Calculation method of stockpiling and use phase in road LCA: case study of steel slag recycling

O. Yazoghli-Marzouk
CEREMA, Direction Territoriale Centre-Est, Département Laboratoire Autun, Autun, France

M. Dauvergne
LUNAM University, IFSTTAR, IM, EASE, Bouguenais, France

W. Chebbi
LUNAM University, IFSTTAR, IM, EASE, Bouguenais, France

A.Jullien
LUNAM University, IFSTTAR, DAEI, Bouguenais, France

ABSTRACT: The environmental assessment of EAF-S recycling in road using LCA is investigated in this paper. Generally, in the LCA framework, the environmental assessment of recycling waste doesn't take into account the phases of life cycle corresponding to stockpiling and use, as they are considered to have no impact, only waste processing is counted. Thus, we propose to assess recycling of EAF-S in road considering the phases of processing, stockpiling, transport and use in road. The calculation of use phase based on results from percolation test is compared to its calculation based on Ecoinvent data (total content and a transfer factor), in order to seek if the results are in the same range or not and propose recommendation on the use of Ecoinvent data in case of lack of data for waste materials. The impact indicators calculated are: energy, global warming potential, ecotoxic and toxic potentials using Ecorcem and OpenLCA softwares.

1 INTRODUCTION

The past two decades, show a great interest in life cycle assessment applied to pavement sector [Santero et al, 2011 (a) and (b); Yu and Lu, 2012; AzariJafari, 2016]. Recently, several symposiums and workshops dealing with this area where also organized [Pavement LCA Workshop, 2010; 2012 RILEM Symposium on LCA for Construction Materials, Nantes, France; 2014 Pavement LCA Symposium, Davis, California and 2016 Development, standardization and implementation of LCA and integration with economics for transportation infrastructure and operations in SETAC Europe, Nantes]. These researches showed that when LCA is applied to pavement, the use phase was rarely considered in comparative LCA, as the emissions and energy flows were considered to be the same for the use phase. Moreover, many questions linked to the assessment of alternative materials actual engineering performances and to their effects on the environment in the context of use in pavement construction, are left with no satisfactory answers for the potential user. In fact, usually, the processes of materials production (primary production) are assessed by LCA practitioners and their production for recycling purposes (secondary production) is taken into account only through waste processing. The phases of life cycle corresponding to stockpiling and use are in general considered to have no impact counted in LCAs. However, rainwater may leach chemicals elements from alternative (and natural) material, such as heavy metals, metalloids, polycyclic aromatic hydrocarbons and salts, either during handling and stockpiling [Yazghli-Marzouk et al., 2012 and 2015; Proust et al., 2014] before recycling or due to infiltration through the pavement surface containing recycled materials [Mroueh et al., 2001; Olsson, 2005, Birgisdòttir, 2005; Yazghli-Marzouk et al., 2012; Proust et al., 2014; Schwab et al., 2014] that contribute to different environmental impacts. Hence, release to water from alternative materials is the important flux to study in LCA of alternative materials in road constructions.

In this paper, we propose to assess recycling of electric arc furnace slag (EAF-S) in pavement as a case study of alternative material recycling, considering the phases of production of steel slag (for recycling purposes), stockpiling, transport and use in pavement. The calculation of stockpiling and use phase based on experimental data (results from lixiviation and percolation tests) is compared to its calculation based on Ecoinvent data which take into account the total content (results from x-ray fluorescence) and a transfer factor (from Ecoinvent data base), in order to seek if the results are in the same range or not and propose recommendation on the use of Ecoinvent data in case of lack of data for waste materials.

2 METHODS AND MATERIALS PROPERTIES

2.1 *Methods*

Performing LCA as initiated by the SETAC [SETAC, 1993] involves two main types of underlying objectives, leading to:

- Compare products (or processes). In that case, chosen systems only include materials, processes and life cycle steps, that may induce differences between compared products (or processes);
- Provide environmental information (for public and/or private organizations). Here, chosen systems may be much wider.

According to some authors, LCA is also a diagnosis tool that enables to improve the global environmental profile of any system considered. It may be decomposed into successive levels that depend upon the authors: 1/ system description, 2/ elementary process, 3/ flux calculations, 4/ build the appropriate model, 5/ analyze and interpret the results and do the report. The system usually gathers all the elementary processes that are defined as the “smallest unit of the system” with inputs and outputs related to the industrial operation of interest [AFNOR, 2006].

Figure 1 indicates the scenario of interest and the processes considered in this study for alternative materials life cycle impacts assessment. The lack of data on EAF-S primary production (EAF-S production in steel plant) conduces to not consider it. The phases investigated are waste processing for recycling purposes, stockpiling (temporary stocks), transport and use in road.

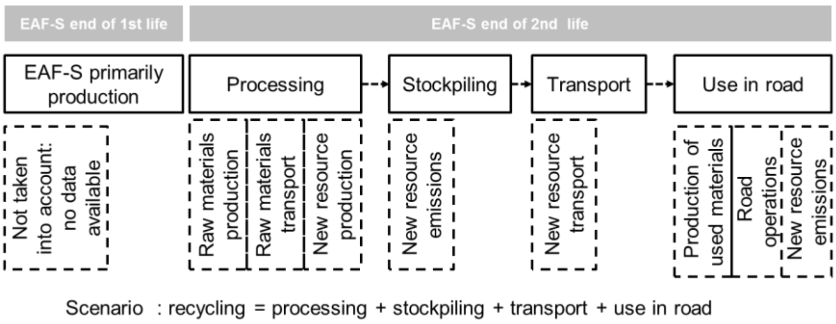

Figure 1. The scenario and processes investigated in this study.

The calculation of impact indicators, according to a model explained in a previous work by Sayagh *et al*. (2010), is described as:

$$Indj = \sum_i \alpha_{ij} \times C_{ij} \times m_i \quad (1)$$

where Indj = indicator associated with impact category j; αij = classification coefficient (from Goedkoop, 2001); C_{ij} = contribution coefficient of inventory flow i to impact category j; m_i = mass of inventory flow i (kg).

Each indicator is expressed in specific units per kilograms or tons.

The contribution coefficients selected from the literature and implemented for the impact calculations, based on Equation (1), and the chosen impact categories (and indicators) derived from classical LCA comprise all references given in [Sayagh et al.,2010]:

- Energy consumption: the specific energy consumption of each equipment (named CESP, as it is the French acronym for Specific Production-related Energy Consumption); Global Warming Potential (GWP), from IPCC (2001),
- Toxic and Ecotoxic Potentials (TP and EP), from Huijbregts et al. (2000).

As a reminder, during stockpiling and use phases [Yazghli-Marzouket al., 2012 and 2015; Proust et al., 2014] rainwater may leach chemicals elements from alternative materials. Therefore, in this LCA calculation, the output flux considered for EP and TP is release into water.

For stockpiling, release into water is simulated by leaching during six months. When a granular material is stockpiled, without compaction, its surface area in contact with water is important and close to leaching test. A duration of six months is considered as generally alternative materials are stockpiled for a short period due to lack of space.

For use phase, the structure simulated is a non-covered (by bituminous material) 10-15 cm thick road layer of EAF-S. The calculations proposed, at this phase, take into account construction operation, equipment working for road making and release of chemical substances from the alternative material into water for 100 years. Two calculation methods of EP and TP indicators at use phase are compared: calculation based on experimental data and calculation based on Ecoinvent data. In the first case, release of chemical substances to water from the waste is based on results from percolation tests, as this test simulates substances transfer through a layer of compacted granular material due to water infiltration. In the second case, release of chemical substances to water from the waste is based on calculation with a general Equation (2), where F_i (kg/kg of waste material) is the output flux of substance i, k_i is the transfer factor from Ecoinvent dataset and m_i is the total content of the substance i in the waste material determined by X-ray fluorescence.

$$F_i = k_i \times m_i \quad (2)$$

Hence, total content, leaching and percolation tests were performed on alternative material (EAF-S) to characterize water release and toxic and eco toxic effects. The leaching test is done on crushed aggregates according to NF EN 12457-2 (24 hours) [AFNOR, 2002]. The test consists of extractions of the material at liquid on solid ratio (L/S) equal to 10 by specific mixing. The percolation test is also done on crushed aggregates according to NF CEN/TS 14405 [AFNOR, 2005] at different L/S (0,1; 0,2; 0,3; 0,5; 1; 3 and 5). The cumulative values correspond to L/S equal to 10. The leachant is demineralized water and the particle size is inferior to 4 mm. The solutions obtained are then filtered (filter pore size 0,45µm) and analyzed to determine the concentrations in mg/kg of released substances. The total content of each element in the alternative material was done on crushed aggregate (particle size < 80µm) using NITON X-ray fluorescence spectrometer. This technique allows elementary analyses. Under the effects of X-ray beam, the sample comes into resonance and emits its own X-rays. On the spectrum obtained of the fluorescent X-rays, each peak (fluorescence emission) shows which element is present in the sample as the fluorescence emission is element-specific, and the peak height gives its quantity.

The distance of 30 km is considered for EAF-S transport as it is the mean distance in France for aggregates market.

2.2 *Material properties*

The tested alternative material is steel slag produced by an electric arc furnace (EAF-S). Its gap-grading analysis, according to EN 933-1 European standard (AFNOR, 2012), shows that it can be assimilated to a 0/1mm sand with a large amount of fines (32% of fines passing 63µm sieve size). Its physical characteristics are presented in table 1.

Table 1. Physical analyses of raw EAF-S

Elements	EAF-S
Real bulk density (t/m^3)	2.5
Natural water content (Wnat%)	18
Blaine specific surface area (cm^2/g)	5790

Chemical characterization of raw EAF-S shows (table 2) that it is composed of 70% by weight of siliceous oxydes of silicium, calcium, aluminum and iron. It also contains metals (cupper (Cu), nickel (Ni), chromium (Cr), molybdenum (Mo), vanadium (V), zinc (Zn)...).

Table 2. Chemical composition of raw and processed EAF-S (X-ray fluorescence).

Elements	Units	Raw EAF-S	Processed EAF-S
Silicon dioxide (SiO_2)	% by weight	32.9	ND
Titanium dioxide (TiO_2)	% by weight	0.4	ND
Aluminium oxide (Al_2O_3)	% by weight	8.1	ND
Iron oxide (Fe_2O_3)	% by weight	14.1	ND
Manganese oxide (MnO)	% by weight	1.5	ND
Magnesium oxide (MgO)	% by weight	3.9	ND
Calcium oxide (CaO)	% by weight	15.8	ND
Sodium oxide (Na_2O)	% by weight	0.2	ND
Potassium oxide (K_2O)	% by weight	0.8	ND
P_2O_5	% by weight	0.2	ND
Arsenic (As)	mg/kg	<100	42
Cobalt (Co)	mg/kg	275	0
Chromium (Cr)	mg/kg	18000	10706
Copper (Cu)	mg/kg	1040	208
Molybdenum (Mo)	mg/kg	589	502
Nickel (Ni)	mg/kg	1510	849
Vanadium (V)	mg/kg	426	228
Zinc (Zn)	mg/kg	399	205
Zircon (Zr)	mg/kg	1350	ND

ND: not determined

Table 3 shows one part of the results of percolation test on EAF-S after processing for recycling purposes. These data are used in EP and TP calculation

Table 3. Results of percolation test EAF-S after processing (cumulative results; Liquid/Solid=10) - ND means non determined

Elements	EAF-S after processing (mg/kg)
Arsenic (As)	$8,6\ 10^{-4}$
Chromium (total)	4.29
Copper (Cu)	$2.4\ 10^{-2}$
Molybdenum (Mo)	9.94
Nickel (Ni)	ND
Zinc (Zn)	0.01

3 RESULTS AND DISCUSSION

Table 4 presents the results of LCA calculation of recycling EAF-S in road considering processing of EAF-S for recycling purposes, stockpiling, transport and use in road. Use in road was calculated using experimental data (method 1) i.e. percolation data of EAF-S. In method 2 Ecoinvent data was used i.e. total content of EAF-S and transfer factor from Ecoinvent data base.

The contribution of use phase to EP and TP is important, whereas, the contribution of stockpiling phase is negligible, when release to water is controlled.

Furthermore, the results (table 4) show that EP and TP calculated with Ecoinvent data are fifty times higher than those calculated with experimental data.

Table 4. Comparisons of impacts range for recycling of EAF-S (400,000 tons) in road by calculation based on experimental data (1) and calculation based on Ecoinvent data (2)

Indicators	Energy MJ	GWP kg Eq CO_2	EP kg Eq 1,4 DCB	TP kg Eq 1,4 DCB
Transport (30km)	54	3.12	2.43	0.47
Processing	34.4	0.4	2.68	0.79
Stockpiling	0	0	0.33	0.006
Use in road (1)			49.9	1.08
Use in road (2)			2640	60.3

GWP: global warming potential, EP: ecotoxic potential, TP: toxic potential.

Arsenic (As), cobalt (Co), chromium (Cr), copper (Cu), molybdenum (Mo), nickel (Ni) and zinc (Zn) contribute to EP and TP indicators. As and Mo are the main contributors, as their coefficient of contribution are close to 1 for Mo et equal to 1 for As. In addition, their transfer coefficient at short term (100 years) is equal to 1. As total content of Mo is higher (502 mg/kg of EAF-S) than As (42 mg/kg of EAF-S), thus EP and TP seem to be driven by Mo content when they are calculated by method 2 (based on Ecoinvent data base). In this case, the calculation suppose that all Mo content is transferred to water.

However, when the calculation uses experimental data (percolation test) all the Mo is not transferred to water (9.94 mg/kg of EAF-S). The diffusion of Mo from its mineral bearing phases - iron silicates (FexSiyO4) and melilite which is a solid solution of akermanite (Ca2MgSi2O7) and gehlenite (Ca2Al[AlSiO7]) - identified in a previous study (Chebbi et al, 2016), is low in demineralised water.

Calculation by Ecoinvent data base seems over-estimate EP and TP. But studies of EAF-S percolation in other solutions, with pH close to pH field, should be implemented to confirm this observation.

4 CONCLUSION

This paper presents the study of the environmental assessment of EAF-S (electric arc furnace slag) recycling using life cycle assessment (LCA) by two methods. The first one use experimental data and the second one use Ecoinvent data base.

Usually, the phases of life cycle corresponding to stockpiling and use are in general considered to have no impact counted in LCAs. Thus, in this study we undertake the evaluation of stockpiling and use phases impacts of a waste (EAF-S) considering that the release of chemicals from the waste occurs during these phases and could be evaluated by EP and TP indicators.

The results obtained show that the environmental assessment of EAF-S recycling should take into account the life cycle phase corresponding to use in road as EP and TP exhibit important impacts, whereas the stockpiling phase shouldn’t be considered as its contribution to EP and TP is very low. In fact, even if recycling this alternative material is considered possible regarding local regulation, water may leach chemical elements during use phase by infiltration (percolation) through the road layer containing the alternative material.

Moreover, EP and TP seem to be driven by Mo content. When these indicators are calculated by Ecoinvent data base, all Mo content is supposed to be transferred to water, whereas experimental data show that a very low fraction is leached by percolation at laboratory conditions. Thus the results obtained using Ecoinvent data base overestimate environmental impacts. This result will be completed by other studies on different alternative materials, in the framework of OFRIR data base (http://ofrir.ifsttar.fr), where life cycle assessment (LCA) is now its main objective.

REFERENCES

AFNOR ISO 14040 (2006) Management environnemental – Analyse du cycle de vie – Principes et cadres, Environmental management -- Life cycle assessment - Requirements and guidelines, in: I.O.f. Standardization (Ed.), ISO 14040:33-46

AFNOR (2002). French standard NF EN 12457-2: Characterization of waste - Leaching - Compliance test for leaching of granular waste materials and sludges - Part 2: one stage batch test at a liquid to solid ratio of 10 l/kg for materials with particle size below 4 mm (without or with size reduction). AFNOR, 2002-12-01

AFNOR. (2012). Essais pour déterminer les caractéristiques géométriques des granulats - Partie 1 : détermination de la granularité - Analyse granulométrique par tamisage
AFNOR NF EN 12457-2: Characterization of waste - Leaching - Compliance test for leaching of granular waste materials and sludges - Part 2: one stage batch test at a liquid to solid ratio of 10 l/kg for materials with particle size below 4 mm (without or with size reduction). AFNOR, 2002-12-01
AFNOR CEN TS 14405: Characterization of waste - Leaching behaviour test - Up-flow percolation test (under specified conditions), AFNOR, July 2005
AzariJafari H., A. Yahia, M. Ben Amor 'Life cycle assessment of pavements: reviewing research challenges and opportunities', Journal of Cleaner Production 112 (2016) 2187-2197
Birgisdòttir Harpa "Life cycle assessment for road construction and use of residues from waste incinerator", PhD Thesis, Institute of environment and resources, Technical university of Denmark, July 2005, 60 pages
W. Chebbi, O. Yazoghli-Marzouk, A. Jullien, J. Moutte, "Valorization of steel slag in road construction - comprehension of molybdenum's repartition", International Journal of Advances in Mechanical and Civil Engineering, ISSN: 2394-2827, Volume-3, Issue-1, Feb.-2016, pp 61-64
Frischknecht R., Jungbluth N., Althaus H.-J., Doka G., Dones R., Heck T., Hellweg S., Hischier R., Nemecek T., Rebitzer G. and Spielmann M.. 2005. The ecoinvent database: Overview and methodological framework, International Journal of Life Cycle Assessment 10, 3–9.
Ifsttar. 2014. http://ecorcem.ifsttar.fr. Accessed 26 October 2015.
French standard NF EN 12457-2. 2002. Characterization of waste - Leaching - Compliance test for leaching of. granular waste materials and sludges - Part 2: one stage batch test at a liquid to solid ratio of 10 l/kg for materials with particle size below 4 mm (without or with size reduction). AFNOR. France, Paris
French standard CEN TS 14405. 2005. Characterization of waste - Leaching behaviour test - Up-flow percolation test (under specified conditions). AFNOR.
Goedkoop M., Spriensma R. (2001) The Eco-indicator 99, a damage oriented method for Life Cycle Impact Assessment, methodology report. *Pré Consultants B.V.* 132.
Huijbregts M.A.J., Thissen U., Guinée J.B., Jager T., Kalf D., Van de Meent D., (2000) Priority assessment of toxic substances in life cycle assessment. Part I. Calculation of toxicity potentials for 181 substances with the nested multimedia fate exposure and effects model USES-LCA. Chemosphere, 41: 541–573.
IPCC, 2007, Intergovernmental Panel on Climate Change. Fourth assessment report, climate change: the physical science basis. Chapter 2: changes in atmospheric constituents and radiative forcing. 106 pp".
Mroueh, U.M., Wahlström, M., 2001. By-products and recycled materials in earth construction in Finland—an assessment of applicability. Resour. Conserv. Recycl. 25 (1–2), 117–129.
Olsson Susanna "Environmental assessment of municipal solid waste incinerator bottom ash in road construction", September 2005, 34 pages. TRITA-LWR.LIC 2030; ISSN 1650-8629; ISRN KTH/LWR/LIC 2030-SE; ISBN 91-7178-151-X
Pavement LCA Workshop, Davis, California; (Harvey et al. 2011. Pavement life cycle assessment workshop, may 5-7, 2010, Davis, California, USA. International journal of life cycle assessment, 16 (9) 944-946
Pavement LCA Symposium, October 14-16, 2014, Davis, California, USA
Proust C., Yazoghli-Marzouk O., Ropert C., Jullien A., "LCA of roards alternative materials in various reuse scenarios", International Symposium on Pavement Life Cycle Assessment, October 14-16, 2014, Davis, California, USA
RILEM Symposium on LCA for Construction Materials, 2012, Nantes, France
Santero NJ, E. Masanet, A. Horvath 'Life-cycle assessment of pavements. Part I: Critical review », Resources, Conservation and Recycling 55 (2011) 801–809
Santero NJ, E. Masanet, A. Horvath "Life-cycle assessment of pavements Part II: Filling the research gaps", Resources, Conservation and Recycling 55 (2011) 810–818
Sayagh S., Ventura A., Hoang T., François D., Jullien A., 2010. Sensitivity of the LCA allocation procedure for BFS recycled into pavement structures, Resources Conservation and Recycling
SETAC Europe, Development, standardization and implementation of LCA and integration with economics for transportation infrastructure and operations in SETAC Europe, 2016, Nantes, France
SETAC (1993). Guidelines for Life-Cycle Assessment: a "code of practice". Ed. SETAC Foundation for Environmental Education, Florida 1993
Yazoghli-Marzouk O., Vulcano-greullet N., Cantegrit L., Friteyre L., Jullien A. (2014). Recycling foundry sand in road construction-field assessment. Construction and Building Materials, vol. 61, 69-78.
Yu B., Q. Lu, « Life cycle assessment of pavement: Methodology and case study", Transportation Research Part D 17 (2012) 380–388