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A Comparative Study on Supplementary Cementitious Materials based Pervious Concrete Using Life Cycle Assessment

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ABSTRACT

Pervious concrete pavement greatly reduces surface runoff, help in the biodegradation of car oil, the infiltration of rainwater into the soil, and reduces urban heating. For usage in concrete flatwork applications, pervious concrete is a unique kind of concrete with high porosity that is created from a mixture of cement, water, coarse aggregate, and at least some fine aggregate. In order to allow water from precipitation and other sources to pass through and reach the underlying soil, pervious concrete provides a porous medium. It is typically utilized in parking lots, places with little traffic, residential streets, and places where people walk their dogs, among other places. This research focuses on the Life Cycle Assessment (LCA) of pervious concrete using Supplementary Cementatious Materials (SCM's) and their role in enhancing engineering features as well as the environmental effects of pervious concrete on environment. The material, construction, transportation, usage, maintenance, and end-of-life stages of a pervious concrete pavement system were all included in a comprehensive life cycle assessment (LCA). The possibility for eutrophication, energy consumption, and global warming were all considered in the impact analysis. Environmentally damaging effects include urban heat islands, an increase in infrastructure-related greenhouse gas (GHG) emissions and energy use, and runoff generation/flash floods during rainstorm events as a result of the conversion of pervious natural ground into impermeable pavement systems. Pervious concrete pavement (PCP) solutions, which have gained acceptability as sustainable substitutes for conventional materials, can be used to solve these issues. However, because to its lower strength and requirement for strict quality control during construction compared to conventional pavements, PCP technology is only used on low-traffic roads, sidewalks, and parking lots.

Keywords: Pervious concrete, Supplimentary cementious Materials(SCM's), Flyash , silica fumes, Life Cycle Assessment (LCA), Data base, Open LCA, Global warming potentials, Green house gases, Eutrophication.

1. Introduction

The assessment of how building materials impact the environment has become increasingly important in the effort to make construction more eco-friendly. Concrete, a vital part of our cities, is known for its significant environmental impact and resource consumption. To address these concerns, researchers and industry experts have explored innovative materials and processes, with one potential solution being permeable concrete, also known as pervious or porous concrete. Permeable concrete not only shares structural properties with traditional concrete but also offers improved water management capabilities.To thoroughly evaluate the sustainability of permeable concrete, this study uses the versatile Open LCS software as a key tool in the Life Cycle Assessment (LCA) process. LCA is a fundamental approach for assessing the environmental impacts of products, components, or systems throughout their entire life cycle, from resource extraction and production to transportation, use, and eventual disposal. By utilizing Open LCA software, the study aims to enhance the accuracy, transparency, and usefulness of its assessment, making valuable contributions to the discourse on sustainable construction.The examination of permeable concrete's life cycle is motivated by several factors. Firstly, this innovative material has great potential to address urgent urban challenges such as stormwater management. It also holds promise for mitigating issues like flood prevention and reducing the carbon footprint associated with traditional concrete.The following sections will delve into key aspects of the LCA process, providing more details on the chosen methodology, data collection methods, system boundaries, and selected impact categories. The life cycle stages of permeable concrete, from raw material extraction to disposal, will be thoroughly analyzed. This includes a detailed exploration of production processes, transportation, installation, usage, and maintenance, all within the context of sustainability.

1.1 Pervious Concrete:

Pervious concrete, also known as porous concrete, permeable concrete, no fines concrete, and porous pavement, is a special type of concrete with a high porosity that allows water from precipitation and other sources to pass directly through, thereby reducing the runoff from a site and allowing groundwater recharge. Pervious concrete is made using large aggregates with little to no fine aggregates. The concrete paste then coats the aggregates and allows water to pass through the concrete slab. Pervious concrete is traditionally used in parking areas, areas with light traffic, residential streets, pedestrian walkways, and greenhouses. It is an important application for sustainable construction and is one of many low impact development techniques used by builders to protect water quality.

1.Porosity: Pervious concrete contains a network of interconnected voids or pores that allow water to infiltrate through the surface and into the ground below. This feature distinguishes it from conventional impervious concrete, which causes surface runoff.

2. Stormwater Management: Pervious concrete is used to manage stormwater effectively. When rainwater falls on pervious concrete pavement, it infiltrates through the surface, reducing the volume and velocity of surface runoff. This helps prevent flooding and erosion and improves water quality by filtering out pollutants.

3. Environmental Benefits: Pervious concrete contributes to environmental sustainability by replenishing groundwater, reducing the heat island effect in urban areas, and lowering the risk of water pollution from stormwater runoff.

4. Applications:

- Parking Lots: Pervious concrete is commonly used in parking lots to manage runoff and reduce the need for traditional drainage systems.
- Sidewalks and Pathways: It is used for pedestrian walkways, where its porous nature can help prevent puddles and slippery surfaces.
- Driveways: Pervious concrete can be used for residential driveways to reduce runoff and flooding.
- Pervious Concrete Pavers: In addition to slab forms, pervious concrete is available in the form of pavers, which can be used in various hardscape applications.

5. Structural Considerations: While pervious concrete is porous, it still needs to meet structural requirements. Engineers and designers consider the appropriate thickness and strength for the specific application to ensure the pavement can withstand the intended loads.

6. Maintenance: Regular maintenance is essential to ensure the longevity and functionality of pervious concrete pavement. Maintenance activities may include vacuum sweeping to remove debris, occasional pressure washing to clear clogs, and resealing the surface as needed.

7. Material Composition: The composition of pervious concrete typically includes Portland cement, coarse aggregates, water, and sometimes supplementary cementitious materials (SCMs) like fly ash or slag. The specific mix design can vary based on project requirements and regional standards.

8. Permeability: The permeability of pervious concrete can vary depending on the mix design. It's designed to strike a balance between porosity for water infiltration and structural integrity.

9. Environmental Impact: Pervious concrete can be analyzed using Life Cycle Assessment (LCA) to evaluate its environmental impact compared to traditional concrete. Factors such as raw material extraction, production, transportation, and end-of-life considerations are assessed in LCAs.

Pervious concrete pavement is an important tool in sustainable urban development and water management. Its application can help reduce the adverse effects of urbanization on water resources and create more environmentally resilient and livable cities. However, it should be designed, installed, and maintained properly to achieve its intended benefits.

1.2 Life cycle assessment (LCA):

General

Life cycle assessment (LCA), sometimes referred to as life cycle analysis, measures the impacts on the environment associated with the life cycle of a product, process, or service. Each stage of a product's life cycle, including the extraction of raw materials from the environment, the manufacturing process, the usage phase, and what happens to the product after it is no longer in use, can have an effect on the environment in different ways. Life cycle stages refer to these phases of a product's life cycle. With LCA, you can assess the environmental effects of your product or service at any point along its life cycle, from the very beginning to the very end.

The product life cycle stages.

Life cycle studies can be performed for various scopes: cradle to gate (raw materials until factory gate), gate to gate (only focusing on the manufacturing processes) or cradle to grave (raw materials until disposal).

Four steps of life cycle assessment

LCA is a standardized methodology, which makes it reliable and transparent. The International Organization for Standardization (ISO) provides standards for LCA in ISO 14040 and 14044. These standards describe the four main phases of an LCA:

1. Goal and scope definition
2. Inventory analysis
3. Impact assessment
4. Interpretation

LCA is an iterative methodology, where you refine things as you go along. For instance, the first round of analysis may tell you that you need more data. Or the results of the assessment or your interpretation may nudge you to revise your goal and scope. In this sense, every LCA you do not only gives you valuable advice to make changes in your business but also tells you how to best plan your next LCA to learn even more.

Goal and scope definition

The goal and scope definition step ensures that your LCA is performed consistently. An LCA models a product, service, or system life cycle. A model is a simplification of a complex reality. As with all simplifications, this means that the reality will be distorted in some way. The challenge for an LCA practitioner is to make sure the simplification and distortions do not influence the results too much. The best way to do this is to carefully define the goal and scope of the LCA study. The goal and scope describe the most important choices, which are often subjective. For instance, the reason for executing the LCA, a precise definition of the product and its life cycle and a description of the system boundaries. The system boundaries describe what is taken into the assessment and what is left out. For instance, small amounts of ingredients that contribute little to the total footprint can be left out of the scope of the study. Thus, the system boundaries exclude this.

Life cycle impact assessment (LCIA)

In the life cycle impact assessment (LCIA), you draw the conclusions that allow you to make better business decisions. You classify the environmental impacts of all processes collected and modelled in the LCI and translate them into environmental themes such as global warming or human health. The most important choice you must make is how integrated you want the results to be. Would you like a single score to show how sustainable your product is? Or to be able to see whether your new design improves on CO2 emissions and how this impacts the land use? This usually depends on how you would like to address your audience and the ability of your audience to understand detailed results.

Inventory analysis of extractions and emissions

In the inventory analysis, you look at all the environmental inputs and outputs associated with a product or service. An example of an environmental input – something you take out of the environment to put into the product's life cycle – is the use of raw materials and energy. Environmental outputs – which your product's life cycle puts out into the environment – include the emission of pollutants and the waste streams for example. Together, this gives you the complete picture of the life cycle inventory (LCI). The LCI is all about collecting relevant data and modeling this data via inputs and outputs in a correct manner.

Life Cycle Interpretation phase:

In this stage of LCA, results from LCI and LCIA are interpreted in accordance to the stated goal and scope. This step includes completeness, sensitivity and consistency checks. Uncertainty and accuracy of obtained results are also addressed in this step.

2. Literature Review

Urbano et al. (2023) aims to conduct life cycle assessment (LCA) and discribed the environmental benfits of using emulsion-based cold recycled mixtures (CRM) based on life cycle analysis. This study also includes global warming potential (GWP), Energy requirement, and water consumption. [1]

R.Gettu et al.(2019) aims to conduct life cycle assessment (LCA) descibed the Scope and system boundries that are gate to gate and cradel to gate. The study involves energy demand and CO2 emission in formation of 1 tonne of clinker. In Ground-to-gate 850 kg of CO2 was emitted for 1 tonne of clinker,in Gate-to-gate it was observed 830 kg of CO2 was emitted for 1 tonne of clinker.[2]

Guoyang Lu et al.(2019)it was declared in his study that during the use of the pavement roughness will increase and greatly impact the vehicle fuel consumption and road Green house gases (GHG) emissions. The study in this paper presents a method to estimate impact of conventional pavement and permeable pavement on environment by using life cycle analysis .. It was observed that the PU (Polyurethane-bound) pavement explicit the least environmental impact.[3]

Onyelowe et.al (2022) aims the life cycle assessment (LCA) of fly ash-silica fume concrete with a focus on the global warming potential (GWP).Concrete's global warming potential in terms of CO2 may be calculated using CO2 using equation =1CO2+25CH4 +298N2O (Ma et al., 2016). Author used a database of 330 mix points.To study (Huijbregts et al., 2017) used ReCiPe Midpoint H to assess the impacts of the different concrete mixes from the 330 data points. calculate the GWP of different concrete mixes.This study showed that cement is the main reason to the GWP of concrete.[4]

Chen et.al(2019) evaluated some engineering properties, cost, energy and environmental impacts of three pervious concrete mixtures. The 3 mixes were regular Portland cement,Portland cement with fly ash and with blast furnace slag. In this stydy it was concluded that the pervious concrete mixtures with fly ash or slag have lower energy consumptions and GHG emissions than regular mix ranging from 14% to 22 % reduction.[4]

Avishreshth Singh et.al(2020)compared the environmental impact of pervious concrete pavement(PCP) and portland cement concrete pavement(PCCP) using life cycle assessment(LCA). Finally the study found that PCP has lower environmental impact than PCCP, with reductions in embodied energy and GHG emissions of up to 3% and 2.7%, respectively.However, PCP is slightly more expensive to construction than PCCP.[5]

Liu et.al(2020) aims to comprehensively evaluate the life cycle benefits of permeable pavement from the perspective of both the economic cost and the environmental impact. This case study aims at comparing the economic cost and environmental impacts of PA and DA with different traffic volumes

(2000 pcu, 5000 pcu, 10000 pcu) and pavement structures, and to evaluate the sustainability of PA (fully permeable pavement). From the perspective of equivalent evaluation, due to the environmental benefits, PA can be an optimal solution pavement pavement alternatives in the long run.[6]

Kourehpaz et.al(2019), has focused on mitigation of greenhouse gas (GHG) emissions. For this work, environmental impact assessments were conducted for cradle-to-gate production of concrete. The mixture resulting in the absolute lowest GHG emissions considered for this work also contained FA (just over 100 kg CO 2-eq/m3).It concludes that as clincker content increases the GHG emissions are increased.[7]

3. METHODOLOGY:

3.1 Life cycle assement approach:

1.Goal and Scope :

The goal of LCA is to quantify the environmental impacts of pervious concrete pavements designed for low traffic applications. For pervious concrete mixes, the functional unit is one cubic meter pervious concrete that has suitable hydraulic and mechanical properties for pervious pavement applications. The system boundary of LCA includes the stages of material, construction, maintenance, use, and end-of-life, as shown in Fig. 1. In this study the parameters considered are Green house gases emissions ,Carbondioxide emissions , Eutrophication potential, Terrestrial ecotoxicity, Acidification.

2. Life cycle inventory

The mix designs for 7 samples are designed manually and the database tool equipped is Eco-invent ecoinvent 3.9.1 LCIA Methods. And also AGRIBALYSE v3.0.1 database is used for the process contributions . The mix design of seven samples is shown in the table below, with the appropriate amounts of coarse aggregate, cement, water, and substituted waste material (fly ash, silica fumes).

3.Life Cycle Impact Assessment:

In the study, we used CML-IA baseline as one of the LCIA methods from the Eco-invent v3.6 database. Using the software, we quantify four environmental impacts from various LCIA approaches, including acidification, eutrophication, carbon dioxide emissions, and greenhouse gas emissions.

4.Interpretation :

This phase includes the results from the attempted LCIA methods. And also compare the results of all seven samples for each parameter individually and identify, quantify, check, and evaluate information from the results of the life cycle inventory(LCI) and the life cycle impact assessment (LCIA).

4. Conclusion:

We calculated a number of characteristics for the concrete mixes in the project, including FA20, FA35, FA50, SF20, SF35, and ordinary concrete mix. The possibility for global warming, ozone layer depletion, eutrophication, and terrestrial Extoxicity are the factors taken into account. Therefore, the results tend to decrease with an increase in fly ash content and recycled waste material for all blends and generally for all parameters, especially for global warming potential. The majority of emissions are caused by the standard concrete mix. The other characteristics vary according to the materials used as input. For eutrophication, the values fall for FA20, FA35, and FA50, whereas the values rise for SP20, SF35, and SF50. The same pattern is shown for terrestrial ecotoxicity. When it comes to ozone layer depletion, the trend rises briefly before dipping once more. This is concluding that as flyash content and recycled waste material grow, the related considerations taken into account decrease.

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