LIFE CYCLE ASSESMENT OF SUSTAINABLE GEO-POLYMER CONCRETE INCORPORATING ALCCOFINE AND SUPPLEMENTARY INDUSTRIAL WASTE MATERIALS

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***Abstract*—The environmental burden associated with Ordinary Portland Cement (OPC) production necessitates the development of low-carbon alternatives for sustainable construction. Geopolymer concrete (GPC), synthesized using industrial by-products, offers significant potential for reducing greenhouse gas emissions. This study presents a comparative life cycle assessment (LCA) of sustainable geopolymer concrete incorporating Alccofine and supplementary industrial waste materials. including fly ash and ground granulated blast furnace slag (GGBS)The LCA was conducted in accordance with ISO 14040 and ISO 14044 standards, adopting a cradle-to-gate system boundary encompassing raw material extraction, processing, transportation, and concrete manufacturing stages. Environmental impact categories such as global warming potential (GWP), cumulative energy demand, acidification potential, eutrophication potential, and abiotic resource depletion were evaluated using a recognized life cycle impact assessment method. The environmental performance of geopolymer concrete was benchmarked against conventional OPC-based concrete of equivalent strength grade. The results reveal that geopolymer concrete incorporating Alccofine and industrial waste materials achieves a significant reduction in GWP and embodied energy relative to OPC concrete, primarily due to the elimination of clinker production and effective utilization of industrial by-products. However, the manufacture of alkaline activators contributes notably to the overall environmental impacts. The inclusion of Alccofine enhances binder reactivity and mechanical performance, enabling optimized mix designs with improved sustainability. The findings confirm that Alccofine-based geopolymer concrete represents a technically viable and environmentally superior alternative for low-carbon infrastructure development.**

***Keywords*—Geopolymer concrete,life cycle assessment,alccofine,life cycle inventery**

I. INTRODUCTION

The construction industry is one of the biggest users of natural resources and a major contributor to greenhouse gas emissions globally. A large amount of carbon dioxide is produced from ordinary Portland cement, which is a key part of regular concrete. However, because of growing worries about climate change, the use of resources, and environmental damage, there is a need to find new materials and methods for construction that reduce harmful effects on the environment. As a result, researching and developing sustainable concrete technology has become an important area of study. Geo polymer concrete has gained attention as a substitute for traditional cement-based concrete because it can turn industrial by-products into binding materials.

Unlike ordinary Portland cement, geopolymer binders are made by activating materials rich in alumina and silica, like fly ash, ground granulated blast furnace slag, and other industrial wastes. This approach not only lowers carbon emissions from cement production but also helps manage industrial waste. Therefore, geopolymer concrete aligns with sustainable development and the idea of a circular economy. Alccofine, a very fine supplementary cementing material made from slag, has also been found to improve the performance of geopolymer concrete.

Because of its fine texture and reactive nature, adding Alccofine can improve particle packing, speed up reactions, and create a more compact structure. As a mix of different industrial wastes, it can also boost the strength, workability, and durability of geopolymer concrete. These improvements increase sustainability and reduce the need for natural resources. While the mechanical strength and long-term performance of geopolymer concrete have been studied, its environmental impact is also a key area of focus. Life Cycle Assessment (LCA) is a method used to evaluate environmental effects from the sourcing of raw materials to the manufacturing of products. Using

LCA on geopolymer concrete that includes Alccofine and other industrial by-products allows for a comparison with normal concrete and helps identify areas where it can offer environmental benefits or where improvements are needed

This project focuses on the life cycle assessment of sustainable geopolymer concrete that incorporates alccofine and other supplementary industrial wastes. The aim of the research is to determine the feasible reduction in energy consumption, emission of carbon, and general environmental impact accrued by replacing conventional cement with industrial by-products. The integration of material performance analysis with environmental impact assessment aims to provide valued insight into geopolymer concrete viability as a supportable construction material that informs appropriate decision making toward greener infrastructure development.

II. Literature Review

Debdutee Bharttacharya, Dr. Hemen Dave (July 2022), "Life Cycle Assessment- A Tool for Environmental Sustainability: Critical Review on Life Cycle Assessment Software"

Increasing awareness with regard to the impacts of human-induced environment-related alterations has led to a growing need for development activities, Environmental Impact Assessment (EIA) has become an obligatory process for decision-making about a proposed developmental activity or a project/industry, that carry out as legal is now being practiced in more than 100 countries. The main drawback in the present process of EIA is that the EIA itself is being performed for "developmental examines effects related to production/development activity within a region, but it neither provides an impact assessment of the product after it is made and circulated. Several methods and techniques have numerous methods have also been developed to solve this problem. Life Cycle Assessment (LCA) is one of these methods and tools: which gained popularity as a method used for the absolute measurement of environmental sustainability. Life cycle assessment provides a holistic effect assessment of a development activity/project/industry or a product by objective analysis of the entire product life cycle from the perspective of sustainability. There are numerous LCAs approaches including cradle to gate, cradle to cradle, cradle to grave, gate to gate, and circular economy. Therefore, the LCA is not an activity performed manually anymore but is conducted by different software for the LCA. And developed for a definite intention. Life cycle inventory information, life cycle impact assessment, and life cycle assessment software offer users a large database and impact assessment in relation to the proposed activity. The diversity of software options available may overwhelm the user in making a decision the software used for LCA Study. The current study gives an introduction to the different software used for LCA in relation to their characteristics, similarities, differences, advantages, disadvantages, usability, and characteristics that are unique to software, if any. In addition, the article gives the feasibility of using LCA for EIA in India.

Jerome Ignatius T. Garees. Ithan Jessemar Dollente, Arnel B. Beltran, Raymond R. Tan, Michael Angelo B. Promentilla [June 2021], "Life Cycle Assessment of self-Healing Geopolymer Concrete"

The current construction developments are leaning towards more sustainable methods, including the use of 'greener' alternatives to construction materials and such as geopolymer. Geopolymer are a group of cements that are derived from inorganic polymers, which have shown great promise in place of ordinary Portland cement (OPC). Nevertheless, research has shown that geo- such as geopolymer. Geopolymer are a group of cements that are derived from inorganic polymers, which have shown great promise in place of ordinary Portland cement (OPC). Nevertheless, research has shown that geopolymer. There is an increase in the susceptibility of polymers to the growth of cracks, resulting in a reduction in durability and serviceability of the material. The present study evaluates the environmental effects of a technique for self-healing in geopolymer. The proposed technique for self-healing of geopolymer involves method is based on microcapsules embedded in geopolymer concrete, where alkali-activators are used. In this study seeks to quantify the expected additional environmental impacts introduced by the addition of self-healing micro-Capsules to Geopolymer. Life cycle assessment

(LCA) of the self-healing geopolymer is very crucial to support the use of the geopolymer from an environmental point of view. The boundaries of the system used for performing the LCA are cradle-to-gate

A.Arvizu-Montes, Oswaldo Guerrero-Bustamante, Rodrigo Polo-Mendoza and M.J. Martinez-Echevarria [September 2025], "Integrating Life Cycle Assessment(LCA) and Artificial Neural Networks (ANNs) for Optimizing the inclusion of Supplementary Cementitious Materials (SCMs) in Eco-Friendly Cementitious Composites:" The construction industry is a large source of greenhouse gas emissions and, particularly by the production and use of cement materials. As an answer to this challenge, challenge, this review work provides an overall compendium on new breakthroughs in norm-Integration of Life-Cycle Assessment and Artificial Neural Networks for cementitious composite optimization with Supplementary Cementations' Materials (SCMs). 14 case studies dealing with this issue have been identified, re-Examined, and evaluated over different compositions of the binder, architectures of the Artificial Neural Network, and LCA frameworks. The results show the capability of hybrid ANN-LCA solutions towards precise forecast mechanical performance on limited environmental impacts, facilitating the development of low carbon, high-performance cement-based concrete composites. The varied SCMs that were explored include fly ash, slag materials, micro-silica fume, waste glass powder, and rice husk ash. Have large potential capacities in cutting CO2 emissions, energy consumption, and raw material depletion. In addition, it is important to note that a systematic Comparative Matrix has been developed within this work provides a great resource for reference for researchers and practitioners seeking to incorporate intelligent and eco-efficient mix designs. In summary, this research aims to advance digital sustainability toolkit and substantiates the feasibility of ANN-LCA merger as scalable decision-support framework for green construction practices

III. METHODOLOGY

Procedure for LIFE CYCLE ASSESSMENT:-

Execution of life cycle account analysis: The life cycle inventory investigation was performed to quantify all inputs and outputs associated with the product system. The software calculated resource consumption and emissions for the defined functional unit.

Performance of life cycle impression assessment: The LCIA was passed out by converting inventory data into environmental impact indicators using the selected assessment method.

Analysis of Results: The results were analysed using contribution analysis to identify processes and materials with the highest environmental impacts. Key environmental hotspots within the system were identified.

Sensitivity analysis: Sensitivity analysis was performed by varying selected parameters such as material proportions and transportation distances to assess their influence on overall environmental performance.

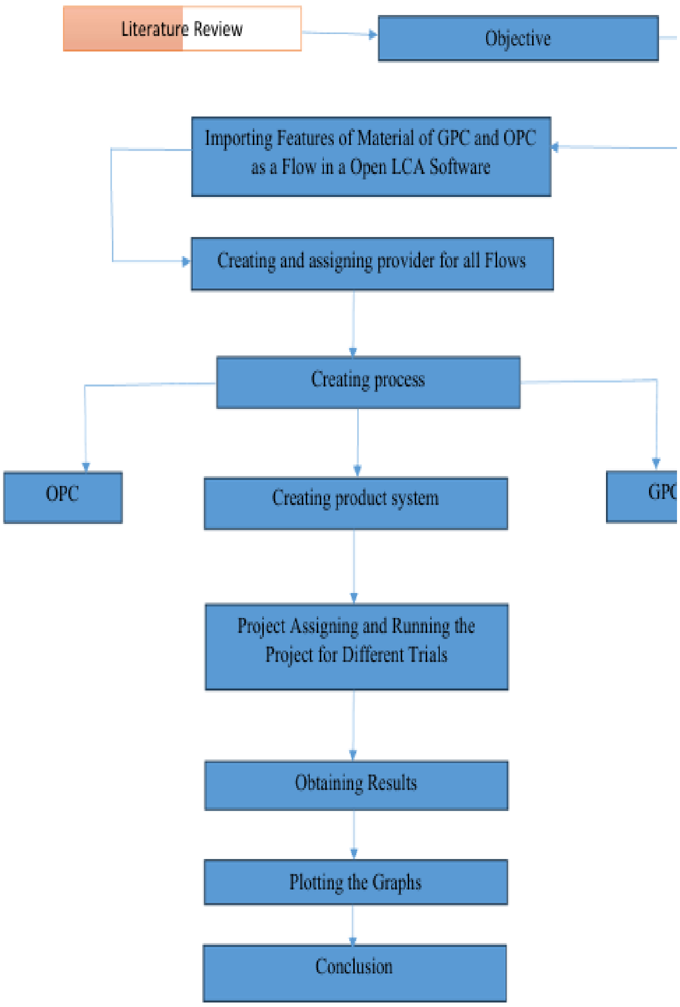

Fig.1:- Flow chart of methodology

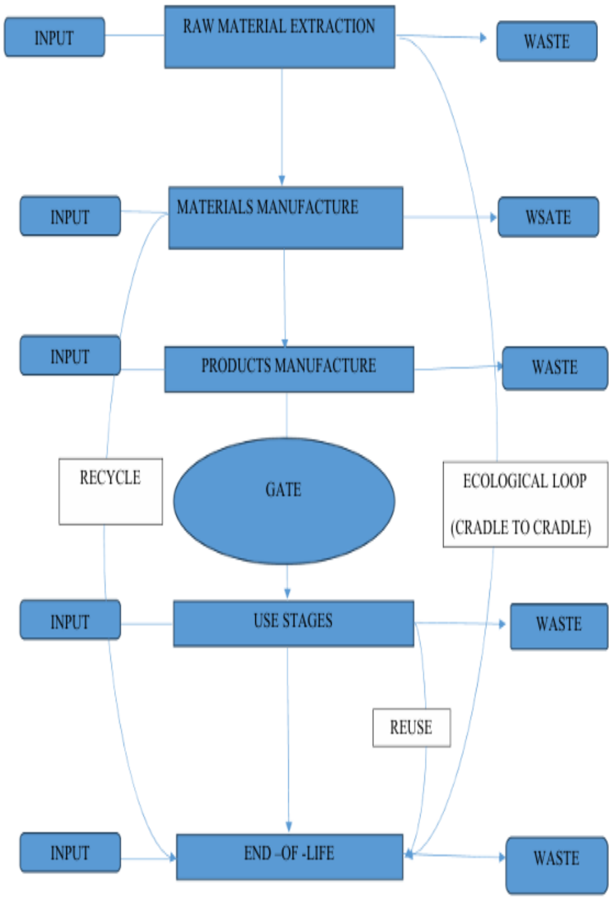

Fig.2 : Flow Chart of working with Open LCA

Validation and consistency check: The model was reviewed to ensure data consistency, correct process linking, and realistic assumptions. Any identified errors or inconsistencies were corrected.
Interpretation and documentation: The results were interpreted in line with the study objectives. Graphs and tables were exported from openLCA and incorporated into the report, and conclusions were drawn based on the findings.

IV. RESULTS AND DISCUSSION

The following flows were prepared in Open LCA Software and provider are assigned for the flows: aggregate, alccofine, electricity, fly ash, GGBS, Sodium hydroxide, sodium silicate, transport and way. The process were prepared and the consequences obtained after the first simulation is shown in figure. The relative contributions of various inventory flows to the overall GWP of the evaluated product system are displayed in the pie chart

Rendering to the findings, sodium silicate is the main contributor, making up the biggest portion of GWP. Sodium hydroxide, which also makes a substantial contribution, comes next. Due to the high margy consumption and upstream emissions involved in their production, these two alkali activators collectively account for most of the climate change impact.

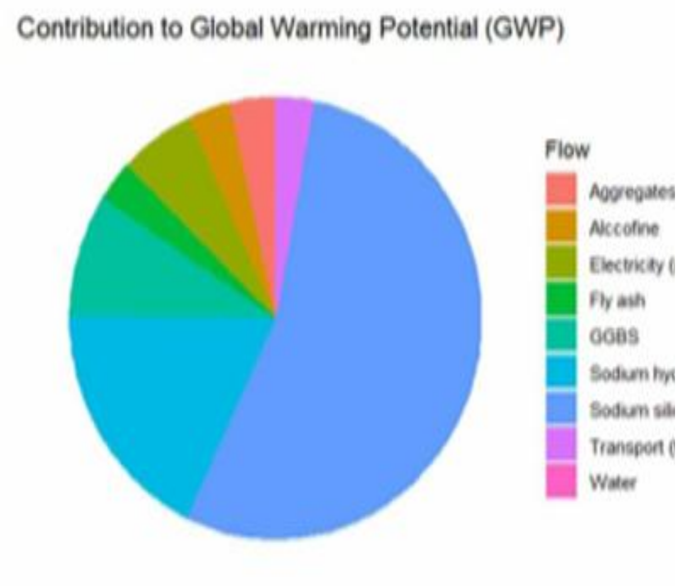

Fig.3 : Contribution to GWP

Figure above illustrates the contribution of the individual material flow and energy flow to the Global Warming Potential of the Normal Portland Cement concrete. The graph evidently depicts that the Ordinary Portland Cement is the most momentous source and accounts for an devastating portion of the overall Global Warming Potential sources. The visual representation of the pie chart reveals that the Ordinary Portland Cement source takes up to nearly the whole pie and hence is responsible for an overwhelming portion above 90% of the overall conservational impression of global warming. In contrast to the other components, the involvement of transport, sand, aggregate, electricity, and water very insignificant. Of the insignificant contributors, the influence of transport and aggregate is slightly higher than the impact of electricity and water.

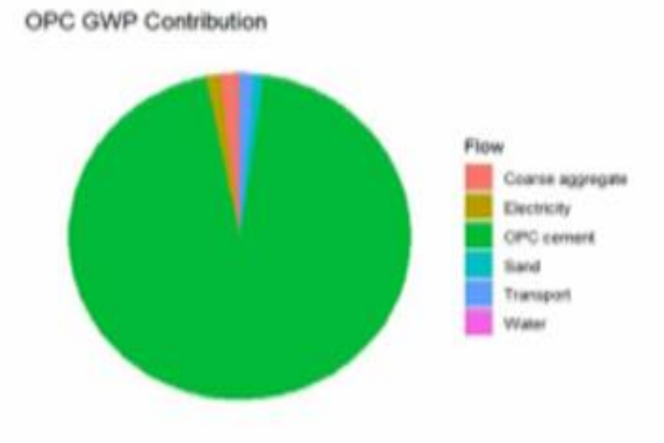

Fig.4 : Contribution of OPC

The above graph shows the impact contribution of material and process by geopolymer concrete. Impact contribution is measured based on three impact groups of the environment: Comprehensive Warming Potential (GWP), Acidification Potential (AP), and Eutrophication Probable (EP). For all impact contributions, sodium silicate has the largest impact value among all the impact contributors, specifically on GWP. Sodium hydroxide is the second most significant contributor of GWP, followed by GGBS.Moderate levels of contribution are noticed in the usage of electricity in the processes that involve mixing, aggregates, and transport via truck, while the contribution by fly ash, alccofine, and water is relatively insignificant. However, the influence of AP and EP is originated to be relatively low associated to the influence in the GWP.The major contributing factor of sodium silicate in environment-related impact assessment is primarily outstanding to the high energy requirements for the construction of sodium silicate. Similarly, in Sodium hydroxide, high electricity demand, which in most cases comes from non-renewable resources, es it a major contributor in GWP.

The figure 5 shows a Proportional LCA between two types of concrete, namely GPC (Geopolymer Concrete) and OPC (Ordinary Portland Cement), for a functional unit of m³. For open LCA-an open source, one of the prominent open source software for LCA, this would be the "Comparison" tab after having calculated the impacts of two different product systems. Breakdown of the Categories of

Environmental Impacts This chart compares the materials against three common Midpoint indicators: GWP-This is the biggest difference depicted. OPC has a GWP value of about 300, whereas GPC is roughly 160. Interpretation: GPC provides close to a 50% reduction in greenhouse gas emission when compared to traditional cement. This is generally because GPC uses industrial by-products like fly ash or slag instead of energy-intensive clinker. AP: The values are very low associated to GWP, with their values near the bottom of the scale. OPC has a to some extent higher impact equated to GPC, though generally quite marginal in this visualization. EP: Just like in AP, the values are inconsiderable. Also again, OPC has shown a to some extent higher bar, meaning higher potential for nutrient enrichment of water bodies per cubic meter produced.

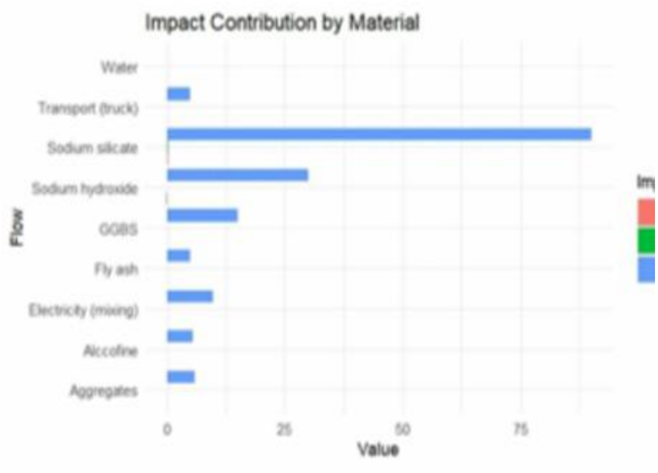

Fig.5 : Impact Contribution of materials

V. Conclusion

Usages of sodium silicate as an alkaline activator in the geopolymer concrete is found to have major percentage of contribution in global warming. The materials used in geopolymer concrete had relatively higher contribution in global warming when compared to acidification and eutrophication. Hence it can be determined that assessing global warming impending is required. Cement is the major supplier to the global warming hence replacing the cement in concrete could potentially reduce the impact on global warming.

Per meter cube of specimen it is originate that geopolymer concrete consumes reduction of approximately 50% of global warming impending associated to Opc concrete. Based on analysis of stage wise global warming prospective, raw materials stage was found to have major contribution towards global warming when compare to other stages. From the cradle to grave life cycle valuation it is institute that global warming potential of the geopolymer concrete is less when compared to OPC concrete. Maximum global warming prospective was bring into being in the mix having increased proportion of alkaline activators in comparison with other mixes.

Different GPC mixes (20 mixes) were analyzed for sustainability index and it is found that GPC mix-16 was very efficient and had higher sustainability index. With the proportion of alccofine retained constant, other materials are varied and analyzed 20 mixes for sustainability index and it is found that GPC mix 20 had higher sustainability index..

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