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Life Cycle Assessment of Concrete with Ferrock as partial replacement of cement

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Abstract: Due to the significant amount of cement used during the production process, concrete has a negative impact on the environment during its entire life cycle. The main constituents of Ferrock, a novel iron-based binding substance, are waste products. It is a carbon-negative substance with a compressive strength that is nearly five times greater than that of regular concrete. This study sought to compare the effectiveness of concrete incorporating Ferrock using the Life Cycle Assessment (LCA) technique. In the Kerala district of Palakkad, in the village of Pandaruthu, the LCA study was carried out. It was decided to conduct a manufacturing and transportation-focused cradle-to-gate life cycle analysis. The study's objective was to suggest Ferrock as a cement substitute that is superior in terms of durability and strength. This is done by doing a Life Cycle Assessment (LCA) on Ferrock and Ferrock concrete, and comparing the resulting environment profiles with those of OPC and regular concrete, respectively. Thus, it was possible to determine the emissions and energy requirements of Ferrock concrete and regular concrete. The analysis was carried out using OpenLCA software, the Ecoinvent database, and the Ecoindicator-99 impact assessment method. Additionally, laboratory studies are used to evaluate the strength characteristics of concrete containing Ferrock and determine the ideal ratio.

1. INTRODUCTION

Currently, one of the biggest risks to our eco system is global warming. Carbon dioxide accounts for the majority (76%) of greenhouse gases that cause global warming. Analysis of the gas's origins was done in an effort to reduce the overall percentage of carbondioxide emissions. The construction of multi-story or high-rise buildings, highways, bridges, skyscrapers, and other structures has increased linearly in this quickly evolving world due to the increasing emphasis given to infrastructure development. The cement utilised in this building is the most crucial component. Concrete's strength and endurance come from the cement used as the binding agent. It is a manufactured product with a 6–8% environmental impact since carbon dioxide was released during production. Despite the fact that cement comprises a far lesser portion of concrete than aggregates, it nevertheless has a significant carbon footprint. Supplementary cementitious materials (SCM) are frequently employed in concrete compositions as a substitute for clinker in cement or cement in concrete. With this technique, concrete is made more cheaply, sustainably, and with improved long-term strength and durability. One such substance that has less of an impact on the environment but better strength characteristics than regular Portland cement is Ferrock. Because Ferrock is made out of leftovers from many businesses, it is a carbon negative building material.

2. NEED OF THE STUDY

Due to its significant energy consumption and substantial carbon dioxide (CO_2) emissions, cement production is one of the main causes of environmental damage. The production of cement requires the burning of fossil fuels, which contributes significantly to CO_2 emissions, as well as the extraction of raw materials like limestone, which can result in the destruction of habitats. In addition, the process of making cement uses a lot of water and produces a lot of waste, including residues of heavy metals and air pollutants.

Ferrock is a viable solution with less of an environmental impact than conventional cement. Steel dust and other industrial leftovers are among the recycled elements used to create the form of concrete known as Ferrock. Ferrock contributes to minimizing the extraction of virgin resources and lowering landfill waste by using these waste materials. Ferrock stands out due to its capacity to capture CO_2 during the curing process. Ferrock's manufacture uses less energy than conventional cement, which reduces greenhouse gas emissions. Ferrock is a strong and long-lasting building material due to its increased strength and durability. But Limited studies have been conducted on Ferrock and this study aims to find out to what extent ferrock will reduce the harmful impacts of cement.

3. MATERIALS AND METHODS

Utilizing a set of guidelines and principles, Life Cycle Assessment is a tool for assessing the environmental effects of a process or product over a specified life cycle time. A life-cycle assessment (LCA) study analyses the emissions to the environment that result from the use of energy and materials along the industry value chain of the product, process, or service. LCA assesses potential environmental repercussions throughout time as a result. Keeping track of and improving the product's overall environmental profile is the goal. It is a useful technique for comparing sustainability based on how different products and processes affect the environment. International Organization for Standardization (ISO) has specified principles and guidelines for carrying out an LCA in its 14000 series of standards. There are various methods for carrying out an LCA study. For instance, environmental effects of manufactured products are evaluated from the extraction and processing of raw materials (cradle), through the production, distribution, and use of the product, to the recycling or final disposal of the materials that make it up (grave).A Cradle to Gate strategy is another option; it involves doing anything up until certain points or gates.

3.1 Goal and Scope Definition

The intended use, the justifications for conducting the study, the intended audience, or those to whom the study's findings are to be communicated, and whether the results are intended to be used in comparative assertions intended to be made public are all things that must be clearly stated when defining an LCA's goal. The following items must be taken into account and specifically mentioned when determining an LCA's scope: the product system under study, the useful component, System boundaries, LCIA methodology, and impact types, limitations and the appropriate interpretation. In this project, our goal is to conduct LCA of Ferrock and concrete with Ferrock as partial replacement of cement in concrete. LCA of ordinary Portland cement and Concrete will also be conducted. The results will be compared with each other to draw conclusions of environmental implications. Pandarathu (Pndth), a region located in Palakkad, in the state of Kerala is proposed to be analyzed in this project. A cradle-to-gate study, or evaluation of a portion of the product life cycle from resource extraction (the "cradle") to the factory gate (before it is shipped to the consumer), is proposed here. Raw materials processing is a part of this phase.

Cement, Ferrock, and concrete production, as well as transportation. This decision was inspired by the knowledge that, as various authors have shown, the production phase is the most pertinent in terms of environmental implications. The energy needed for the materials' processing and transportation is also included in the system's boundaries

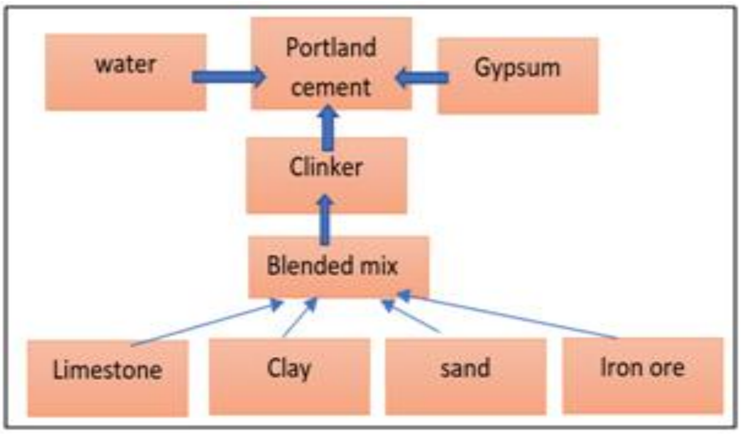

Fig 1.System boundary for Ordinary Portland Cement

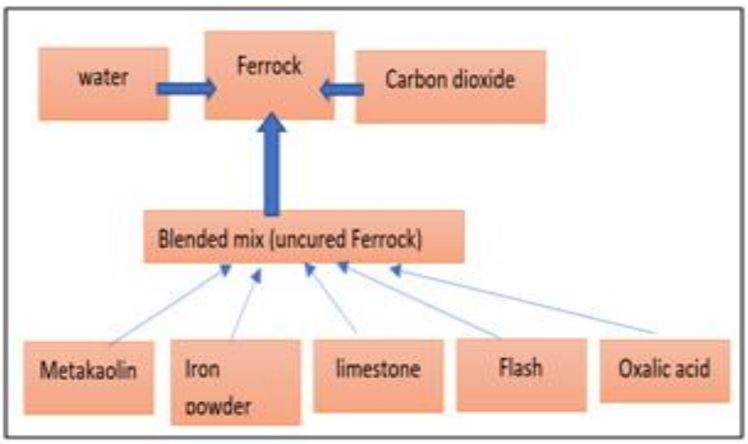

Fig 2.System boundaries for Ferrock production

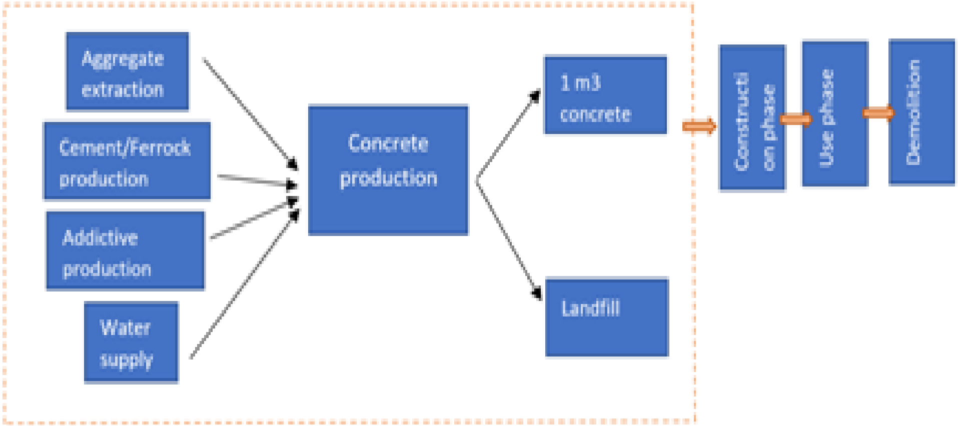

Fig 3.System boundary for Ferrock concrete and ordinary concrete

3.2 Inventory Analysis

Inventory analysis of Ferrock and cement was carried out. The data of raw materials required were collected and are tabulated as shown in Table 1 and Table 2.

Table 1: Raw materials inputs for 1m^3 of Cement production.

Material	**Unit(kg/m^3)**
Clay	232.416
Gypsum	102
Iron ore	21.6
Limestone,	2,332.96
Silicon dioxide	47.036

Table 2: Raw materials inputs for1m^3 of Ferrock production.

Material	**Unit(kg/m^3)**
Iron powder	1642.8
Flyash	547.6
Metakaolin	273.8
Limestone	219.04
Oxalic acid	54.76

All this necessary information can be obtained directly from the industries involved using detailed questionnaires or from publicly available annual environmental reports (ERs) and environmental product declarations (EPDs). Obviously, data from questionnaires will result in a more reliable LCI because ERs and EPDs will always hold a certain risk of misinterpretation and double counting. However, first hand data is not always provided by the companies because of confidentiality issues. As a consequence, the larger part of the LCIs are based on data from ERs, EPDs and LCA related journals. Therefore, it is understandable that ISO 14044 requires detailed documentation referencing for all public sources used. LCA databases (e.g., Ecoinvent) are seen as another important data source. . As data availability and quality are identified as critical problems affecting all four LCA phases, there is still an existing need for more peer-reviewed, standardized LCA inventory databases. The embodied energy values for various constituents for concrete was obtained from International Finance Corporation's (IFC's) India Construction Materials Database of Embodied Energy and Global Warming Potential – METHODOLOGY REPORT.

Table 3: Energy input for 1m^3 cement production

Resource	**Source**	**Transportation Distance to plant(km)**	**Truck Category**	**Distance travelled per MJ**	**Total energy MJ**
Clay	Kannur	200	16-28t	0.0473	9.46
Gypsum	Chennai	500	16-28t	0.0473	23.65
Iron ore	Koyilandi	175	3.5-16t	0.0944	16.52
Silicon dioxide	Ernakulam	150	3.5-16t	0.0944	14.16
Limestone	Pandarathu	10	28t	0.0473	0.473

Table 4: Energy input for 1m^3 Ferrock production

Resource	**Source**	**Transportation Distance to plant(km)**	**Truck Category**	**Distance travelled per MJ**	**Total Energy MJ**
Iron powder	Kanjikod	15	28t1	0.0473	0.7095
Flyash	Aluva	140	628t	0.0473	6.622
Metakaolin , Oxalic acid	Chennai	530	16-28t	0.0473	25.069
Limestone	Pandaruth	10	3.5-16t	0.0944	0.944

As data availability and quality are identified as critical problems affecting all. The data obtained from both of these steps contribute to the LCI phase. This data along with details of emissions from the various mixes make up the life cycle inventory of the mixes. The emission details including emissions of various compounds including CO_2, CO, NO_x, SO_x, CH_4, HC, N_2O etc. Any missing information and supplementary details were sourced from the Ecoinvent 3.7.1 database. The Ecoinvent database provides well documented process data for thousands of products.

Table 5: Emission/Output data for cement

Substance	**Amount(kg/m^3)**
Carbon dioxide, fossil	1296
Carbon monoxide	0.00111
Cement	1440
Hydrocarbons, unspecified	0.00058
Methane	0.00121
Nitric oxide	0.00775
Sulfur dioxide	0.0018

Table 6: Emission/Output data for Ferrock

Substance	**Amount(kg/m^3)**
Ferrock	2532
Carbon dioxide, fossil	-205.99539
Carbon monoxide	0.00069
Hydrocarbons, unspecified	0.0004
Methane	0.0018
Nitric oxide	0.0009
Sulfur dioxide	0.00082

All this data was then entered into OpenLCA. For the study, a project was first set up with all the processes involved in the manufacturing of cement and Ferrock. A process can be a part of a higher order process, can have other processes linked to it or can have its own sub processes each with its own flows and parameters. The sub-processes include extraction, quarrying operations, market for energy expenditure (market for diesel, electricity) etc. All these sub-processes were worked on first, branching into and out of the main process of cement, Ferrock production at the end. The effect assessment phase was launched when the Cement and Ferrock process networks had been fully configured with all necessary processes and flows, values from the LCI phase, and additional data from the Ecoinvent database. For Ferrock and cement concrete, similar inventory analyses were done. Data on the amount of raw materials needed was gathered (Dasan et al., Wijayasundara et al).

Table 7: Raw materials inputs for1m^3 of Ordinary Concrete production

Material	Unit(kg/m^3)
Cement	115
Fine aggregate	763
Coarse aggregate	1108
water	0.234
Plasticizer	53

Table 8: Raw materials inputs for1m^3 of Ferrock Concrete production

Material	Unit(kg/m^3)
Ferrock	415
Fine aggregate	763
Coarse aggregate	1108
water	0.234
Plasticizer	53

To determine the energy needed for transporting all the components in construction, Wijayasundara et al.conducted calculation based on the location of cement/Ferrock manufacturing plant, retrieval point of components and construction/LCA site.

Table 9: Energy input for 1m^3 cement concrete production

Resource	Source	Transportation Distance to plant(km)	Truck Category	Distance travelled per MJ	Total energy MJ
Cement	Pandarath	10	3.5-16t	0.0473	0.473
Fine aggregate	Vadakkancheri	60	28t	0.0473	2.838
Coarse aggregate	Nattukal	20	28t	0.0473	0.946
Super plasticizer	Coimbatore	50	3.5-16t	0.0944	4.72

Table 10: Energy input for 1m^3 Ferrock concrete production

Resource	Source	Transportation Distance to plant(km)	Truck Category	Distance travelled per MJ	Total energy MJ
Ferrock	Pandarath	10	3.5-16t	0.0473	0.473
Fine aggregate	Vadakkancheri	60	28t	0.0473	2.838
Coarse aggregate	Nattukal	20	28t	0.0473	0.946
Super plasticizer	Coimbatore	50	3.5-16t	0.0944	4.72

3.3 Impact Assessment

The hierarchical type of assessment, which is widely used and accepted, was chosen for the study. The product system was opened in OpenLCA software, and the impact analysis calculation was selected. The Ecoindicator-99 method was chosen as the impact assessment method for the study. The relevant indicator was selected from the menu, and the assessment was conducted. The results were summarized and exported to Microsoft Excel for a more comprehensive analysis. In Microsoft Excel, the obtained results were organized into 10 distinct sub-categories, which could further be grouped into 3 main categories. By examining the contributions of all the relevant flows, it was possible to identify the significant inventory elements that played a major role in each impact category.

Table11: Eco-indicators/Point scale values for ecosystem quality impact category

Causes	**Cement**	**Ferrock**
Acidification & Eutrophication	0.06170	0.07448
Ecotoxicity	0.03980	0.15964
Land occupation	0.041147	0.02871
Total	0.51297	0.26283

Table12: Eco-indicators/Point scale values for human health impact category

Causes	**Cement**	**Ferrock**
Carcinogenic	0.06301	0.31121
Climate change	0.06123	-0.35399
Ionizing radiation	0.00037	0.00062
Ozone layer depletion	4.42956E-5	0.00012
Respiratory effects	4.61569	1.11556
Total	4.74035	1.07351

Table13: Eco-indicators/Point scale values for Resource usage impact category

Sources	**Cement**	**Ferrock**
Fossil Fuels	0.44220	1.08446
Mineral extraction	0.03772	0.02955
Total	0.47992	1.11401

Now for Cement Concrete and Ferrock Concrete, assessing impacts on ecosystem quality, human health and resource usages, we get the following results.

Table 14: Eco-indicators/Point scale values for ecosystem quality category

Causes	Cement Concrete	Ferrock Concrete
Acidification & Eutrophication	0.51238	0.36369
Ecotoxicity	0.74737	0.73590
Land occupation	3.25139	3.83161
Total	4.5114	4.23240

Table 15: Eco-indicators/Point scale values for human health impact category

Causes	Cement Concrete	Ferrock Concrete
Carcinogenic	0.84808	0.82992
Climate change	0.52210	0.50445
Ionizing radiation	0.00383	0.00372
Ozone layer depletion	0.000054	0.00053
Respiratory effects	5.54460	3.53734
Total	6.91915	4.87597

Table 16: Eco-indicators/Point scale values for Resource usage impact category

Sources	Cement Concrete	Ferrock Concrete.
Fossil Fuels	5.67232	5.54488
Mineral extraction	0.12813	0.11726
Total	5.80044	5.66213

3.4 Interpretation Phase

The values obtained from LCA of both cement and Ferrock are plotted on a single graph for comparison (Fig 4).

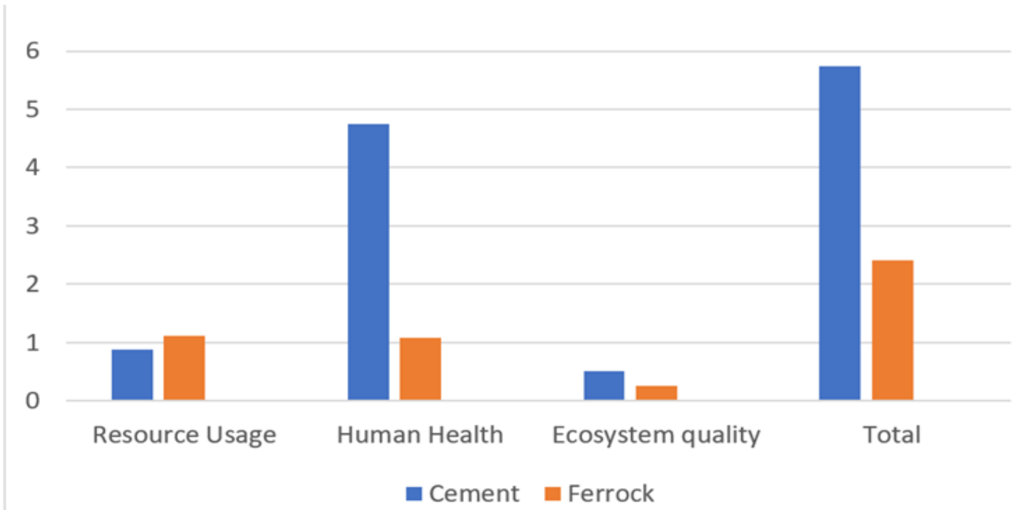

Fig 4. Comparison of environmental impact of cement and Ferrock

The values obtained from LCA of both cement concrete and Ferrock concrete are plotted on a single graph for comparison (Fig 5).

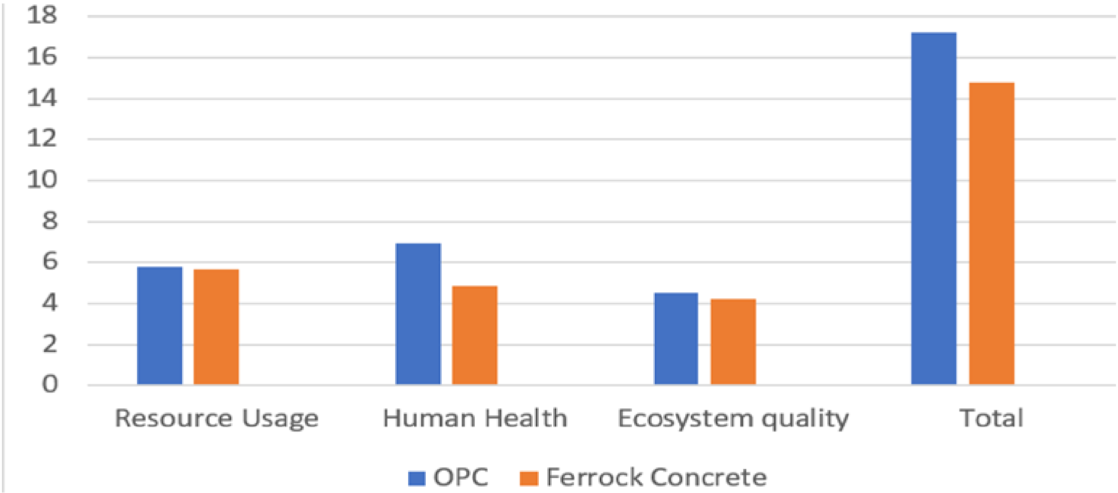

Fig 5. Comparison of environmental impact of Cement concrete and Ferrock concrete

Ferrock demonstrates a reduced environmental impact compared to cement, considering both ecosystem quality and human health impacts. Although Ferrock has slightly higher resource usage compared to cement, this can be attributed to limitations in accurately accounting for inputs as by-products or waste from other industries. However, when analyzing the total impact values, it becomes evident that Ferrock causes significantly less overall environmental impact than cement. Taking into consideration all impact categories, Ferrock concrete exhibits a lower overall environmental impact compared to cement concrete.

4. CONCLUSION

Concrete is currently the most widely utilized construction material, with approximately 25 billion tons produced globally each year, equivalent to over 3.8 tons per person annually. However, the use of Ferrock as an alternative to cement concrete offers environmental benefits by reducing carbon emissions and utilizing waste materials. The present study focused on investigating Ferrock as a substitute for cement concrete and concluded that Ferrock has a lower environmental impact than cement, as determined through life cycle assessment (LCA). The adoption of Ferrock has the potential to yield long-term benefits and even contribute to addressing global issues such as ozone layer depletion and the occurrence of diseases like cancer. Nonetheless, it is important to acknowledge the limitations and drawbacks of tools like Ecoinvent, Ecoindicator-99, and the LCA process as a whole, which can lead to skepticism regarding the study findings. LCA, being a simplified model of the real world, relies on assumptions and scenarios, as does the Ecoinvent database, where some data may need to be estimated or inferred from previous scenarios. This inherently introduces variation in the results. Additionally, the scope of the study may have overlooked certain impacts that another LCA study might have considered, further contributing to result variability. The present work specifically focused on investigating the use of Ferrock to enhance the strength of materials when employed as solid blocks.

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