alternative for natural ones and the environmental footprint of RAC can be limited by using high grade RA. Furthermore, the delivery distance of NA is the key parameter in assessing the environmental impacts of RAC, compared to NAC. Results showed that global warming indicator impact is greater for NAC, compared to RAC with 50% of RA, provided that NA delivery distance exceeds 50 km, which is the case in Paris' region. With 20% of substitution rate, high-grade RA improve all environmental impacts of RAC, except *Waste*, compared to NAC.

1. Introduction

Over the past decades, the demand of natural resources has increased so much, as it is closely linked to the cities' development and their economic growth. Nowadays, this phenomenon becomes a serious threat to our economic and social equilibrium, which makes the sustainable development a major challenge, particularly in building and construction sector. Indeed, construction industry is one of the main consumers of raw materials, depleting the stock of non-renewable bulk resources and causing great production of construction and demolition waste C&DW). According to European Commission [1], this material represents a third (1 billion tons) of whole waste produced in Europe, each year. The produced volume increases yearly, particularly in developed countries, and huge amounts of wastes have to be managed in the future, challenging Scientifics and designers. Actually, large volumes of C&DW end in landfills, despite their recycling potential. Indeed, C&DW typically

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comprise large quantities of inert materials (concrete, bricks, wood, plastic, bituminous material, glass…), with smaller amounts of other components. Therefore, re-using/recycling these materials should decrease the environmental footprint of construction industry, solve the growing waste disposal crisis and in the same time stimulate Europe's transition towards a circular economy.

In this context, the European Waste Framework Directive 2008/98/CE required member states to take any necessary measures to achieve a minimum target of 70% of non-hazardous C&DW by 2020, *for reuse, recycling and other material recovery*. In its report of 2011 [2], the European Commission presented the progress in each member state: more than 70% Danemark, Germany, Netherlands…), 60–70% Austria, Belgium and Lithuania), lower than 40% Spain, Poland, Portugal…). In France, this rate was lower than 60%. To improve this rate, avoid landfill storage and preserve non-renewable resources, legislative proposals are recently enacted; the "Loi NOTRe" [3] and "Loi Transition TECV" [4]. The latter deals with circular economy and the sustainable economic development, with a minimum target of 70% of valorised C&DW, by 2020. Achieve this target is a real challenge, particularly in big agglomerations where the rapid growth resulted in enormous pressure on ecosystem. In Paris' region Paris and its suburbs), C&DW including excavated materials) represent 30 million tons in 2010 [5]. According to [5], 95% of C&DW are inert. 8 million tons of them come from building's demolition and 99% are non-hazardous. This waste production will increase greatly with "Grand Paris" project, aiming at building a sustainable city, with a production peak between 2018 and 2021 [5]. Otherwise, the yearly aggregate needs of Paris' region are on average 30 million tons, which amounts to 2.5 million tons per person, if we consider Paris and its suburbs 12 million persons). Actually, to cover these needs, 45% of aggregates are imported from other regions [6]. Thus, it is imperative to identify a new economic growth mode, promoting C&DW management and recycling, particularly in Paris' region where many recycling platforms exist (see Fig. 1. In this region, considered as dense-populated zone, three transport modes are considered; boat, railway and road. They represent respectively 26%, 8% and 66%. These rates are of 4%, 3% and 93% in France [7].

1.1. Literature review

Recent studies focused on new approaches for managing C&DW [8,9]. These wastes could be recycled and used as an alternative source of aggregates to produce concrete and solve the problem of depleting natural aggregates NA). However, their undesirable properties high water absorption, low abrasive strength) could reduce their use as a construction material. Indeed, recycled aggregate RA) is a heterogeneous material, composed of one or more aggregates of the original concrete surrounded by a mortar residue. This porous residue and its interface with the original aggregate are responsible for the decline in the properties of recycled aggregates compared to natural ones [10]. It represents 30–50% of whole aggregate [11–15], which decreases by approximately 0.3 the density of the latter and increases by 2–10 times or more its water absorption [11–13,16–31]. The properties of RA depend greatly on the properties of original natural aggregate [32] and those of parent concrete [33]. Their water absorption coefficient may range from 3 to 11%. This absorption depends on the amount of old mortar residue adhering to the original aggregate, which itself depends on the size of produced RA [15,17,29,34,35]. The absorption of recycled fines is close to 10%, while that of coarse/medium aggregates is around 5%.

Some authors [11,12,15,23–26,29–31,36] focused on the effect of residual mortar on the mechanical properties of RA and showed a decrease of Los Angeles and Micro Deval coefficients, respectively, by 25–76% and 67%.

As the key parameter is the attached old mortar, some research works attempted to decrease its porosity or remove it partially/completely. Spaeth and Tegguer [37] proposed a polymer treatment which supplies water repellent performance and improves physical properties of RA. The water absorption and Los Angeles coefficient of NA were achieved, when polymer treatment is applied on RA. Recent researches [38,39] investigated chemical (HCl, $C_2H_4O_2$, H_2SO_4, HNO_3) and thermal (250–750 °C) treatments to improve RA properties by removing, partially, the mortar residue.

For structural concrete, it is advised to use coarse RA. Their mortar content is lower, compared to recycled fines, which could be used in clinker production [40–42] and as sand [15,29,43,44].

The use of RA affects greatly the fresh properties of manufactured concrete. The high water absorption of these aggregates and their heterogeneity make difficult the control of concrete workability. When RA are used in dried state, they could induce an important decrease 70–89%) of concrete slump [30,35–45] and fresh density [46]. In contrast, Poon et al. [20] measured higher slump for RAC compared to NAC and explained that by the high quantity of free water when RA are used. The magnitude of fresh properties variation depends on RA source and composition [17,29–46] and the properties of parent concrete [48]. To achieve the required slump of NAC, RA could be pre-wetted/saturated [14,30–35] and a superplasticizer could be added to compensate

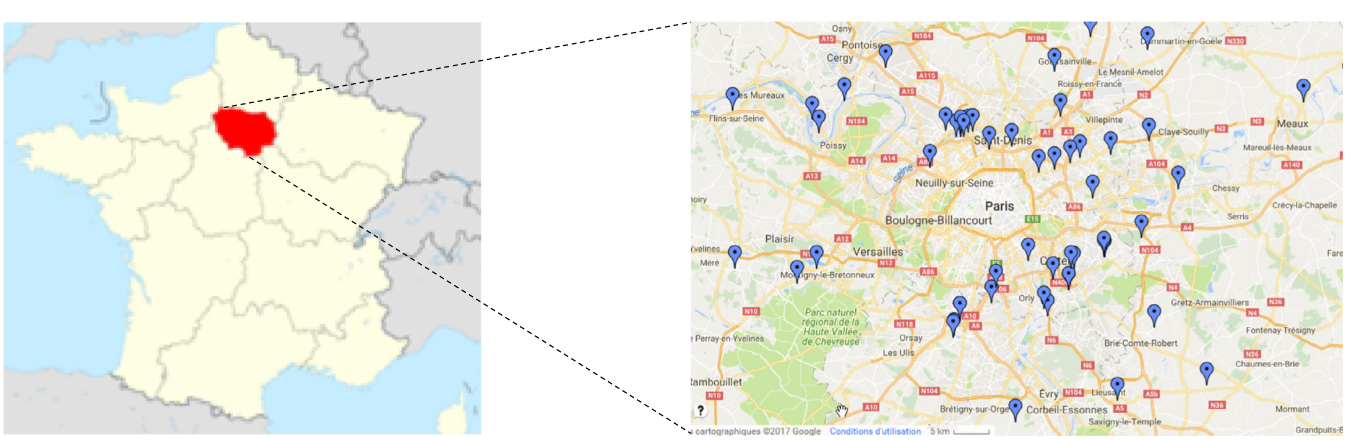

Fig. 1. Location of fixed recycling platforms in Paris' region (Google map).