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Environmental evaluation of concrete made from recycled concrete aggregate implementing life cycle assessment

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ABSTRACT

Recycled concrete aggregates from demolition constitute one of the largest waste streams within the developed countries. These study aims to quantify environmental impacts associated with mixing compositions of concrete made of waste materials by using LCA. Environmental performances of natural, recycled and mixed 20-mm concrete samples, formulated with the same mechanical strength regarding the functional unit, were evaluated. Eight millimeter concrete samples, formulated with natural or recycled (concrete or terracotta brick) aggregates – with the same volume composition of the granular skeleton for apparent concrete application regarding the functional unit – were also studied. The LCA results are presented using various impact assessment methods, according to both EN 15804 and NF P 01–010 standards. Recycled samples present good environmental behavior, even if recycled materials (sand and aggregates) involve different operations (crushing against extraction, etc.). The terracotta 8-mm concrete sample presents low environmental impacts in comparison with the other 8-mm concrete samples. This sample exhibits a low aggregate density, which decreases transport impacts, and good mechanical strengths, which improves its lifetime.

1. Introduction

Building activity is requiring amounts of materials (such as gravel and sand) derived mainly from natural sources and is generating high quantity of wastes. The growing environmental concerns; the increasing footprint of landfills coupled with waste landfill costs; the quickly depletion sources of valuable natural aggregate in some developed countries, as well as waste storage limitation, inciting a reduction of the environmental footprint of waste treatments, are the driving forces promoting the recycling of concrete demolition wastes in new concrete. The recycling of these wastes and the solid waste stream are in this way considered important steps towards sustainable construction applications [1,2].

The abusive extraction of aggregates from natural resources has been highlighted at an international level, because of the depletion of quantity of primary resources in context of an awareness of the environmental protection [3]. The construction field is responsible for considerable waste flows within human society, as well as for the depletion of material and energy consumptions [4]. Recycled concrete aggregate used for construction can ease aggregate shortage problem and reduce both environmental pollution and ecological footprint [5].

It has been recognized that concrete manufactured using recycled concrete aggregate could have mechanical properties equal to the natural aggregate concrete provided that the parent concrete is of good quality [6,7]. However, manufacturing problems encountered limit their industrial use, mainly attributed to the high water absorption, the angular character of these aggregates, the particle size distribution of recycled sand [8] and to the substitution of natural sand by recycled sand [9].

During the last decade, there has been an increasing interest in assessing and measuring the environmental performances of cement and concrete [10–12]. Life cycle assessment (LCA), a standardized methodology (ISO 14040–14044), allows the evaluation of both material and energy flows, as well as environmental impact of products and processes over their lifecycle. LCA offers potential as a tool for qualitative and quantitative evaluation of the environmental advantages of a process, and for ranking processes according to cleanliness in the construction industry [13]. Papers which deal with environmental assessment of recycled concrete aggregate were published [14,15] and they were mainly focused on impacts of aggregate production *versus* waste treatment, without worrying about the nature and the origin of the aggregates. There is a published work in the specific area of environmental assessment of natural aggregate concrete and

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recycled aggregate concrete and their comparison [16,17]. It has been demonstrated (from Swiss data) that recycled concrete (RC) mixtures reduce the environmental impacts to about 70% of the conventional concrete samples impacts if co-products from the recycling process are not excluded from the scope, and cause similar global warming potential if additional cement and transport for RC are limited [16]. However, as it is often the case in the current literature, other LCA results (from Serbian LCI data) show that the impacts of cement and aggregate production phases are slightly larger for recycled aggregate concrete than for natural aggregate concrete, because a slightly larger amount of cement is required for recycled aggregate concrete in order to obtain the same compressive strength and same workability for both samples [17].

Thus, it seems interesting to evaluate the environmental impact of concrete materials with regards to the origin of aggregate content. Beyond materials, this is the global design of the construction structure which must be taken into account in order to appreciate its ecological behavior. Firstly, three 20-mm concrete samples have been studied: a traditional concrete, which was elaborated with natural aggregates; a recycled concrete, which was elaborated with recycled coarse aggregates and recycled sand; and a mixed concrete, which was elaborated with recycled coarse aggregates and natural sand. Secondly, 8-mm concrete samples which were manufactured with waste products (concrete or terracotta brick wastes) were compared to a natural aggregate concrete (gravel extraction).

2. Experimental procedure

2.1. Materials

Six concrete samples were studied (Table 1). They were manufactured using the EN 206–1 standard [18]. The recycled aggregates (coarse gravel and sand) come from recycling of demolition waste and they are produced in Alsace (France). The natural aggregates are silico-calcareous rolled rocks from a gravel pit based in Alsace. Three grading classes were delivered for natural aggregates: 0/4 mm, 4/8 mm and 8/16 mm, while one grading class (0/20 mm) was delivered for recycled aggregates, and grading selections have been completed to obtain the three following classes: 0/6.5 mm, 6.5/13.5 mm and 13.5/20 mm. Terracotta aggregates are issued from crushed waste bricks. From one grading class (0/20 mm), grading selections have been completed in order to obtain the following classes: 0/4 mm, 4/8 mm, 8/20 mm.

2.1.1. 20-mm Concrete samples

The constitution of the granular skeleton was established according to the Dreux–Gorisse method [19], with continuous grading curves. The densities of aggregates were considered for the formulation, with an identical volume of solid phase for all samples. Three 20-mm concrete samples were studied (Table 1). The composition is given in cube meter, with the aim to reach a concrete compressive strength class of C35/45. CEM I 52.5 N CE CP2 NF Portland cement was used for experimentation. The cement content was kept constant, *i.e.* 350 kg/m^3. The other parameters were fixed using the Dreux–Gorisse method and the Bolomey formula [20]. The traditional concrete will be considered as the referential concrete, consequently it was formulated without admixture. It is assumed that the water absorbed into the aggregate (recycled or not) will not affect the effective water.

For both recycled (RC) and mixed (MC) 20-mm concrete samples, a superplasticizer admixture (Sika® Viscocrete 5400 F) was used in order to increase the fluidity of the fresh concrete and thus to reach the desired workability (slump class S2). The admixture dosage, *i.e.* 0.75% of the cement mass for the MC sample and 3% of the cement mass for the RC sample, was found experimentally to reach a slump class S2 (50–90 mm of slump) according to the EN 206–1 standard.

2.1.2. 8-mm Concrete samples

Three other concrete samples, *i.e.* 8-mm concrete with a coarse aggregate size of 8 mm, were also studied (Table 1). The aimed application of these 8-mm concrete samples is apparent concrete, thus another formulation method was used, *i.e.* the volume composition of the natural aggregate concrete (NAC) was determined in order to reach a minimal concrete compressive strength class of C30/35, with a constant cement content (495 kg/m^3) and a fixed water content to reach a W/C rate of 0.5 (considering total water).

Table 1
Mixture composition of the samples used in this paper.

20-mm concrete samples (*size of the grain: 20 mm*)

Concrete	**Nomenclature**	**Natural sand**[a] **0/4 mm** kg/m^3	**Recycled sand**[a] **0/6.3 mm**	**Natural coarse gravel**[a] **8/16 mm**	**Recycled coarse gravel**[a] **13/20 mm**	**Natural fine gravel**[a] **4/8 mm**	**Recycled fine gravel**[a] **6.5/13 mm**	**Cement** (CEM I)	**Total water**	**Admixture**[b]
Traditional	TC	685	0	1065	0	111	0	350	194	Without
Mixed	MC	759	0	0	852	0	115	350	180	2.6
Recycled	RC	0	769	0	424	0	442	350	165	10.5

8-mm concrete samples (*size of the grain: 8 mm*)

Concrete	**Nomenclature**	**Sand** 0/4 mm kg/m^3	**Gravel** 4/8 mm	**Cement** (CEM II)	**Water**	**Admixture**[b]	**Aggregate density** g/cm^3
Natural	NAC	1100	742	495	247	Without	2.41
Brick [c]	BAC	1215		495	247	24.7	1.60
Recycled [d]	RAC	1067	770	495	247	4.9	2.38

[a] Natural aggregate density: 2.60 g/cm^3; recycled aggregate density: 2.35 g/cm^3.
[b] The Sika® Viscocrete 5400 F superplasticizer agent, produced by the Sika Company, was used.
[c] The recycled brick aggregate concrete (BAC) sample was formulated with recycled terracotta tiles.
[d] The recycled concrete aggregate concrete (RAC) sample was formulated with recycled sand as well as recycled coarse gravel.