

Impact Of Nano Graphene Oxide And FlyAsh On Life Cycle Assessment Of Self-Healing Mortar

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ABSTRACT

In the recent times, a considerable increase has occurred in cement manufacturing, due to which the Cement production accounts for about 5% of the total anthropogenic CO₂ emissions and 12–15% of the global energy use from the industrial sector. It is critical to examine the potential environmental implications of cement manufacturing process in order to reduce the negative effects of the cement industry on climate change, ecosystem quality, human health, and cement production resources. Thus, a LCA of self-healing mortar with cementitious materials was carried out using open LCA software. The goal of this work is to investigate an alternate pathway based on microbial NO⁻³ reduction (denitrification), which leads to CaCO₃ precipitation, which can also contribute to the generation of NO⁻³, a corrosion inhibitor and hence, calculate the environmental impact parameters for each of the products used in this particular bacterial cement mortar mix to attain the emission rate of individual products used.

Keywords: Life Cycle Assessment(LCA);Mortar; Self-Healing; Cement; Global Warming; Abiotic Depletion; Acidification; Eutrophication.

1. INTRODUCTION

Cement production has been a focal area of ongoing attempts to develop sustainable construction materials to help cities become more sustainable [1]. However, given of the enormous greenhouse gas emissions connected with OPC manufacturing, these practises are not sustainable. According to estimates [2] the cement manufacturing contributes roughly 5 percent of global anthropogenic CO₂ emissions and 12–15 percent of total CO₂ emissions percent of global industrial energy use. Because the breakdown of limestone to calcium oxide requires a lot of energy, cement manufacture is particularly energy-intensive. In summary, the key environmental concerns facing the cement production business include (Environment Agency, 2005) releases of nitrogen oxides, sulphur dioxide, particulates, and carbon dioxide into the atmosphere, resource utilization, particularly primary raw materials and fossil fuels, and waste generation [3]. Thus, cement alternatives are continually being developed to improve the sustainability of concrete and the construction sector. Were, Nano graphene oxide and Fly ash are one among these alternatives.

In this study as an alternative for cement, Nano graphene oxide is added to the cement mortar, the addition of Nano graphene is due to their advantage of good paramagnetic properties, durability and self-healing parameter. Nano graphene oxide enhance the compressive and flexural properties of cement. The addition of a small 0.05 weight percentage of nano graphene oxide content to cement mortar results in an increase up to 5% - 8% for the Compressive strength, Tensile strength and Young's modulus. Similarly, a partial replacement of cement with fly ash is done, the replacement of cement with Fly ash is adopted because Fly ash is eco-friendly and economical. The ability to self-heal improves as the proportion of fly ash rises. The application of fly ash as an additive in cement mortar/concrete not only improves the technical features of the cement mortar/concrete, but it also helps to reduce pollution. Environmental analysis of the self-healing modified mortar using life-cycle assessment (LCA) can provide an additional perspective for researchers to evaluate and improve a specific self-healing method. LCA is a systematic methodology for quantifying the environmental impacts [4] for products or processes using multiple footprint metrics. Nevertheless, [5] showed that LCA could be performed in conjunction with life-span estimation techniques to evaluate the environmental benefits brought about by self-healing. Additionally, cradle-to-gate LCA can be used to show the initial impacts of self-healing on a material and how this can be counteracted in the long run [6].

1.1 LIFE CYCLE ASSESSMENT

Life cycle assessment (LCA) is one of the most used strategies for addressing environmental issues and its negative consequences (such as resource use and release to water, air, and soil).

We followed the four primary stages of LCAs, as defined by the ISO 14040 standard [7]

- (a) Goal and scope definition
- (b) Life cycle inventory analysis
- (c) Life cycle impact assessment (LCIA)
- (d) Interpretation.

- a) **Definition and scope of objectives:** Define and explain the item, process, or activity. Determine the context in which the assessment will be conducted, as well as the limits and environmental effects that will be examined.
- b) **Inventory evaluation:** Determine and measure energy, water, and material consumption, as well as environmental releases (e.g., air emissions, solid waste disposal, waste water discharges).
- c) **Impact evaluation:** Examine the human and environmental consequences of energy, water, and material use, as well as the environmental emissions discovered in the inventory study.
- d) **Interpretation:** Evaluate the inventory analysis and impact assessment results to determine the preferred product, process, or service, while keeping in mind the uncertainty and assumptions that were utilized to obtain the results.

2. MATERIALS AND METHODS

The proposed LCA of self-healing mortar is expected to contribute to the overall environmental impact of Nano Graphene Oxide and Fly Ash. The International Organization for Standardization (ISO) defines LCA as an analytical tool used to address the environmental impacts brought about by the process or product throughout its life cycle from raw material acquisition, to production and use and its final disposal as shown in Fig. 1 (ISO, 2006a) [7]

2.1 GOAL AND SCOPE DEFINITION

The cradle-to-gate LCA was used in this study, which limits the assessment to raw material acquisition and manufacturing of the material in issue; the system boundary is terminated at the factory gate, excluding product usage and disposal. As a result, the research was limited to a cradle-to-gate approach, with the goal of determining the magnitude of environmental consequences that will occur during the raw material extraction and manufacture phase of the self-healing material.

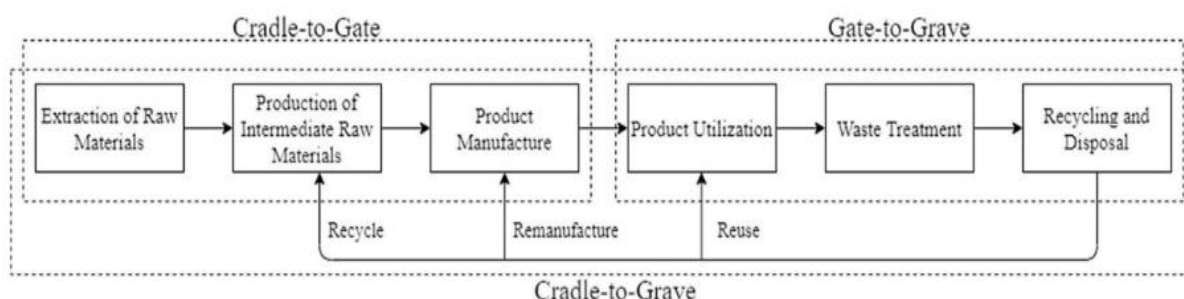


Figure 1. Scope of Life cycle assessment

2.2 DECLARED UNIT

In this LCA, the declared unit was defined as a volume unit (1 m^3) of cement mortar.

2.3 PERFORMANCE OF LCA MODEL

There are several many other software available to find the products Life cycle assessment, but in this study openLCA software was adopted. All the models were run using OpenLCA version 1.10.3 installed in HP laptop intel core i5 CPU @ 1.60GHz and 4 GB RAM 64bit window10 operating system. OpenLCA software was used for calculations and data analysis [8] Inventory data was obtained using the databases available with the OpenLCA software and from literature.

2.4 LIFE CYCLE INVENTORY ANALYSIS

The energy and material fluxes are comprehended and noted throughout the inventory analysis process. In the initial step is to model the process structures to provide a foundation for data assembly. In terms of the system boundary, material and energy fluxes are calculated as sizes of input/output for each partial procedure. There is a representation between the modules and the environment by connecting all partial processes, and the mass balance is put up as the complete system's inventory. When appropriate, the Ecoinvent and US Life Cycle databases were also consulted for inventories. The LCA data of cement, Nano graphene oxide and Fly ash were obtained from International EPD. The environmental impacts of cement were obtained from a report of the European Cement Research Academy [9] and the cementitious materials (from three different reports of the European Federation of concrete admixtures associations [10–12], all from the year of 2015. The LCA data of sand (natural aggregate) were obtained from a generic dataset available in openLCA (using version 1.10.3 of CML baseline 2000 released by CML in April 2013, and CED version 1.10).

2.5 LIFE CYCLE IMPACT ANALYSIS (LCIA)

It is a step of LCA that tries to convert the LCI into particular impact indicators from the elementary flows in order to comprehend and evaluate the potential environmental repercussions. LCIA changes the energy and materials consumed to easily understood impact metrics. The intensity of the impact categories' contribution to the environmental burden is represented by these measurements.

Table 1. Major Environmental Impact Categories

Ecosystem Impacts	Human Impacts	Resource Depletion
Climate Change	Ozone Depletion	Fossil Fuel
Acid Rain	Smog	Fresh water
Eutrophication	Particulate Matter	Soil
Land use change	Toxicity	Forest
Solid waste	-	Grassland
Toxicity	-	Minerals

2.6 ENVIRONMENTAL IMPACT CATEGORIES

The environmental implications of the life cycle were analyzed by an examination of eight environmental impact categories. Abiotic Depletion Potential (ADP), Global Warming Potential (GWP100), Ozone Layer Depletion (ODP), Acidification Potential (AP), Eutrophication Potential (EP), and Photochemical Oxidation (POCP) are the specific effect indicators evaluated in this study

Table 2. Environmental parameters

IMPACT CATEGORY	UNIT	DESCRIPTION
Abiotic depletion potential a) Materials	kg Sb-eq	Indicator of depletion of natural non-fossil resources.
Global warming potential total, fossil, biogenic and land use	kg CO ₂ -eq	Indicator of GW owing to greenhouse gas releases into the atmosphere. Based on the source of emissions, there are three subcategories: (1) fossil resources, (2) bio-based resources, and (3) land use change.
The ozone layer	kg CFC-11-eq	Indicator of air pollutants that induce stratospheric ozone layer deterioration.
Photochemical oxidation	kg NMVOC-eq	Photochemical ozone production in the lower atmosphere (smog) catalysed by sunlight is affected by gas emissions.

Acidification	kg mol H ⁺	Indicates the potential for soil and water acidification as a result of gas emissions such as nitrogen oxides and sulphur oxides.
Eutrophication	kg PO ₄ -eq	indicator of the addition of nutritional nutrients to the freshwater ecosystem as a result of the release of nitrogen or phosphorus-containing chemicals

Table 3. Alternate names for Environmental Impact Parameters used in Life Cycle Analysis and Software

Sl. no	Original Parameter	Alternate Name
1	Abiotic depletion potential (ADP)	Ecosystem quality
2	Global warming potential (GWP)	Climate change
3	The ozone layer potential (ODP)	Human health - ozone layer depletion
4	Photochemical oxidation potential (PCOP)	Human health – Photochemical oxide
5	Acidification potential (AP)	Aquatic acidification
6	Eutrophication potential (EP)	Aquatic Eutrophication

3 RESULTS AND DISCUSSION

3.1 OPENLCA ANALYSIS RESULTS

Analysis is a method used in openLCA to analyses the environmental impact of a product during the course of its life cycle, which includes the extraction and processing of raw materials, production, distribution, usage, recycling, and final disposal. The inventory analysis is the foundation of openLCA and is an expression of the core LCA data. The analysis entails a quantitative analysis of resource, energy, or environmental emissions from items, processes, or activities at different phases of their life cycle.

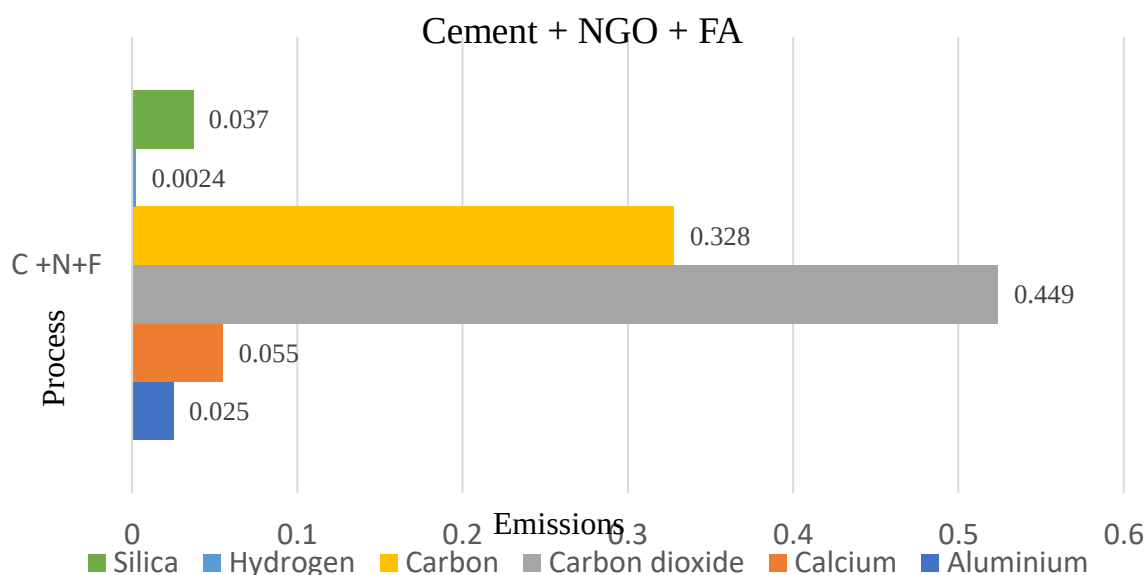


Figure 2. Emission values for Cement mortar, Nano graphene oxide and Fly ash.

The above chart is an analysis result of Bacterial cement with the addition of Nano graphene oxide and partial replacement of FA. The purpose of the mix was to analyze the performance of cement mortar with Nanographene and fly ash wherein we can find the emission rates and implement in the technology. Since Adding fly ash to mortar can cut expenses while also improving the mortar's workability. Furthermore, addition of Nano graphene oxide helps in enhancing the material's strength and durability cement mortar.

3.2 RELATIVE RESULTS

The term relative results refer to a single score results in Life Cycle Analysis. Where a single bar chart representation is given to one or more products. For a number of environmental impact categories, evaluated by the Inventory endpoint and midpoint methods, the relative result gives the overall view of the product along with its environmental impact emission values obtained from the software.

3.2.1 RELATIVE RESULTS FROM OPENLCA

Every relative result includes two approaches (Midpoint and Endpoint), where the Midpoint method considers the Endpoint technique finds the impact of environmental at the conclusion the chain, while the Impact method considers it earlier in the cause-effect chain, before the endpoint. The method used to obtain the Environmental parameter Emissions is IMPACT 2002+ method. The endpoint method involves Parameters such as global warming, photochemical oxidation potential Abiotic depletion, and ozone depletion, and are all factors to consider. Whereas the Midpoint method involves Acidification potential and Eutrophication potential.

The following charts shows the relative indicator results of the respective project variants:

1) CEMENT MORTAR + FLY ASH + NANO GRAPHENE OXIDE

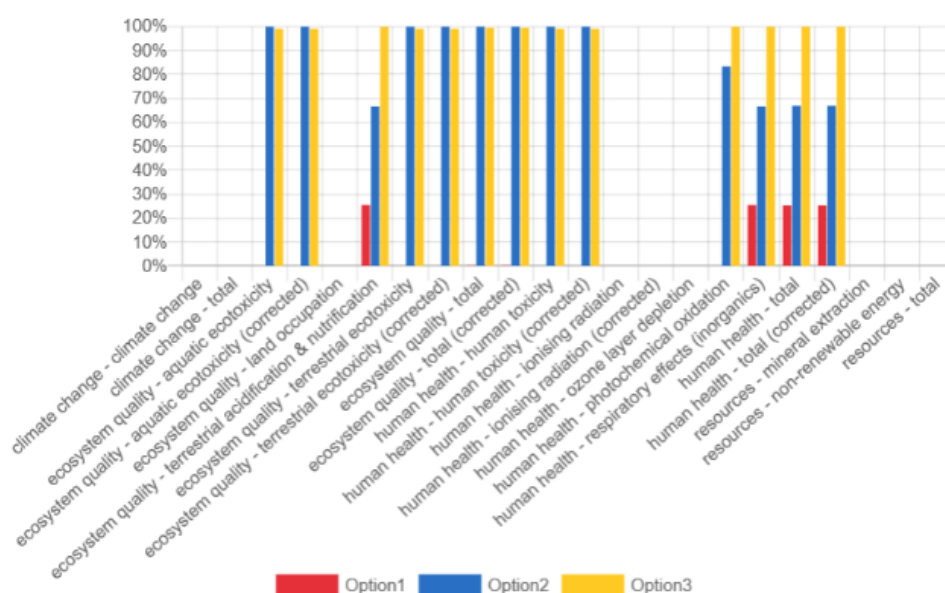


Figure 3. Relative results of Cement mortar +Nano graphene oxide + Fly ash using endpoint approach

In this model three options are inputted as, Option 1 is Cement mortar, option 2 is Nano graphene oxide and option 3 Fly ash by using endpoint IMPACT 2002+ method from which impact indicators such as Eco system - which deals with direct and indirect reliance on ecological resources to govern their management. The value for ecosystem quality - aquatic ecotoxicity was 3.616×10^{-5} for option 1, 2.169×10^{-4} for option 2 and 2.147×10^{-4} for option 3. Similarly, the other indicator Human health - which deals with the area of protection, altogether with environment and natural resources got human toxicity value of 3.84040×10^{-6} for option 1, 2.30424×10^{-5} for option 2 and 2.281×10^{-5} for option 3. photochemical oxidation value of 2.32901×10^{-8} for option 1, 1.16450×10^{-5} for option 2 and 1.397×10^{-7} .

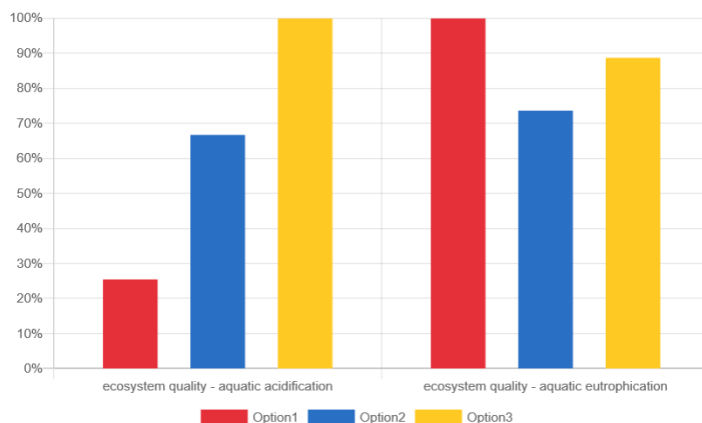


Figure 4. Relative results of Cement mortar +Nano graphene oxide + Fly ash using midpoint approach

In this model three options were inputted, Option 1 is Cement mortar, option 2 is Nano graphene oxide and option 3 Fly ash by using midpoint IMPACT 2002+ method from which impact indicators such as Acidification- the indicator of probable Acidification of the land and water due to the discharge of pollutants such as nitrogen oxides and sulphur oxides. The ecosystem quality for aquatic acidification is 4.06000×10^{-2} , 1.064×10^{-1} and 1.59705×10^{-1} for option 1, 2 and 3 respectively. other indicator Eutrophication - indicator of the addition of nutritional nutrients to the freshwater ecosystem as result of the release of nitrogen or phosphorus having aquatic eutrophication value of 1.04040×10^{-1} , 7.659×10^{-2} and 9.22590×10^{-2} for option 1, 2 and 3 respectively. The aquatic acidification is 25%, 67% and 100% for option 1, 2 and 3 respectively and eutrophication is 100%, 74% and 89% for option 1, 2 and 3 respectively.

3.3 LIFE CYCLE IMPACT ASSESSMENT

Table 4. Environmental impacts for the production of 1 m³ of cement mortar.

Components	ADP Kg Sb-eq (10 ⁻³)	GWP Kg Co2-eq (10 ⁻⁴)	ODP Kg CFC11-eq (10 ⁻³)	POP Kg ethene-eq (10 ⁻⁷)	AP Kg So2 -eq (10 ⁻²)	EP Kg PO4 -3- eq (10 ⁻¹)
Cement+ Sand	2.818	1.70	4.40	2.99	4.06	4.97
C + NGO	2.71	1.66	4.23	2.764	4.064	4.869
C+ NGO 0.06 %	2.522	1.29	3.958	2.387	3.38	4.10

C + FA	2.80	1.64	4.35	2.89	4.02	4.55
C + FA 15 %	2.447	1.321	3.929	2.609	3.538	4.183
C + NGO + FA	2.72	1.57	4.33	2.86	3.99	4.51

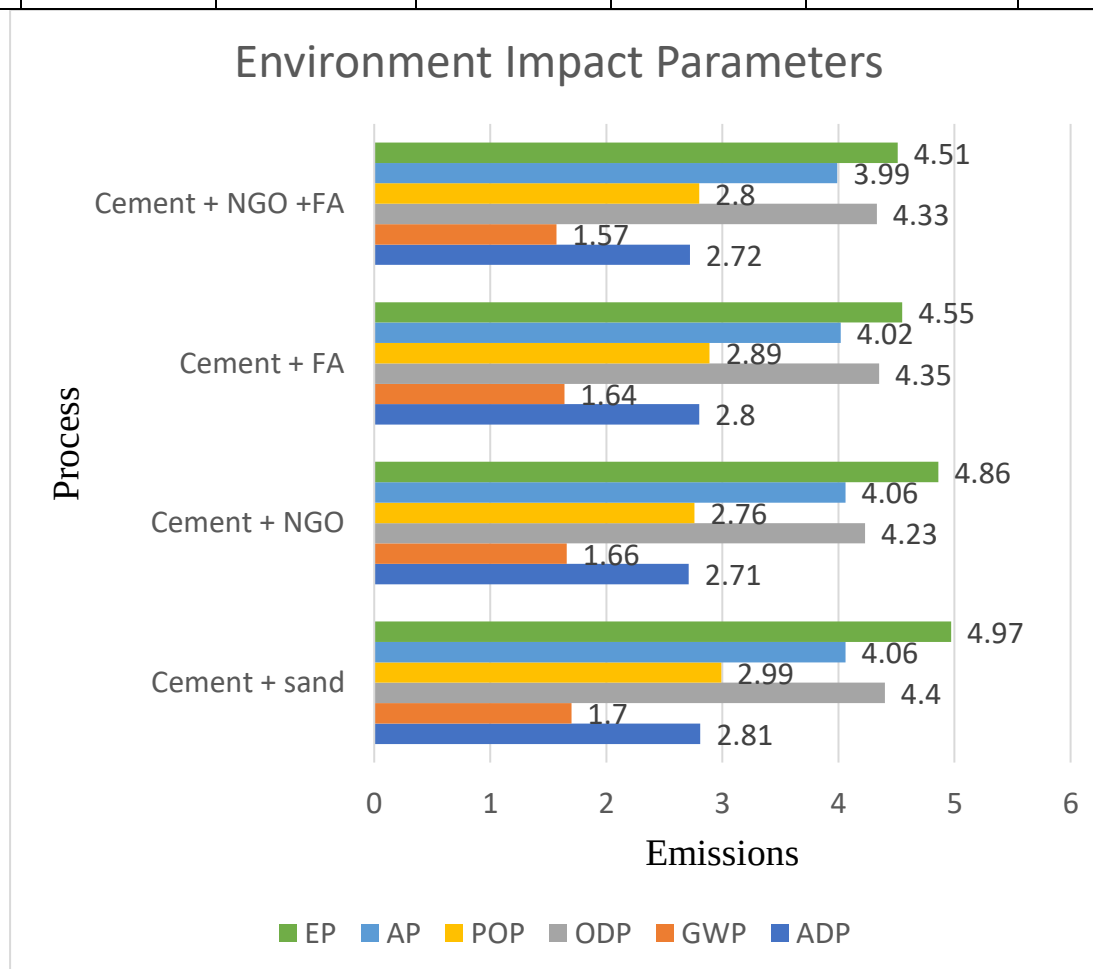


Figure 5. Environmental impact parameters for 1m³ of cement mortar.

The above chart is a representation of the Environmental impact parameters in Life cycle analysis which includes all the environmental parameters.

a) Abiotic Depletion Potential (kg Sb-eq) - ADP is a measure of the depletion of non-fossil natural resources. Cement and sand are the materials with the highest influence in this component of the ADP impact category in this study. Over 75% of all impacts were caused by mortars, and nearly 25% were caused by explosives. All mortars in this indicator had an impact same or less than the Cement mortar. As a result, when compared to present cement mortar, the introduction of Nano graphene oxide reduces the ADP—Materials.

b) Global Warming Potential (kg CO₂-eq) - The indicator of possible GW caused by the release of greenhouse gases into the atmosphere. There are three subcategories based on the source of emissions: (1) fossil resources; 2) bio-based resources; and 3) changes in land use. The investigated cement had the highest influence on global warming in this study, increasing the amount of greenhouse gases released into the atmosphere.

c) Ozone Depletion Potential (kg CFC-11-eq) - ODP is a measure of air contaminants that cause ozone layer depletion in the stratosphere. Natural air was the most significant contributor to the Ozone Depletion impact, accounting for about 60% of the total impact created by the cement mortar. The mortars were responsible for

nearly all of the remaining 40% of the impact. In this investigation, the emission is the focus. All of the mixes had an ODP impact that was less than or equivalent to the present cement mortar.

d) Photochemical Ozone Creation Potential (kg NMVOC-eq) - POCP is a measure of gas emissions that influence the production of PCO in the lower atmosphere (smog), which is catalysed by sunshine. More than 75 percent of the POCP impact was due to cement. Depending on the mortars, the reduction in POCP impact (in contrast to cement sand) ranged from 1% to 23%. Fly ash was the trash that had the greatest influence on the environment in this category.

e) Acidification Potential of Land and Water (kg mol H⁺) - AP denotes risk of soil and water acidification as a result of gas emissions such as nitrogen oxides and Sulphur oxides. Cement and sand were the key influences on the AP impact produced by the mortars (raw materials production and transportation). Cement and sand accounted for nearly 90% of the total effect in cement mortar.

f) Eutrophication Potential (kg PO₄-eq) - EP is a measure of the number of nutritional elements added to a freshwater ecosystem as a result the emission of nitrogen or phosphorus-containing compounds. Cement is the reason for more than 60% of the entire impact, whereas sand was responsible for 25%. Due to cement replacement with fly ash, all of the products cement sand, cement and nano graphene oxide, and cement and fly ash had an impact comparable to or lower than that of cement mortar. The reduction was anything between 0% and 25%.

4. CONCLUSION

The effect of nano graphene oxide and fly ash on the life cycle assessment of self-healing mortar was investigated in this chapter utilizing the Cradle to Gate system boundaries. The mortar mixes with incorporation of cementitious materials were analyzed in parallel with a standard mortar designated as cement mortar. Six environmental impact categories were examined using two alternative methodologies from the IMPACT 2002+ category, employing the Life cycle assessment to identify the environmental improvements of these mortars. The LCA of mortars containing various percentages of nano graphene oxide and fly ash was calculated in order to estimate the renderings' potential environmental sustainability. The primary goal was to compare the environmental effects of the modified mortars to that of the control cement mortar. It was discovered in this study that incorporating cementitious materials has environmental benefits when cement is replaced with fly ash and Nano graphene oxide is added. Table4 summarizes the normalized outcomes of the analysis. The results are shown in contrast to cement mortar, where the environmental characteristics of Cement mortar with Nano graphene oxide, fly ash, and a mixture of both nano graphene and fly ash are either reducing or staying the same as cement mortar, as shown in (Table 4). As a result of these LCA results, together with improved technical behavior, it is feasible to conclude that mortars using cementitious elements also help to reduce environmental impacts.

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