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Potential Health Impacts of Use of Secondary and Recycled Aggregates in Building Materials

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ABSTRACT

In this study, we aim to develop a general methodology for the evaluation of health impacts of the use of secondary and recycled aggregates in building materials. Particulate matter (PM, i.e. dust) and heavy metals therein are considered the major risks to human health. The risks associated with the use of secondary and recycled materials will be assessed during 3 different life stages, namely a) the production of the building materials, b) the construction of buildings and infrastructure using these building materials and c) the use of the buildings after construction (i.e. small decorating and renovating actions).

Subsequently, the methodology will be tested in several case studies on building materials that contain secondary or recycled aggregates. Finally, on the basis of these results, the potential human health impacts related to the use of secondary and recycled aggregates as a replacement for gravel will be discussed for the Flanders region.

INTRODUCTION

The Flanders region of Belgium strongly depends on ever scarcer stream of primary resources. Therefore, a more sustainable use of primary and secondary raw materials is one of the top priorities of the Flemish government. Recognizing that natural resources are limited, the Flemish parliament voted the decree on surface raw materials in 2003 which defines the framework to come to a rational, sustainable exploitation of surface raw materials such as clay, sand and gravel in Flanders (BS 25.08.2003). To guarantee the availability of sufficient resources to future generations, both the exploitation and the use of valuable natural raw materials have to be optimised.

One mechanism to reach such an optimisation is the use of substitutes in applications where it is technically feasible and environmentally acceptable. At this moment, the Flemish Regulation on waste prevention and management [VLAREA] offers a legal framework for the use of several streams of "secondary raw materials", thereby decreasing the need for primary raw materials whilst at the same time protecting the environment (soil and groundwater). To qualify for use as a "secondary raw material", a secondary or recycled aggregate has to comply with stringent criteria with respect to leaching of metals like As, Cd, Cr, Cu, Hg, Ni, Pb and Zn. Moreover, the concentrations of specific organic pollutants have to be below certain values [VLAREA].

Although specific legislation for public health and guidelines for occupational health and safety do exist, the impact of the use of these secondary raw materials, like secondary and recycled aggregates, on human health are rarely assessed. In fact, there is not yet a clear-cut methodology available to assess the human health risks associated with the use of secondary raw materials. Such a methodology can prove particularly useful with the implementation of REACH in the European Union which makes the industry responsible for the burden of proof on the safe use of their secondary raw materials.

An important stream of primary raw materials are natural aggregates, i.e. the granular material used in construction. The most common aggregates of mineral origin are sand, gravel and crushed rock. Aggregates can be used as such in railway ballast or as armour stones, or they can be used as a raw material for the manufacturing of other vital construction products such as ready-mixed concrete (made of 80% aggregates), pre-cast products, asphalt (made of 95% aggregates), lime and cement. These natural aggregates can be replaced by either secondary aggregates (defined as secondary materials arising from industrial processes, so called by-products) or recycled aggregates (produced from processing material previously used in construction, e.g. demolition waste, etc).

Aggregates can be used in unbound applications (where the aggregate is used as such) and bound applications, where the aggregates are mixed with a binding agent, such as cement, bitumen or a substance that has binding properties, in contact with water, similar to cement to form products like concrete. Concrete is used in many types of applications for the construction of buildings and structures including the production of pre-cast structures and masonry units (e.g. brickwork, stonework etc). In the present study, only aggregates > 4 mm will be discussed, hence all fractions < 4 mm are considered a sand-fraction and are not included in further analysis. The focus is also on bound applications as they are considered high added-value applications but at the same time they can lead to greater human health risks. Often the secondary and recycled aggregates contain elevated levels of heavy metals compared to natural aggregates and exposure to these metals is considered the biggest risk for human health.

In this study, we aim to develop a general methodology for the evaluation of health impacts of the use of secondary and recycled aggregates in building materials. The risks associated with their use will be assessed during 3 different life phases, namely (a) the production of the building materials, (b) the construction of buildings and infrastructure using these building materials and (c) the use of the buildings after construction by doing small decoration or renovating activities.

The study consists of 4 major steps: (1) an inventory of secondary and recycled aggregates, their applications in building materials, and their total metal content (2) the development of a road map for the risk-assessment of the use of secondary and recycled aggregates, (3) a measurement campaign and (4) the development of a final conclusion regarding the use of secondary and recycled aggregates as a replacement for gravel in building materials in the Flanders region.

STEP 1: INVENTORY OF SECONDARY AND RECYLCED AGGREGATES AND THEIR APPLICATIONS IN BUILDING MATERIALS

The most important streams of secondary and recycled aggregates in Flanders comprise various iron and steel furnace slags, construction and demolition wastes (concrete, bricks, tiles, blocks, road surface etc.), E-bottom ash (bottom ash from burning coal to generate electricity) and MSWI (municipal solid waste incineration) bottom ash. Most up-to-date data on the quantities produced and the amounts being used in the construction industry are discussed in an ALBON report [Nielsen, 2008] on the use of alternative streams as replacements for primary resources.

According to this report, recycled aggregates (demolition waste) represent the biggest stream of used secondary raw materials in Flanders with 10,454,042 tons used in 2007 including both sand and gravel fractions. Most important aggregates within demolition waste are concrete rubble (2,761,000 tons), mixed concrete and masonry rubble (2,948,000 tons) and asphalt rubble (1,048,000 tons).

Secondary aggregates include non-ferrous metal slags like Pb-slags, Cu-slags and FeMo-slags; steel furnace slags like LD-slags (from the Linz-Donawitz process) and stainless steel-slags; MSWI-bottom ash and E-bottom ash. Their current use varies from 17,000 tons/year (FeMo-slags) to 165,000 tons/year (stainless steel-slags) in Flanders. Whereas the amount (in tons/year) currently being used is a small proportion of the total amount of recycled aggregates, they often contain several times more potentially harmful metals. A range of metal concentrations typically found in the various streams of secondary and recycled aggregates in Flanders is given in Table 1.

Table 1. Ranges of total metal concentrations typically found in the various streams of secondary and recycled aggregates in Flanders (VITO analyses).

(mg/kg ds)	As	Cd	Cr	Cu	Hg	Pb	Ni	Zn
	min max							
Pb-slag	340 401	23.1 23.3	1240 1590	4820 4990	<0.1	19600 21500	813 981	35300 41000
Cu-slag	<3.5 10.5	0.9 3.9	514 628	2480 4960	<0.1	2200 3820	192 482	10200 18000
FeMo-slag	4.1 15	0.12 0.26	41.4 799	180 357	<0.15 0.5	49.4 118	29.2 129	105 504
LD-slag	<2	<15	873 1045	13.7 20.4	<3	<3 6.3	<7 16.6	22.9 44.4
stainless steel-slag	<0.5 9.5	<0.12 1.86	2090 20700	32.9 249	<0.5	<0.6 20.4	637 7340	3.1 286
MSWI-bottom ash	6.8 19	1.6 28	264 746	1800 3610	<0.1	993 2620	61 323	1819 4850
E-bottom ash	14	<0.5	52	961	<0.1	60	15	1200
concrete rubble	5.3 10.5	<0.3 0.75	16 1600	12.5 65.8	<0.1 0.4	8.6 206	13.4 310	68.4 492
mixed concrete and masonry rubble	6.1 79.7	<0.3 2.11	30 286	15 223	<0.1 1.17	16 380	9.6 72.4	75 311
bituminous rubble	5.2 6.4	0.4 2	22.7 314	5.5 23.6	<0.1 0.16	10 46	14 219	41 160

Together with their ranges in metal content, the actual and potential use (in tonnes/year), also a list of possible applications (see below) is made. Clearly, different applications can lead to different exposure routes during the various life-stages of the building materials. For example, exposure to dust during the construction phase of a house when using bricks containing secondary or recycled aggregates will likely be much higher compared to the exposure whilst living in the same house (use phase). On the other hand, when the same secondary or recycled aggregates are used in ready-mix concrete, the exposure to dust during the construction phase will be minimal (wet versus dry).

In this study, 4 types of applications are considered, namely:

- ready-mix concrete,
- concrete products for road construction and infrastructure (CP for RI),
- concrete products for buildings and bricks (CP for BB), and
- asphalt

It is clear that not all aggregate streams will be used in all applications (Table 2).

Table 2. Overview of the use of recycled and secondary aggregates in various applications of building materials that currently exist in Flanders. (note: X = existing, N = non existing)

	Applications			
Aggregate	ready-mix concrete	CP for RI[1]	CP for BB[2]	asphalt
Pb-slags	X	X	N	N
Cu-slags	N	X	X	N
FeMo-slags	N	X	X	N
LD-slags	N	X	X	N
stainless steel-slags	N	X	X	X
MSWI-bottom ash	N	X	X	N
E-bottom ash	N	X	X	N
concrete rubble	X	X	X	N
mixed concrete and masonry rubble	N	X	X	N
bituminous rubble	N	X	N	X

[1]CP for RI: concrete products for road construction and infrastructure; [2]CP for BB: concrete products for buildings and bricks

Based on several selection criteria taking into account the metal contents and their potential toxicity, the total amount of the secondary or recycled aggregate currently and potentially used and the use of these aggregates in particular applications, a couple of ‘priority combinations’ were selected by an expert panel for further investigation. For these priority cases, several measurements were made during the 3 different life stages, namely the production of the building materials (production phase), the construction of buildings and infrastructure using these building materials (construction phase) and during the use of the buildings/infrastructure after construction (use phase). Real-time measurements of various processes are combined with exposure scenarios that are developed for each individual application (see STEP 2) in order to quantify the final overall risk of a particular combination of secondary or recycled aggregate in a specific application during a well-defined life stage.

STEP 2: DEVELOPMENT ROAD MAP FOR RISK ANALYSIS

The second step is the development of a general roadmap that can be used for the risk analysis for each of the possible combinations of secondary aggregate and application. Human exposure to heavy metals in secondary aggregates, considered the biggest human health risk in this study, is possible via direct inhalation or resuspension of the particles, but also oral ingestion of dust can not be excluded. Skin contact was considered less relevant as a potential exposure pathway.

The roadmap for risk analysis is applied to all 3 life stages mentioned above and for 4 different applications (asphalt, ready-mix concrete, products for road construction and infrastructure, and products for buildings). The **exposure assessment** from the one side and the **dose-response functions** from the other side form the cornerstones of the risk analysis.

Step 2A: Exposure Assessment

Important here is the identification of the potential exposure pathways and the exposure scenarios (duration of exposure, dose, etc…). Direct inhalation of dust and the metals therein is considered the most important exposure pathway in this study. A schematic overview of the methodology used to build the exposure scenarios is illustrated in figure 1.

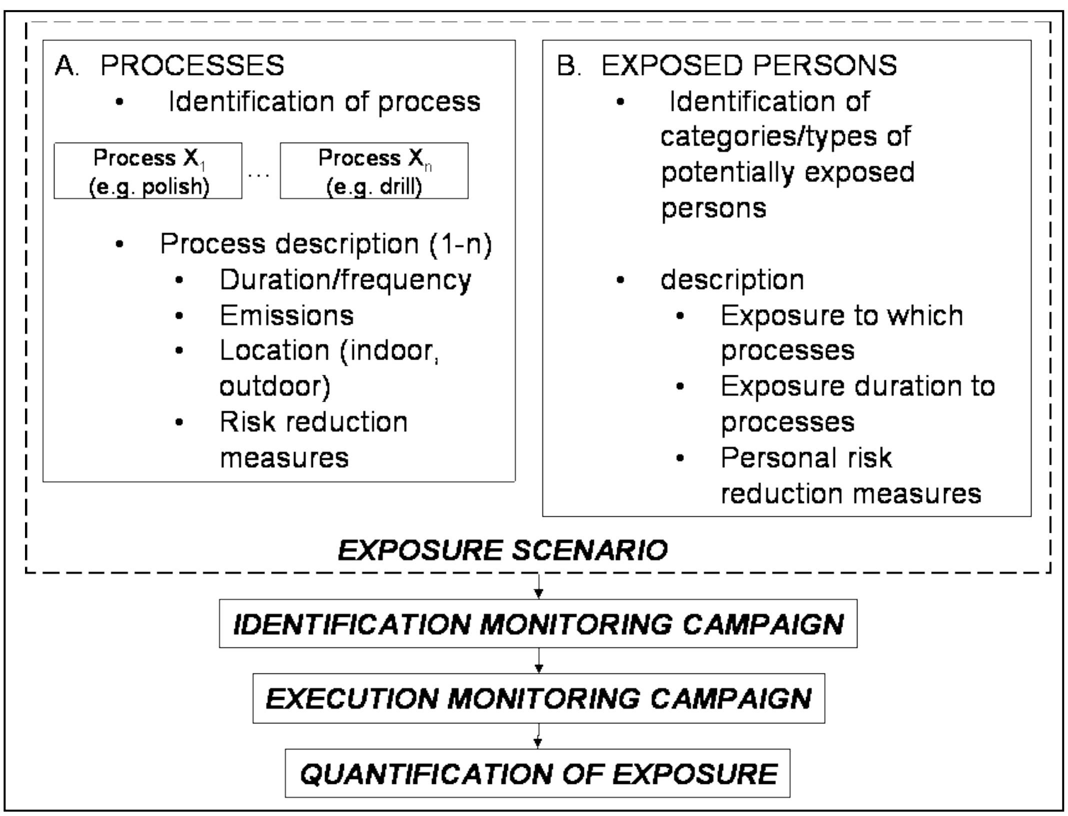

Fig. 1. Exposure scenario development

In this study, the first step in the risk analysis is the identification of the danger, or in this case, an assessment of the total metal concentration in the various building materials made using secondary and recycled aggregates. Several methodologies are investigated to quantify metal exposure to humans (workers/general public): personal monitoring/sampling, sampling at fixed locations, laboratory-controlled experiments and extrapolations based on the total metal content of the building materials. This information, in combination with detailed exposure scenarios, form the key to quantify the complete exposure to metals in dust during the several life stages of the building materials. In the exposure scenarios, the connections between the various processes, the conditions under which these processes take place (e.g. protection measurements taken or not, etc.), the exposed population and the duration of the exposure are described. Hence, for each of the applications, an exposure scenario is defined specifically for the production phase, the construction phase and the use phase.

Step 2B: Dose-response relations

To evaluate the final exposure compared to potential health risks, an inventory of dose-response relationships of the investigated metals is made. An overview of dose-response functions for inhalation for several metals is given in Table 3. Two types of dose-response functions are given: unit risk dose response functions for carcinogenic effects, and threshold values for non-carcinogenic effects.

For carcinogenic effects, the unit risk approach is applied since no safe thresholds can be derived for this type of effects. The unit risk expresses the number of extra cancer incidents in a hypothetical population in which all individuals would be exposed during their entire life to 1 µg/m³. For example, the unit risk for cadmium of 1.8 10^{-3} per µg/m³ means that if 1000 persons would be exposed during their whole life to 1 µg/m³ Cd, 1.8 persons would develop long cancer during their life due to cadmium exposure.

For non-carcinogenic effects, threshold levels below which no adverse health effects are expected can be applied for this type of effects. In general, higher thresholds are in place for workers in comparison to the general public because the former consists of a healthy, homogenous population, whilst the latter also includes sensitive groups such as small children, pregnant women and the elderly. The occupational exposure limits (OEL) of the Belgian legal framework on the protection of workers (ARAB) were selected for the evaluation of risks for workers exposed to metals present in secondary and recycled aggregates. In addition, the Belgian workers limit values were compared to OELs which are in place in other countries, and to limit values for workers derived by toxicological agencies (SCOEL, NIOSH, OSHA (data not shown).

A selection of limit values established by toxicological instances (WHO, ATSDR, EC, RIVM) were used for the evaluation of risks for the general public exposed to metals present in secondary and recycled aggregates.

Table 3. Overview of dose-response functions for inhalation for several metals.

	thresholds for non-carcinogenic effects					unit risk for carcinogenic effects
	workers		general public			workers and general public
	Belgian OEL		*threshold for inhalation (chronic exposure)*			
element	*(mg/m³)*	*time frame*	*mg/kg bodyweight/ day*	*reference*	*time frame*	per µg/m³
Ni metal	1	8h TWA	$5,71\ 10^{-6}$	EC, 2004	lifelong	$3,8\ 10^{-4}$
Pb metal	0,15	8h TWA	$3,6\ 10^{-3}$	WHO, 2000	lifelong	-
Cr^{3+}	0,5	8h TWA	$3\ 10^{-3}$	WHO	lifelong	-
Cr^{6+}	0,05 $	8h TWA	$7,14\ 10^{-8}$	ATSDR	lifelong	$4,0\ 10^{-2}$
	0,01 $$	8h TWA			lifelong	
Cd	0,002 *	8h TWA	$1,43\ 10^{-6}$	EC, 2005	lifelong	$1,8\ 10^{-3}$
Cu	1 *	8h TWA	$1,6\ 10^{-1}$	WHO/JEFCA, 1998	lifelong	-
As	0,1	8h TWA	$3,7\ 10^{-6}$	EC, 2004	lifelong	A
Zn	10	8h TWA	0,5	RIVM	lifelong	-

TWA: time weighted average, $: soluble, $$: insoluble,
A: thresholds for non-carcinogenic effects are protective enough for carcinogenicity due to As exposure (evidence fro threshold mechanism).

Step 2C: Risk Assessment

In this step, the exposure is referenced against dose-response functions. For non-carcinogenic effects, risk can be evaluated as acceptable if exposure is below OEL for workers, and below chronic thresholds for general public. For carcinogenic effects, risk is evaluated by comparison of the extra risk to develop cancer due to metal exposure against numbers considered as acceptable (10^{-5} for workers and 10^{-6} for general public).

STEP 3: MEASUREMENT CAMPAIGN

The results of a large measurement campaign are currently being assessed. During the measurement campaign, the general methodology described above is tested and improved where necessary. The campaign comprises of a characterization of the various streams of secondary and recycled aggregates (total metal content) and PM measurements (both levels of dust and their heavy metal content are measured) during real life situations (production and construction of building materials using secondary aggregates) and lab-controlled conditions (in order to mimic potential use and exposure conditions). Furthermore, control measurements are included at situations where only primary aggregates (gravel) are used.

Important to note is that several measurements are taking place in real work environments of existing companies and often confidentiality of the data is required. Therefore, data will be presented at the conference in a general way without references to either company or specific secondary or recycled aggregate.

STEP 4: EXPOSURE AND RISK ASSESSMENT FOR SELECTED CASE STUDIES

In this step, information from the exposure scenarios and measuring campaign is applied in order to assess exposure. Finally, on the basis of these results, the potential human health impact related to the use of secondary and recycled aggregates as a replacement for gravel will be mapped out for the Flanders region.

CONCLUSIONS

In this study, a general methodology has been developed to assess the potential health impacts of the use of secondary and recycled aggregates as gravel replacements in building materials. Direct exposure to dust and metals therein were considered the biggest human health risk for this particular case. Selected results and conclusions of the measurement campaign and the general roadmap will be presented and discussed at the conference in relation to potential human health impacts. The developed methodology can prove particularly useful with the implementation of REACH in the European Union which makes the industry responsible for the burden of proof on the safe use of their secondary and recycled aggregates.

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