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ENVIRONMENTAL PERSPECTIVES OF FINE GROUNDED CONCRETE POWDER: LCA CASE STUDY OF LIGHT-WEIGHT CONCRETE BLOCK

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Abstract. The construction elements produced with low demand for primary resources are being developed in the building industry. However, not only consumption of primary resources but also environmental impacts of such products should be considered to increase the sustainability of the construction industry. To investigate the environmental impacts of lightweight concrete blocks, life cycle assessment (LCA) was used as an analytical tool according to the EN 15 804 + A2. Firstly, the properties of fine grounded concrete powder (FRWC) were measured to declare functionality and potential to use of the considered product. Then, the lightweight concrete block containing FRWC was designed. The potential environmental impacts of the lightweight concrete block were assessed for the following phases: raw material production, transport of materials, production of concrete block, and end of life of the block. The considered system boundaries includes the production of fine grounded concrete powder, which was produced by recycling demolished concrete structures. The results were related to 1 tun of lightweight concrete block. Unsurprisingly, the calculated impact is mainly influenced by cement production. The total impact of the life cycle of 1 t of the lightweight block is 336 kg CO_2 eq. On the other hand, the lightweight block reached better results in the comparison with the Aerated Autoclaved Concrete block in most of the categories.

Keywords: Light-weight concrete, environmental aspect, LCA.

1. Introduction

During the design phase of a product, the equilibrium among three pillars of sustainability (environmental, economic, and social) is balanced. The environmental perspective is based on the natural limitation of our planet, which can be considered as a system with limited resources. In such a system with limited resources, the production of new products is limited without developing of circularity of materials.

The global circularity gap, the difference of materials consumed in the global economy and materials, which are recycled or reused, is more than 90 % [1]. Especially, construction and demolition waste represent almost one-third of European waste [2]. Moreover, the construction industry consumes more than 30 % of domestic material consumption in the Czech Republic [3].

To increase circularity, new construction products are being developed containing recycled content. This contribution describes the environmental performance of such a product, which was designed to use recycled concrete. One possible way, how to recycle concrete waste, is the production of fine grounded concrete powder. In comparison with processes, in which concrete is recycled to be used as recycled aggregate, this process due to fine grinding leads to the production of concrete powder with utilization as an admixture in the concrete mixture for lightweight concrete block.

To assess environmental perspectives of fine grounded concrete powder (FRWC), the case study considering the lightweight concrete block was conducted using Life Cycle Assessment (LCA) as a method to analyse environmental benefits and burdens caused by the life cycle of product or service. This method considers not only elementary flows of materials or elements and energies, but it also describes potential impacts, which can be caused by these flows in the environment.

The Life Cycle Assessment is standardized by ISO 14 040:2006 [4], which describes conditions for the assessment of products and services. The results of such assessment can be used for Environmental Product Declaration (EPD) [5]. The EPD for construction products is standardized by EN 15 804+A2 [6], which also states the method for characterization of environmental impacts.

In this contribution, LCA was used to assess environmental impacts related to 1 t of the lightweight concrete block. The assessed system boundaries include recycling of concrete and production of FRWC. The environmental performance of considered concrete block was compared with environmental impacts declared in the EPD of Aerated Autoclaved Concrete.

2. Materials and methods

2.1. Lightweight concrete block

The LCA study was conducted to assess the environmental performance of a lightweight concrete block containing fine recycled waste concrete (FRWC), which was used as a fine filler. The density of the block is 800 kg/m^3. The proportions of the block are as follows: 500 mm length, 250 mm height, 175 widths. The concrete mixture is described in the following table 1.

Materials	kg per t of blocks
Superplasticizer (SPL)	10
Cement I 42.5 R	331
FRWC	490
Recycled polypropylene fibres	8
Water	157
Foaming agent	7

Table 1. Description of materials used for 1 t of blocks.

Measured energy consumption in the process of preparing concrete mixture (mixing and foam preparation) was 15 kWh for the amount of concrete mixture used for the production of 1 t of blocks.

The fire resistance and mechanical properties of the mixture were improved by using 100 % recycled polypropylene fibres. According to their manufacturer (Trevos, s. r. o., Czech Republic), they have 32×10^{-3} mm in diameter and 4 mm in length. Other properties are following: average tensile strength, <3.0 cN/dtex ($\sim$272 MPa); average elongation, $\leq$50 %; density, 910 kg/m^3; Young modulus of elasticity, $\sim$4 GPa. The properties of concrete mixtures were improved by adding polycarboxylates as a superplasticizer (SPL).

2.2. Production of fine recycled waste concrete

FRWC was produced by crushing 100-years old concrete to a 0–32 mm fraction on the site of the recycling plant. As a by-side process, the steel scrap was removed from the crushed structure. In the following step, the crushed concrete was transported to the other recycling facility, where FRWC was produced by grinding of 0-1 mm fraction of crushed concrete using a high-energy electric mill (SBD 800 from Lavaris ltd.). The energy consumption of milling was estimated as 6.25 kW per milled tun of concrete. Moreover, steel spins are considered to have a high rate of wear and so, the amount of steel spins used for the production of 1 t is calculated as 0.27 g per 1 t of recycled concrete. During the milling, no losses of recycled concrete are considered. After milling, FRWC was transported to the plant, where concrete was prepared by mixing.

2.3. Environmental assessment

The environmental assessment was performed using the Life Cycle Assessment method [7]. This method is standardized according to ISO 14040 [4]. Based on this standard, the study was conducted in the four basic steps: goal and scope definition, life cycle inventory, life cycle impact assessment, and life cycle interpretation. These four steps are iterative and the results of each of them can be used for assessment, which will be more appropriate for the goal and purpose of the study. The core category rules for building products are standardized by the European standard EN 15 804 + A2 [6], which was applied in this study.

In this study, the goal was to assess the environmental impacts of 1 t of concrete blocks containing FRWC. The purpose of this study is to discuss the environmental burdens or benefits of using FRWC for the production of concrete blocks with similar utilization as aerated autoclaved concrete.

2.3.1. System boundaries

In compliance with EN 15 804 + A2, the system boundaries include the following phase of the life cycle of the block: mining of raw materials, production of materials (including recycled concrete), transport of materials, preparing of concrete mixture, and end of life of the product (EoL). The EoL phase includes deconstruction, transport of waste materials, and landfilling of construction waste. During the life cycle, the use phase of the block is not considered. The reference service life is assumed to be higher than 50 years.

2.3.2. Life Cycle inventory

Gabi Professional was used as software model to describe the boundaries of the system and to assess the functionality environmental impacts [8]. The model was used to describe elementary energies and materials flowing through considered system boundaries. In the following step, the potential environmental impacts caused by these elementary flows were assessed. For the creation of the model, specific data about the production of FRWC were used. To model the production of other materials, generic data from the Gabi database were used [9]. Also, generic data were used for models of unspecific processes such as transport using trucks, Czech electricity grid mix production, landfilling of construction waste, and diesel supply.

2.3.3. Life Cycle Impact assessment

In this step, elementary flows of described system are classified and characterized. Classification of elementary flows represents the assigning of the flow to the impact category in the case, that the flow has the potential to cause impact in that category. One flow can be assigned in several impact categories. In the

Non renewable energy resources	Total	Raw materials production	Transport	Production of concrete	End of life
Crude oil (resource)	2.12E+01	1.45E+01	1.31	3.24E-02	5.31
Hard coal (resource)	7.06	5.77	8.42E-03	6.39E-01	6.45E-01
Lignite (resource)	3.06E+01	2.42E+01	1.03E-02	5.70	6.60E-01
Natural gas (resource)	9.94	8.22	1.01E-01	2.54E-01	1.36
Peat (resource)	8.08E-03	6.95E-03	1.52E-04	7.88E-05	8.98E-04
Uranium (resource)	3.41E-04	2.45E-04	4.97E-07	8.52E-05	1.05E-05

Table 2. Consumption of non renewable energy resources during life phases of 1 t of lightweight concrete block (consumption in kg).

characterization, the potential impact of flow is calculated. The calculation is performed by multiplying of the amount of a flow by its characterization factor for each environmental indicator. Characterization factors are estimated by characterization models and in this study, characterization models were used in compliance with the EN 15 804 + A2. The calculated results of some environmental indicators represent the potential environmental impact in the category.

3. Results

Results of environmental assessment of lightweight concrete block containing fine recycled concrete powder are described in the following chapter.

3.1. Life cycle inventory outputs

The life cycle of the lightweight concrete block can be assessed based on the consumption of resources. In table 2, the energy resource consumption is described. Regarding consumption of crude oil, the processes related to transport in the life cycle are connected with lower consumption than raw material production. Moreover, natural gas consumption is significantly influenced by the end of life processes. However, the processes of raw materials production have the highest consumption regarding all of the considered energy resources.

3.2. Potential environmental impacts

In this study, environmental indicators according to EN 15 804 + A2 were applied to assess potential environmental impacts related to 1 t of the lightweight block. The results of this assessment are described in table 3.

The raw materials production phase is responsible for the biggest contribution to impacts in each impact category. However, the EoL phase has also a high impact in the category of Water use (1.70 m^3 world equiv.), which represents almost 21 % of the whole impact in this category. Similarly, the production of concrete contributes almost 20 % to the impact in the Ionising radiation category. This result is mainly influenced by the production of electricity for processes. Nevertheless, the production phase and transport processes cause negligible impact compared to the raw production phase.

4. Discussion

4.1. Contribution analysis

The contribution of each process was analysed to declare the processes with the highest influence on potential impact assessed for the life cycle of 1 t of the lightweight block. In table 4, the relative contribution of processes to impact in a category are declared. Categories Climate change – fossil, biogenic, and land-use change are not included. In the table, processes contributing more than 10 % of the total impact in each category are stated. Results of contribution analyses were conducted only with environmental indicators, which are characterized according to EN 15 804 + A2.

The concrete recycling process contributes beneficially to several impact categories. Unsurprisingly, recycling of concrete decreases the overall impact in the Resource use (mineral and metals) category. Moreover, the recycling of concrete cause a beneficial impact in the Water use category. On the other hand, the process, which is most contributing to several categories, is cement production. The impact of this process represents more than 80 % of impact in the Climate change (total) category. Also, it is significantly contributing to the impact in categories such as Acidification, Eutrophication, Photochemical ozone creation, Resource use (fossil), and Water use. The impact in these categories is also influenced by the contribution of landfilling process, which describes environmental impacts caused by construction inert material disposed on the landfill.

Superplasticizer production is another process, which affects the impacts of considered lightweight concrete blocks. This process, which represents the production of 10 kg of superplasticizers, contributes 96 % to ozone depletion and it significantly increases the results of three other impact indicators (Eutrophication freshwater; Resource use, mineral and metals; Water use).

4.2. Comparison of the lightweight block with an aerated autoclaved concrete block

The lightweight concrete block is intended to be a commercial product and so its environmental performance was compared to another block, which is available

	Total	Raw materials production	Transport	Production of concrete	End of life
Climate Change - total [kg CO_2 eq.]	3.36E+02	2.99E+02	4.47	9.76	2.31E+01
Climate Change, fossil [kg CO_2 eq.]	3.36E+02	2.98E+02	4.44	9.68	2.35E+01
Climate Change, biogenic [kg CO_2 eq.]	2.23E-01	6.44E-01	-5.29E-03	6.10E-02	-4.76E-01
Climate Change, land use and land use change [kg CO_2 eq.]	3.81E-01	2.19E-01	3.63E-02	1.30E-02	1.13E-01
Ozone depletion [kg CFC-11 eq.]	1.79E-06	1.79E-06	8.77E-16	1.19E-13	6.10E-14
Acidification [Mole of H+ eq.]	7.05E-01	5.13E-01	1.47E-02	2.25E-02	1.55E-01
Eutrophication, freshwater [kg P eq.]	3.70E-03	3.61E-03	1.32E-05	2.40E-05	5.05E-05
Eutrophication, marine [kg N eq.]	1.94E-01	1.32E-01	6.76E-03	4.45E-03	5.09E-02
Eutrophication, terrestrial [Mole of N eq.]	2.11	1.43	7.55E-02	4.64E-02	5.62E-01
Photochemical ozone formation, human health [kg NMVOC eq.]	5.75E-01	4.19E-01	1.33E-02	1.23E-02	1.30E-01
Resource use, mineral and metals [kg Sb eq.]	2.35E-04	2.31E-04	3.94E-07	1.45E-06	2.18E-06
Resource use, fossils [MJ]	2.14E+03	1.62E+03	5.91E+01	1.44E+02	3.13E+02
Water use [m^3 world equiv.]	9.66	7.78	4.12E-02	1.36E-01	1.70
Resource use indicators					
Use of renewable primary energy (PERE) [MJ]	3.07E+02	2.39E+02	3.40	3.14E+01	3.36E+01
Total use of renewable primary energy resources (PERT) [MJ]	3.07E+02	2.39E+02	3.40	3.14E+01	3.36E+01
Use of non-renewable primary energy (PENRE) [MJ]	2.14E+03	1.62E+03	5.93E+01	1.44E+02	3.13E+02
Total use of non-renewable primary energy resources (PENRT) [MJ]	2.14E+03	1.62E+03	5.93E+01	1.44E+02	3.13E+02
Use of renewable secondary fuels (RSF) [MJ]	1.64E-22	1.64E-22	0.00	0.00	0.00
Use of non renewable secondary fuels (NRSF) [MJ]	1.93E-21	1.93E-21	0.00	0.00	0.00
Use of net fresh water (FW) [m^3]	6.34E-01	5.27E-01	3.90E-03	4.64E-02	5.68E-02
Output flows and waste categories					
Hazardous waste disposed (HWD) [kg]	8.40E-04	8.40E-04	3.13E-09	3.16E-08	2.73E-08
Non-hazardous waste disposed (NHWD) [kg]	1.00E+03	2.78	9.31E-03	5.75E-02	1.00E+03
Radioactive waste disposed (RWD) [kg]	6.43E-02	4.37E-02	1.08E-04	1.82E-02	2.28E-03
Optional indicators					
Particulate matter [Disease incidences]	8.46E-06	6.67E-06	8.51E-08	1.71E-07	1.54E-06
Ionising radiation, human health [kBq U235 eq.]	7.52	6.05	1.57E-02	1.21	2.43E-01
Ecotoxicity, freshwater [CTUe]	1.10E+03	8.09E+02	4.39E+01	5.28E+01	1.97E+02
Human toxicity, cancer [CTUh]	7.65E-08	5.60E-08	8.87E-10	1.10E-09	1.85E-08
Human toxicity, non-cancer [CTUh]	5.00E-06	2.92E-06	5.24E-08	7.43E-08	1.95E-06
Land Use [Pt]	4.51E02	3.03E+02	2.03E+01	4.74E+01	8.09E+01

Table 3. Results of environmental indicators for the life cycle of 1 t of the lightweight block according to EN 15 804 + A2.

	Concrete recycling process	Cement (CEM I 42.5) production	Landfilling of construction matter	Polypropylene fibres production	Steel parts production	SPL
Climate Change - total	-2.83	80.94	4.39	5.31	0.31	3.30
Ozone depletion	0.00	0.00	0.00	0.00	3.01	96.04
Acidification	-1.32	61.45	15.28	3.33	0.76	5.52
Eutrophication, freshwater	0.13	3.43	0.69	0.87	11.84	80.51
Eutrophication, marine	1.28	55.09	14.41	3.60	0.62	3.74
Eutrophication, terrestrial	1.50	55.12	14.53	3.48	0.52	3.54
Photochemical ozone formation, human health	-0.08	60.15	14.74	4.73	0.52	4.84
Resource use, mineral and metals	-10.97	7.70	0.61	1.63	9.91	89.69
Resource use, fossils	-3.35	33.49	9.38	28.63	0.66	11.14
Water use	-24.03	28.51	16.77	1.50	5.14	58.59

TABLE 4. The relative contribution of processes (only processes with relative contribution higher than 10 % of total impact in a category are stated), %.

	FRWC Block	AAC
Climate Change - total [kg CO_2 eq.]	2.51E+02	2.32E+02
Ozone depletion [kg CFC-11 eq.]	1.43E-06	1.90E-03
Acidification [Mole of H+ eq.]	4.40E-01	6.28E-01
Eutrophication, freshwater [kg P eq.]	2.92E-03	2.35E-02
Photochemical ozone formation, human health [kg NMVOC eq.]	3.56E-01	1.03E+00
Resource use, mineral and metals [kg Sb eq.]	1.86E-04	2.69E-03
Resource use, fossils [MJ]	1.46E+03	1.79E+03
Water use [m^3 world equiv.]	6.37E+00	1.40E+01

TABLE 5. Comparison of the environmental performance of lightweight block with AAC block (results of A1-A3 modules.

on the market. To investigate products with similar properties and their environmental performance, the Environdec database was used as a database of products [10], which were assessed using LCA and their environmental performance was declared in Environmental Product Declaration according to EN 15 804 + A2.

To ensure comparability of products based on their functionality, the aerated autoclaved concrete (AAC) blocks were searched. The AAC produced by Gasbeton was selected as the most appropriate alternative [11]. The selected product is called Sysmic Idro (density 580 kg/m^3). The comparison of their environmental performance related to the 1 m^3 od product is presented in Table 5.

In most of the categories, the lightweight block reached better results than the AAC block. On the other hand, the AAC block contributes less to the impact in the category Climate Change. This comparison is limited by system boundaries. The environmental performance of the AAC block was calculated only in the cradle-to-gate scope, which includes only A1-A3 phases, so the EoL phase is not included in this comparison. The result of the FRWC block was calculated based on a measured density of 800 kg/m^3.

5. Conclusion

The LCA was performed for the lightweight concrete block. The environmental indicators were used according to EN 15 804 + A2 and so the results can be compared with another construction product with the same function. In the comparison with AAC, the lightweight block reached lower environmental impacts in most of the categories. On the other hand, the production of lightweight block caused a higher impact (251 kg CO_2 eq.) than the production of AAC (232 CO_2 eq.) considering the Climate Change indicator.

Unsurprisingly, the cement production influence mainly the result of the Climate Change (total) indicator. However, the recycling of concrete producing FRWC have a beneficial impact not only in this category (-9.41 kg CO_2 eq.) but also in the categories such as Resource use, mineral and metals (- 2.58E-05 kg Sb eq.) and Water use (-2.32 m^3 world eq.). Therefore, further research will be conducted to optimize cement reduction and increase the use of FRWC.

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