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A FRAMEWORK FOR LIFE CYCLE ASSESSMENT OF CONCRETES WITH RECYCLED AGGREGATES IN LARGE METROPOLITAN AREAS

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Abstract

The use of coarse recycled aggregates (RCAs) obtained from crushing and grading of concrete construction and demolition waste (CDW) has been widely studied and commercialized in several countries. In the US, over 350 million tons of CDW is produced yearly; 140 million tons of which is concrete that is recycled and used primarily as road-base, fill and drainage material. Only a small portion of U.S. RCA is used in structural concrete, and then only in pavements. To make a compelling case for the use of these recycled materials in concrete, in addition to mechanical performance and durability of RCA concrete, the environmental impacts of replacing coarse natural aggregates (NAs) with RCA need to be investigated. These impacts are highly dependent on local conditions, local recycled material sources, aggregate production methods, transportation distances, and concrete mix proportions. The presented study focuses on the local conditions of New York City metropolitan area and utilizes Life Cycle Assessment (LCA) to compare the environmental impacts of using either natural or recycled aggregates in structural concrete.

Keywords:

Aggregate; concrete; LCA; RCA; recycled

1 INTRODUCTION

For decades the concrete portion of construction and demolition waste (CDW) has been processed into coarse aggregates, referred to as recycled concrete aggregate (RCA) (Fig. 1). RCA is usually used as a replacement for coarse natural aggregate (NA) (Fig. 2), i.e., crushed stone or gravel, for unbonded applications such as drainage filler and base material in road construction. RCA can be used in concrete as a replacement for NA. The construction codes in many countries, e.g., Germany, Switzerland and Spain allow the partial replacement of NA with RCA in structural concrete [1]. The main constituents of concrete are water, portland cement, coarse aggregate (typically crushed stone), and fine aggregate (sand). To determine if any of these constituents can be replaced with a new material, parametric studies are performed to compare the mechanical properties, durability, and cost of concrete with the conventional and new materials. Today, sustainable development and the impact of materials, during their life cycle, on the environment is of paramount importance. Landfilling regulations are becoming more stringent and green building certification programs such as LEED [2] are being widely used. Therefore, it is important to compare the environmental impacts of using alternative constituents in concrete. Some of the environmental benefits of using RCA as a replacement for NA are obvious. For example, production of NA requires the consumption of natural resources through mining, typically by using explosives. In some countries (e.g., Qatar) there is a shortage of rocks and NA is mostly imported. Moreover, recycling CDW leads to a reduction in the size of landfills. The above-mentioned benefits can be achieved regardless of the application for which RCA is used. The quality and cost of concrete aggregate is higher

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than the aggregate used in unbonded applications. It is therefore important to compare the environmental impacts of producing concrete with NA and RCA. For this purpose, life cycle assessment (LCA) must be performed, with a focus on the parameters that differ between NA and RCA concretes throughout their lifecycles. Few such comparative LCA studies have been performed in the past [3, 4]. The environmental impacts of concrete production depend on regional factors such as transportation distances and means, and the methods used for the production of the raw materials. This work presents a preliminary LCA study which compares the environmental impacts of producing NA and RCA concrete in the New York City area.

Fig. 1: Recycled concrete aggregate (RCA) graded as coarse aggregate.

Fig. 2: Crushed granite used as coarse natural aggregate (NA) in concrete.

2 METHODOLOGY

2.1 Goal and scope

The goal of this study is to determine the difference in the environmental impacts of producing the same volume of NA and RCA concretes with the same compressive strength in the New York City area. The total amount of concrete that can be made monthly using the RCA produced by the recycling plants in the New York City area with their full production capacity was used as the unit volume. In this study the New York City area is defined as an area of land within a circle cantered at Manhattan, NY with a radius equal to the length of Long Island (Fig. 3). The area has a high density of RCA and NA production plants that supply New York City.

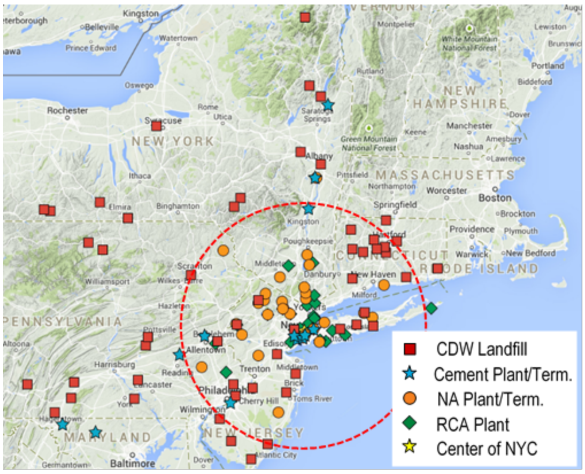

Fig. 3: The region investigated in the study.

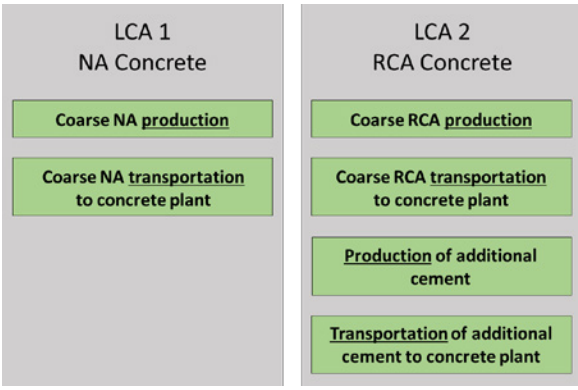

Fig. 4: The LCAs performed on the life cycle phases of NA and RCA concretes that are unique.

In this study only the environmental impacts of the stages of lifecycle that differ between NA and RCA concretes were measured and compared. Those stages are (1) coarse aggregate production, (2) transportation of coarse aggregates to the concrete production plant, and (3) production and transportation of additional cement. When NA is fully replaced with the same volume of RCA in a concrete mix the compressive strength of concrete can decrease by as much as 30% [5].

2.2 Assumptions

The following assumptions were made in this study:

(i) 30% of the CDW processed in an RCA plant is suitable for use as coarse aggregate in concrete. The remaining 70% is sold as unbonded aggregates and fillers. This assumption was made based on the findings

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from interviewing a number of RCA plants in the New York City area.

(ii) All the concrete consumed in New York City is produced at the centre of the city (Empire State Building), to which the aggregate and cement must be transported.

(iii) The only difference in the mix properties of NA and RCA concretes having the same compressive strength that influences the environmental impact is the additional cement in the RCA concrete.

(iv) Producing NA and RCA concretes in a concrete production plant has the same environmental impact.

(v) Both the NA and RCA concretes have the same durability, need for repair and maintenance, and the same period of service life. Therefore, the "use" or "service" period of concrete life cycle was not incorporated in this LCA.

Fig. 5 shows the transportation routes associated with the production of coarse aggregates and delivering them to a concrete plant. NA production plants are typically located in rock quarries or gravel pits and the transportation within the plant is minimal; the transportation is mainly associated with sending the NA to the concrete production plant. As for RCA, first the CDW must be transported from the construction or demolition site to an RCA Plant (T1). By doing so, the transportation of CDW to a landfill (T3) is avoided. The produced RCA is then transported from the RCA plant to a concrete production plant (T2). It should be mentioned that since 30% of the processed CDW is usable for concrete, to transport each ton of RCA from the RCA plant to the concrete plant, 3.3 tons of CDW is transported from a construction or demolition site to the recycling plant.

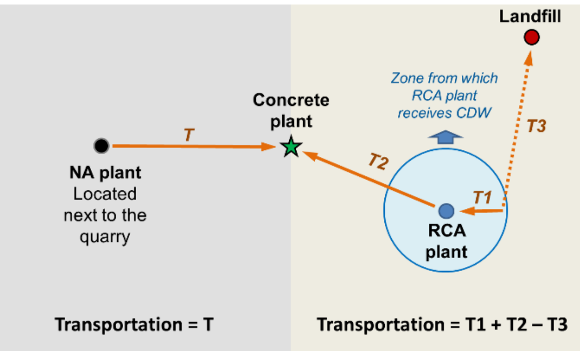

Fig. 5: Transportation required for producing and sourcing coarse aggregate.

2.3 Database and data collection

2.3.1 Transportation distances

The location of the main producers of NA and RCA and their distribution terminals in the New York City area were found. In addition, the main regional producers of cement that supply New York City were located. Also the CDW landfills that receive waste from New York were located. Some of the above–mentioned cement producers and landfills are not located in the New York City area. Some of them are in other states including New Jersey, Pennsylvania, and Connecticut. 28 NA production plants and terminals, 37 RCA plants, 14 cement producers/terminals, and 85 CDW landfills were identified. It was found that NA from many of the quarries is partially transported by barges (mostly on Hudson River). In the majority of the cases, the NA is shipped by barge to main distribution terminals in or close to New York City and then transported by truck to other distributors or directly to concrete production plants. The water and land transportation distances were distinguished as the two types of transportation cause different environmental impacts. To find a value for the transportation distance *T* (Fig. 5), and its water and land portions, the water and land transportation distances of all the NA plants to the centre of New York City were averaged. The distances for transporting cement and RCA to the centre of New York were calculated similarly. It was assumed that CDW, if landfilled, is sent to either of the two closest landfills to the RCA plant which is closest to the CDW source. Therefore, for each RCA plant, to calculate the distance for the alternative transportation of CDW to a landfill, the distance between each RCA plant and the two closest CDW landfills were averaged. *T3* (Fig. 5) was calculated by averaging all the above-mentioned alternative transportation distances. Managers of several RCA plants were interviewed to find the average distance between demolition sites and an RCA plant (*T1*). The distance of 48 kilometres (30 miles) was used for *T1*. Google Maps was used to identify the truck and water routes and find transportation distances.

2.3.2 Life cycle inventories

In this study, the LCA for NA concrete production incorporates three "processes": (i) NA production, (ii) transportation (of NA) by water, and (iii) transportation by truck. The LCA for RCA concrete production incorporates four processes: (i) RCA production, (ii) cement production (iii) transportation (of CDW, RCA, and cement) by truck, and (iv) transportation (of cement) by water.

A life cycle inventory (LCI) is a list of inputs and outputs, and their amounts for each process. The inputs consist of energy, raw materials and ancillary inputs. The outputs are the products, co-products, solid waste, emission to air, and discharge to water and soil. The amounts of the outputs from all the processes in an LCA is used by life cycle impact assessment (LCIA) methodologies to calculate values for different environmental impacts such as global warming potential (GWP).

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For transportation and cement production commercially available LCIs were used. Since a commercial LCI for RCA production was not available, data from the literature was used to compile LCIs for both RCA and NA production [6]. It should be mentioned that the data is collected from European aggregate production plants and, therefore, cannot accurately represent the emissions caused by aggregate production in the New York City area. For example, the machinery in some European plants use biofuel, which results in the emission of different gasses and particles, compared to the emissions from heavy fuels used in New York.

2.3.3. Concrete mix proportions

Many studies have been performed on proportioning NA and RCA concrete mixes to achieve the same compressive strength. There is a significant variation in findings on the additional amount of cement required for concrete with the full replacement of NA with RCA. For example for the type of RCA and mix design used by Knaack and Kurama [7] no additional cement was required. In the experimental study performed by Bai and Sun [8] the additional amount of cement required was 9% of the weight of RCA. In this study the mix proportions presented by Etxeberria et al. in which the amount of additional cement was 2% of the weight of RCA is used [9]; this additional amount of cement is also consistent with the findings from the preliminary investigations of the authors for the RCA in the New York City area.

2.3.4 Life cycle impact assessment

There are numerous methodologies for measuring different environmental impacts in an LCA. Each methodology defines a number of impact categories such as "Global warming" and "Eutrophication". In an LCA the magnitude of each impact category is calculated by multiplying the magnitudes of outputs from the LCIs of the processes in the LCA by the categorization (or weighing) factors defined by the methodology used for impact assessment. There are two types of impact categories; midpoint and endpoint (Fig. 6). Midpoint impacts can be quantified with a relatively high accuracy and have environmental themes such as climate change, acidification and human toxicity. Endpoint environmental impacts are more detailed and directly related to human health, natural environment, and natural resources. In this study the ReCiPe methodology [10] was used to measure three midpoint impacts often used by decision and policy makers: (1) climate change potential, (2) acidification, and (3) human toxicity. GaBi platform [11] was used for performing the LCAs.

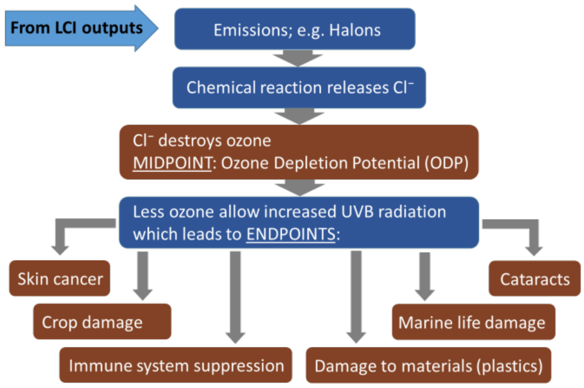

Fig. 6: Midpoint vs. endpoint impact categories. (From GaBi literature).

3 RESULTS

The results for the investigated midpoint environmental impacts from LCA of NA and RCA concretes are presented in Figures 7 to 9. Fig. 7 shows the results for the climate change potential, which is notably higher for NA concrete due to the higher emissions caused by transportation (by truck and water). One reason is that NA production plants, compared to RCA plants, are further from the centre of the New York City area. The other reason is the transportation of CDW to the landfills (T3, Fig. 5) is avoided when the waste is transported to the nearby RCA production plants. Fig. 10 shows that the avoided transportation of CDW to the landfills reduces the total environmental impacts caused by transportations *T1* and *T2* by 80%.

Fig. 7 shows that the additional cement used in RCA concrete has a clear impact on climate change. Therefore, if for another type of RCA or different mix design, such as those used by Bai and Sun [8], more additional cement is required for RCA concrete, the climate change potential caused by this type of concrete will be higher than that from producing NA concrete.

Fig. 8 presents the acidification impact results. Acidification is highly affected by water transportation and since in the New York City area RCA is transported only by truck the acidification impact of producing RCA concrete is significantly smaller than that of NA concrete. Fig. 9 shows the human toxicity results. Human toxicity is mostly affected by cement production and therefore the overall human toxicity caused by RCA concrete production is higher due to the additional cement used in this type of concrete.

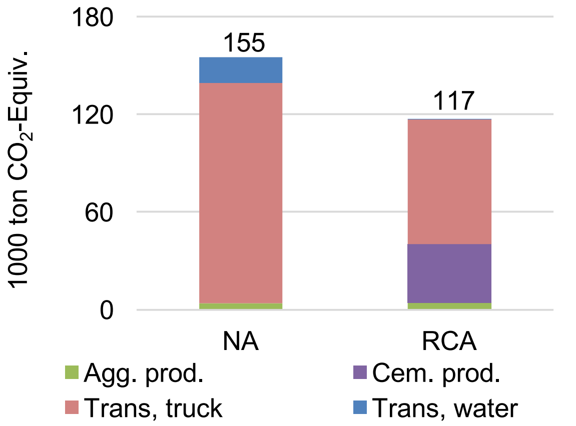

Fig. 7: Climate change potential from the LCAs of NA and RCA concretes.

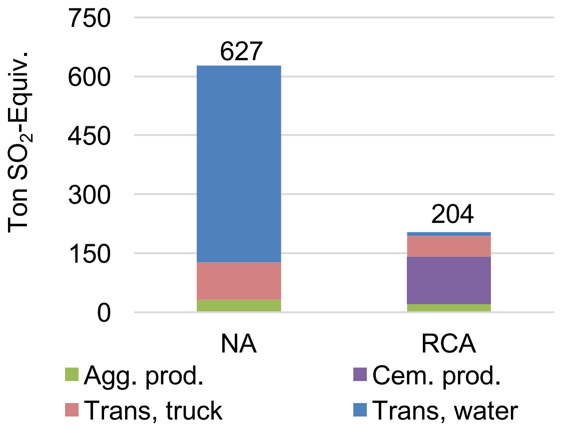

Fig. 8: Acidification impact results from the LCAs of NA and RCA concretes.

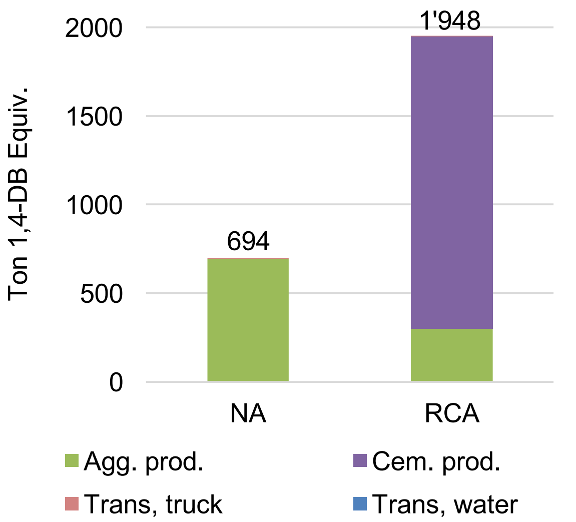

Fig. 9: Human toxicity impact results from the LCAs of NA and RCA concretes.

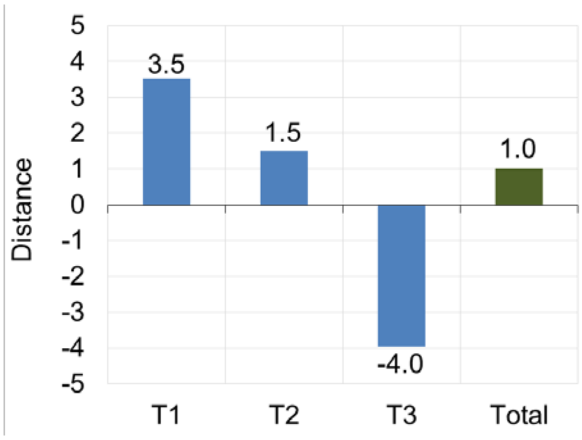

Fig. 10: Contribution of different stages of transportation for RCA concrete on environmental impacts.

4 SUMMARY AND CONCLUDING REMARKS

A life cycle assessment was performed to compare some of the main midpoint environmental impacts caused by producing the same volume of NA and RCA concretes with the same compressive strength in the New York City area. The LCAs consisted of only those phases of life cycles of NA and RCA concrete production that were different. Those phases are coarse aggregate production, transportation, and cement production. The results showed that transportation and cement production affected the studied environmental impacts significantly. Transportation by truck has the highest impact on climate change potential. The overall total transportation by truck for RCA concrete production is lower than that for NA concrete production due to the significant amount of transportation avoided by not sending the CDW to landfills. It was also found that the small additional cement used for RCA concrete production has a significant impact on human toxicity.

More detailed comparative LCAs with less simplifying assumptions should be performed for the production of RCA concrete in the New York City area. The location of concrete production plants in the area should be identified to calculate a more realistic total distance for the transportation of NA and RCA to the plants. In addition, since increasing the cement content in a mix changes the ratios of other constituents of concrete, performing an LCA that incorporates the processes of the production of all the constituents of concrete will lead to more accurate results.

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6 REFERENCES

1. J. De Brito, N. Saikia, Recycled aggregate in concrete, use of industrial, construction, and demolition waste, Springer2013.
2. U.S. Green Building Council. http://www.usgbc.org/leed. 2015).
3. S. Marinkovic, V. Radonjanin, M. Maleev, I. Ignjatovic, Comparative environmental assessment of natural and recycled aggregate concrete, Waste Manag. 30(11) (2010) 2255-2264.
4. C. Knoeri, E. Sanyé-Mengual, H.-J. Althaus, Comparative LCA of recycled and conventional concrete for structural applications, Int J Life Cycle Assess 18(5) (2013) 909-918.
5. A. Yazdanbakhsh, L.C. Bank, J. Rosen, Flexural strength of reinforced concrete beams incorporating coarse recycled concrete aggregate, ACI Special Publication, Technical Comittee 555. (2016).
6. A. Korre, S. Durucan, Life cycle assessment of aggregates, EVA025 -Final Report: Aggregates Industry Life Cycle Assessment Model: Modelling Tools and Case Studies (2009).
7. A. Knaack, Y. Kurama, Behavior of reinforced concrete beams with recycled concrete coarse aggregates, J. Struct. Eng. DOI: 10.1061/(ASCE)ST.1943-541X.0001118. (2014).
8. W. Bai, B. Sun, Experimental study on flexural behavior of recycled coarse aggregate concrete beam, Applied Mechanics and Materials 543 (2010) 29-32.
9. M. Etxeberria, A.R. Marí, E. Vázquez, Recycled aggregate concrete as structural material, Mater. Struct. 40(5) (2007) 529-541.
10. M.J. Goedkoop, R. Heijungs, M. Huijbregts, A. De Schryver, J. Struijs, R. Van Zelm, ReCiPe 2008, A life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level, Report I: Characterisation, First edition http://www.lcia-recipe.net (2009).
11. GaBi Software for Life Cycle Assessment. http://www.gabi-software.com/america/. 2015).