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GREENHOUSE GAS (GHG) EMISSIONS OF CONCRETE DURING ITS LIFE CYCLE: A REVIEW

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Abstract – One of the most commonly used building materials, concrete is consumed at around 25 gigatonnes annually. Manufacturing of concrete and cementitious material produces GHGs that are currently the most important environmental impacts. Knowing and reducing the adverse environmental effects of concrete and other construction materials many manufacturers are interested in sustainable concrete production. Concrete production significantly increases greenhouse gas emissions and strains the ease of access to natural resources like water. Accordingly, the need for concrete is expected to grow during the next 50 to 100 years, prompting the development of solutions to reduce its adverse effects on the environment. In terms of carbonation, maintenance and rehabilitation, other indirect emissions, and recycling operations, the use of concrete and its end-of-life phases can have a tremendous impact on the life cycle GHG emissions of concrete. This paper reviews concrete's life cycle and post-life emissions of greenhouse gases and the effects of carbon emission on the globe from the production of cement, its transportation, and its usage. Additionally, the use of heavy equipment in the extraction of coarse and fine aggregates from the earth's surface contributes significantly to the creation of carbon emissions.

Keywords – Concrete Life Cycle, Sustainability, GHG Emissions, Environmental Impact, After Life Phase of Concrete

I. INTRODUCTION

Cement manufacturing has developed enormously since it started some 2000 years ago. It has a lengthy history, with modern cement manufacture beginning in the midway 19th century, Rotary kilns were eventually replaced with shaft kilns, which have taken their position as standard equipment worldwide [1]. Cement production generated 2823 million metric tons (Mt) of CO2 emissions in 2010. This was around 9% of all CO2 pollutants and greenhouse gases in the globe that same year. Cement manufacturing accounts for around 58% of the world's CO2 emissions [2].

Sand is one of the leading and essential parts of concrete. Generally, 30% of sand is present in concrete production. Sand particle has a massive effect on the radiation budget, biogeochemical cycles, greenhouse effect, quality of air, and human health, as well as the climate system due to the emission of Greenhouse Gases [3]. The chemical composition of peat changes as a result of both the preferential release of CO2 by mineralization and fertilization and the concentrations of Nitrogen, Phosphorous, and Potassium in the topsoil of agriculturally utilized peatlands rise. Field research has demonstrated that the Nitrogen concentrations in the aerobic zone affect CO2 emissions. Phosphorous availability has a favorable impact on CO2 and N2O emissions [4].

Depending on how land is used, soil (aggregates) may be a source of atmospheric concentrations of greenhouse gases (GHGs) in concrete production [5]. Because of anthropogenic activity, the number of greenhouse gases (GHGs) has been gradually increasing in the atmosphere due to the breakdown of soil organic matter (SOM). The release of greenhouse gases from the soil is determined by delicate relationships between climatic variables, biological, chemical, and physical aspects of soil, and the scale-dependent correlation of soil attributes [5].

Global warming is largely acknowledged to be the most serious environmental and economic hazard of our time. They conclude that greenhouse gas emissions (GHGs) are to blame for global warming. Progressive carbon emissions are a result of fast construction industry extension. The production of cement used in concrete leads to the emission of CO2. It is to be said that 900kg of CO2 is emitted into the air by producing 1 ton of cement [6]. Similarly, the depletion of the earth to produce aggregates and sand for concrete production also lead to greenhouse gases (GHG) and carbon emissions. The majority of the greenhouse gas emissions from creating concrete today are related to the cementitious material (more than 90% of the GHG emissions from concrete production), with the binder contributing the majority of these emissions [7].

Buildings account for even more than 40% of the globe's energy consumption and up to 33% of its emissions of greenhouse gases both in developing and industrialized countries. There are majorly 3 phases of building that are:

- CONSTRUCTION PHASE
    - i. RAW MATERIAL PROCUREMENT
    - ii. BUILDING MATERIAL PRODUCTION
    - iii. BUILDING MATERIAL TRANSPORTATION
    - iv. BUILDING MATERIAL CONSTRUCTION
- USE PHASE
    - i. HVAC USE
    - ii. LIGHTING USE
    - iii. ELEVATOR, OFFICE, AND ELECTRIC EQUIPMENT USE
    - iv. WATER, WATER SYSTEMS, AND WASTE WATER PROCESSING
- DEMOLITION PHASE
    - i. DEMOLITION
    - ii. WASTE MATERIAL DISPOSAL

This paper examines concrete's life cycle and post-life emissions of greenhouse gases. The effects of carbon emission on the globe from the production of cement, its transportation, and its usage. Additionally, the use of heavy equipment in the extraction of coarse and fine aggregates from the earth's surface contributes significantly to the creation of carbon emissions.

II. MATERIALS AND METHOD

Manufacturing Phase of Concrete

The reduction of GHG emissions in the industry is moving more slowly than the frequency at which manufacturing is increasing. Between 2005 and 2013, cement manufacturing increased by approximately 73%. In terms of kg, CO2/t clinker, the emissions of CO2 are decreased by 14.8%. Between 2006 and 2011, the kWh/t cement electric energy consumption decreased by 3.6%. There are several explanations for why energy efficiency and reductions in CO2 emissions initiatives are being implemented slowly [2]. While the availability of Supplementary cementitious materials is occasionally neglected in assessments, it happens far more frequently. Some worldwide evaluations consider the potential decrease in emissions of greenhouse gases from cement and cement-based substances. Natural resource availability is anticipated to be adequate to fulfill future demand for some SCMs, such as calcined clay [7].

Portland cement was the sole type of cement created initially. Still, subsequent types of cement with several major components were made by substituting extra cementitious materials for some clinker. As a result, natural pozzolans, fly ash from coal power plants, and iron slag in granule manufacture was employed more often. Limestone can also replace some cement clinker. Because only clinker is correlated to substantial fuel consumption and the calcining of limestone, substituting clinker for cement is the most efficient strategy to minimize a concrete measure of CO2 emissions per ton of cement [1].

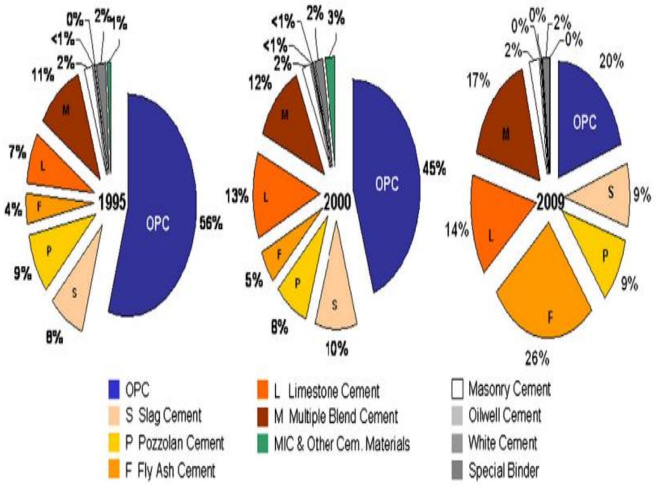

Figure 1: Cement Types [1]

Table 1: EMISSIONS RESULTING FROM CEMENT PRODUCTION [8]

CEMENT TYPE	EMBODIED CARBON (KG CO2/KG)
Average CEM Portland Cement (94% clinker)	0.95
6-20% Fly Ash (CEM II/A-V)	0.89 to 0.76
21-35% GGBS (CEM II/B-S)	0.75 to 0.62
36-65% GGBS (CEM III/A)	0.64 to 0.39
66-80% GGBS (CEM III/B)	0.38 to 0.26

Human knowledge of the effects of global climate change has increased significantly during the past ten years. The primary drivers for numerous studies in the fields with innovative construction methods and other raw materials throughout the next decades will be the need to demolish more buildings due to rapid growth in population, expansion of infrastructure (especially in developing nations with poor infrastructure), garbage buildup, and infrastructure expansion. By utilizing new materials, civilization can remain sustainable. such as recycled materials, without depleting resources. It minimizes the quantity of CO2, NO2, and other air pollutants released from the aggregates maker while saving energy. They stated that 23–33 kg of CO2 is released during the manufacturing of natural river sand [9].

Under snow cover and very low temperatures, agricultural soils leak considerable N2O. High N2O emissions have also been seen during winter thawing-freezing cycles and spring soil melting. High N2O emissions seen during thawing are thought to result from topsoil N2O generation and subsurface soil N2O diffusion. Due to the release of N and C substrates that were previously trapped in aggregates that are disturbed by freezing or from microbial biomass and microfauna that are destroyed by the freezing process, denitrification may be boosted during the soil thawing process. N2O emissions emphasized from agricultural soils that it is important to consider that soils in colder locations emit more N2O than soils in warmer regions. The impact of winter has been extensively researched in the temperate zone, but less is known about the mechanisms that produce N2O in the more deeply frozen boreal areas. [10].

Aggregates are one of the essential parts of concrete, with approximately 40% of its content. Aggregates are of different sizes depending upon their composition. Aggregates are mainly made up of crushing the earth's crust. The proportions of sieved aggregate sizes showed insignificant differences among the investigated sites. However, the average proportion of aggregate size, 0–2 mm, over all sites and depths at 17.8% was much lower than 2–8 mm and 8–20 mm. The last two had average proportions of 29.5 and 42.8%, respectively. Normally the pH of the soil ranges from 3.6-4.1. This is because of the carbon and nitrogen content in the soil. At the same time, excavation of aggregates from soil emission of carbonates and nitrates emits into the surroundings [11].

The ratios of emission and absorption were greater at the start of the hatching and decreased as it progressed. There was no discernible trend in surface soil's cumulative CO2 emission rates according to various aggregate sizes. In contrast, CO2 emission rates tended to rise for subsurface soil as aggregate size increased. Particularly for 0 –2 mm, the treatment with 70% soil moisture was much greater than those with 30%. For subterranean soils, larger aggregate sizes at both soil moisture treatments demonstrated greater CO2 emission rates than smaller sizes. There were no obvious differences in the cumulative emission/uptake rates of CH4 between different soil depths and soil moistures. While aggregate sizes of 0–2 mm demonstrated absorption, larger aggregate sizes revealed emission rates for all land uses, except for surface soil with an aggregate size of 8–20 mm and a soil moisture content of 30% in forest soil. Both negative and positive values were included in the total N2O emission rates. Only with 70% soil moisture were significantly bigger emissions discovered [11].

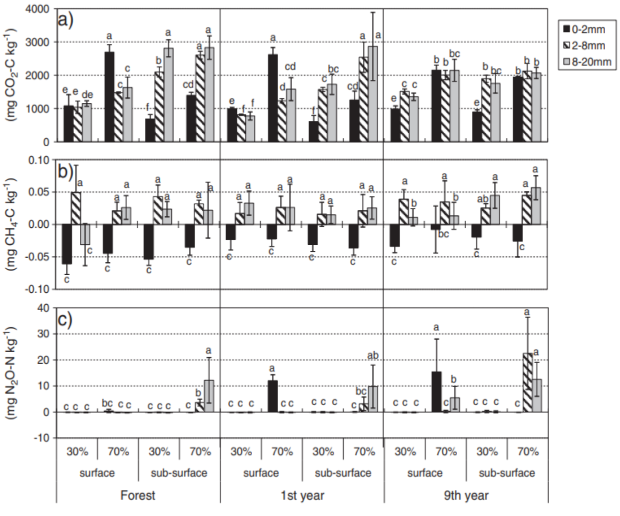

Figure 2: CUMULATIVE AMOUNT OF EMISSION OF a) CO2, b) CH4 and c) N2O flux of AGGREGATE

Use Phase of Concrete

The effects of concrete's usage from its life span Carbonation, maintenance, rehabilitation, and significant indirect pollutants are all examples of GHG emissions. In the process of carbonation, GHGs released throughout the manufacturing of cement might rebind to Ca(OH)2 inside the cement. A 1.4% to 15% re-absorption may be expected, based on the concrete's compressive strength and the typical yearly temperature. The amount of GHG might rise due to rehabilitation and maintenance operations using more fuel or energy. Additionally, concrete's thermal or non-thermal effects, such as thermal mass and surface roughness, might result in various kinds of indirect emissions [12].

The significance of carbonation towards concrete's life cycle greenhouse gas emissions has been confirmed by several research. The primary and secondary stages of the concrete life cycle must be distinguished. Secondary life begins when recycled concrete is used in new the building, whereas from the extraction of the raw materials, basic life relates to a conventional life cycle until destruction. The recovered concrete had a carbonation of -136.2 kg CO2 equivalent, which resulted in a reduction of 23.6% in concrete's life cycle emissions of greenhouse gases. The water/cement (w/c) ratio, permeability, and aggregate size of the concrete are a few factors that affect the carbonation rate. Strength overall is a common way to describe porosity. Low total strength often denotes high porosity and, hence, a high carbonation rate. The w/c ratio is also discovered to be crucial. Concrete with a high w/c ratio has the potential to carbonate at a pace ten times faster than concrete with a low w/c ratio. Particle size may also have an impact on the pace of carbonation. The maximum carbonation rate is seen in concrete with particles that are between 1 and 8 mm in size. Throughout its lifespan, carbonation has varying effects on the Greenhouse gases emitted by concrete [12].

Concrete's usage phase indirect emissions, such as those from restoration, can possess a big influence on the emissions of Greenhouse Gases from a material. To keep concrete performing at a suitable level throughout its lifespan, extensive maintenance and rehabilitation need to be performed. This is crucial for concrete pavements and other commonly used concrete constructions. Recent research has revealed that maintenance may have a greater than anticipated concrete impact mostly on life cycle Greenhouse gases. The life cycle GHG emissions of concrete can also be impacted by other passive sources of emissions. Due to its large thermal mass, concrete reduces the energy consumption of buildings. The planned usage of concrete will also have an impact on the size of the effect. Concrete, for instance, can increase the fuel consumption of automobiles due to pavement roughness, which is a result of wear and tear accumulated on the road surface. An unevenness of the road can contribute to pavement roughness. Great vehicle traffic on the rough pavement has a high potential to increase global warming. Rough pavements have a lower potential for global warming than even raw material extraction, which is often thought to have the biggest impact on the life cycle of Greenhouse gas emissions of concrete. Similarly, the additional fuel needed by relocating automobiles in congested areas during maintenance and restoration work throughout the course of a concrete pavement's lifespan contributes to substantially high GHG emissions [12].

Table 2:GHG emissions through concrete pavements (ton CO2 per km) [12]

PAVEMENTS (ROADS)	GHG EMISSIONS CAUSED BY TRAFFIC DELAY	LIFE CYCLE GHG EMISSION	%
INTERSTATE	1930	6188	31.19
FREEWAY	1199	3981	30.12
PRINCIPAL	435	2361	18.42
MINOR	199	1289	15.44
COLLECTOR	171	944	18.11
LOCAL	40	518	7.72

The importance of GHG emissions above other air pollutants in building construction has been recognized in several research. To analyze the GHG emissions of concrete building construction, the study establishes an emission scope. Carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), fluorocarbons (FC), and Sulphur hexafluoride are examples of GHG emissions (SF6). However, because fossil fuel burning is what causes GHG emissions during the building stage, CO2, CH4, and N2O are the main air pollutants. This study refers to CO2, CH4, and N2O emissions as GHG emissions.

Concrete may have various benefits and drawbacks depending on how it is used, the material's composition, and the structure's stability. Research has been focused on examining environmental sustainability after later studies confirmed the suitability of concrete as a building material. However, there has been little to no study on examining and contrasting the difference in emissions during the building period. For designers and contractors to maintain sustainable designs and the building environment, the evaluation and study of GHG emissions during the construction stage is essential. [13]

The second-largest source of carbon dioxide (CO2) emissions, accounting for around 33% of all emissions globally, is the building construction industry. In this context, it is important to reduce emissions in construction to enhance the quality of the environment and ultimately support the goal of sustainable development. For evaluating the performance of the built environment, many approaches have been established. The life cycle assessment (LCA) method, for instance, created a strategic role for assessing an item's energy and environmental performance. LCA can offer a suitable tool for supporting environmental decision-making. The input/output research methodology is based on input/output tables, with energy and natural resources as inputs and CO2 and other gas emissions as potential outputs. The implementation of a CO2 performance standard technique to minimize CO2 emissions from coal plants was pioneered by the state of California in the United States, and many other states soon followed. The building industry has also been given the task of decreasing CO2 emissions. [14]

To determine how much impact activities and goods have on the environment over the course of their whole lives, the Life Cycle Assessment (LCA) technique is frequently used. According to research from the body of literature, the operating stage—which accounts for around 80–90% of a building's entire life cycle is the one with the greatest environmental effect, with the construction stage making up the remaining 8–20%. According to the study's findings, concrete was the building material utilized in the home with the highest degree of embodied energy.

Table 3:Emissions of GHGs from the major building materials at the manufacturing stage (g/kg) [14]

EMISSION FACTOR	CONCRETE	CEMENT	SAND
CO2	106	994	6.9
CH4	-	0.0273	-
N2O	-	0.0273	-
SO2	0.0039	1.3217	0.0001
CO	0.0081	0.6281	0.0189
NOx	0.0045	2.4413	0.016

Table 4:Emission of GHGs for building materials at the transportation stagnation-km km) [14]

EMISSION FACTOR	DEEP SEA TRANSPORT	COASTAL VESSEL	ROAD TRANSPORT	RAILROAD
CO2	15.98	34.63	168.35	20.35
CH4	0.0004	0.0008	0.0130	0.0023
N2O	0.0010	0.0022	0.0064	0.0006
SO2	0.1011	0.2190	0.0046	0.0006
CO	0.0374	0.0811	0.2716	0.0285
NOx	0.2884	0.6247	1.1216	0.1900

End of Life Phase

Numerous studies did not incorporate the end-of-life phase in the Greenhouse Gas measurement procedure, because it had a negligibly little influence or there were too many unknowns at this stage. When compared to building or usage, the effect of the demolishing technique and the transfer of concrete material is very little. If the structure is demolished and the shattered debris is transferred to a landfill, the end-of-life phase adds very little to the overall life-cycle power usage and pollution emission. This research suggested that if the concrete is destroyed and sent to disposal at the end of the development cycle, it is fair to exclude the end-of-life phase from the measurement process of the concrete's life cycle Greenhouse Gas emissions. However, carbonation was not taken into account in these investigations [12].

Life Cycle Assessments of GHG do not address the post-use of materials, increased efficiency of post-use materials originating from a building industry is already a top concern in many nations. For instance, one method of processing concrete after the end of its useful life is landfilling, which harms the environment. Therefore, to prevent post-use waste from ending up in landfills, the building construction industry in several nations established voluntary material recovery targets. About half of the post-use products in the construction industry are intended to be kept out of landfills. Approximately 140 million tons of concrete are recycled yearly and this amount has been rising since 2010 [12].

A total of 15% of the annual concrete production was made up of concrete that was destroyed in 2003. It was calculated that between 72 and 87% of the concrete made in 2003 will be destroyed after reaching the end of its useful life. It is presumed that any concrete that isn't buried or submerged has been destroyed. In most cases, concrete debris is pulverized in crusher facilities and stacked up for two to four months. This aggregate is mostly utilized in the construction of roads, either as a top layer for small roads or as a component of the sub-base. A 70% recycling rate was utilized in the calculations for concrete made in 2003 because by 2010, around 70% of destroyed concrete will be recycled. Roads are made up of concrete which is known as rigid pavements. These rigid pavements themselves produce Greenhouse Gases in the use phase and it also provides a platform for motor vehicles for transportation which also emits several Greenhouse Gases [15].

If recycling concrete and using it again at the end of its life cycle, the end-of-life phase may have a significant influence on the level of Greenhouse gases in concrete. In the five years following demolition, around 75 percent of prefabricated items would carbonate., and this, along with carbonation during usage, might result in a decrease of 25% in the amount of CO2 released during the calcination process. The process of carbonation, which is heavily reliant on recycling techniques, can have a significant influence on concrete demolition and recycling. In the concrete case study, 37% of the concrete is carbonated after demolition because it is crushed and stored for a period ranging from two weeks to four months to be carbonated before reuse. If the end-of-life phase isn't taken into account, the carbon pollution from fossil fuels needed to recover the post-use concrete is overestimated and should not be disregarded. Recycling can recover around 37–42% of the embodied energy of a structure, which is the total primary energy used throughout the course of its life. Based on the findings of this research, it can be said that if the concrete is destroyed and utilized again as recycled aggregates at the end of its life cycle, the life cycle Emissions of greenhouse gases of concrete are greatly underestimated. This is especially true given that recycled concrete is now a popular method of treating concrete that has reached the end of its useful life, and its use as a whole has been on the rise [12].

Table 5:RECYCLED CONCRETE IN TONS [15]

	NORWAY	**DENMARK**	**SWEDEN**	**ICELAND**
DEMOLISHED CONC (tons)	812500	1000000	1140000	52266
RECYCLED CONCRETE (%)	30	90	60	0
% OF RECYCLED CONC. AGG.				
BOUND	1	0	3	0
UNBOUND BELOW GROUND	94	100	92	0
UNBOUND ABOVE GROUND	5	0	5	0

III. DISCUSSION

Despite an increase in recent years in the number of studies, there is still little knowledge on the Life Cycle Assessment of concrete and its basic ingredients. In published Life Cycle Inventories of concrete manufacturing, environmental effects from the life cycles of components other than Portland cement, such as admixtures and water use, are rarely taken into account. In addition to full, supply-chain encompassing GHG and criterion air pollutant emissions, further research on harmful emissions to the air is required. Similar to cement production, there is a lack of information on technological and regional variances in concrete manufacturing.

IV. CONCLUSION

Carbon emission is increasing concerning tons/per day which leads to global warming. This Greenhouse Gas (GHG) is increasing due to the massive use of concrete in cost the auction industry. Concrete has 3 phases of life i.e. Manufacturing Phase, the Use Phase, and After Life phase. The making of concrete with help of cement sand aggregate, and the use of concrete all processes emits CO2 into the atmosphere and pollutes the environment. GHG emissions are produced during the various stages of a building's life cycle, which typically include the manufacture of building materials, the transportation of those materials, the construction phase, the operation and maintenance phase, the demolition phase, and the disposal of construction waste. Concrete's life cycle Greenhouse gas emissions are examined to show how the usage and end-of-life phases impact them. The use phase of concrete may significantly affect the life cycle GHG emissions of the material as a result of carbonation, maintenance, rehabilitation, and thermal or non-thermal impacts, it has been determined. Similar to how direct landfilling, alternative end-of-life practices may also have a substantial influence on carbonation, recycling, and reusing operations.

Following are the recommendations that I would be suggested from this review article so that the emission of Greenhouse Gases (GHGs) would be minimum.

- Use of Green Buildings
- Production of Blended Cement
- Use of renewable energy
- Reuse and Recycle Demolished Concrete
- Use of natural elements
- Prioritize Eco-Friendly and Bio-Construction
- Transportation distance must be considered
- High energy efficiency equipment must be used

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