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AND ENGINEERING TRENDS

Carbon Negative Cement: A Review

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ABSTRACT

Concrete is the world's most versatile, durable and reliable construction material. Next to water, concrete is the most used material, which required large quantities of Portland Cement. Ordinary Portland Cement production is the second only to the automobile as the major generator of carbon dioxide, which polluted the atmosphere. Around 8% of global carbon emission is happen due to concrete. In addition to that large amount energy was also consumed for the cement production. Hence, it is inevitable to find an alternative material to the existing most expensive, most resource consuming Portland Cement. Most of the CO2 footprint of cement is due to the decarbonation of limestone during the clinkering process. Designing new clinkers that require less limestone is one means to significantly reduce the CO2 footprint of cement and concrete. A new class of clinkers now under development can reduce CO2 emissions by 20 to 30% when compared to the manufacture of traditional Portland Cement Clinker. Simple modification in manufacturing processes and in raw material and also in curing processes can help in reducing carbon footprint of cement

1. INTRODUCTION

Air pollution is a universal problem that the world is facing today, over the years the new capital city will grow significantly which will increase in factors causing air pollution. Maximum of air pollution occurs due to emission of carbon through different activities either natural or artificial. Major sectors which causes the carbon emission are Transportation-29%, Electricity-28%, Concrete industry-8%, etc.

As urbanization increases the concrete requirement also increase leads to increase in carbon emission. As portland cement is the key active ingredient in concrete is one of the most massproduced materials in the world. Global cement production was 4.1 billion metric tons in 2019, and is projected to grow by 12% by 2050. Unfortunately, the production of Portland cement accounts for ≈ 8 % of global industrial energy consumption and 7-8 percent of anthropogenic CO2 emissions. The main component of Portland cement is calcium oxide (CaO), which is almost exclusively sourced from limestone (CaCO3). The conventional manufacturing process starts from excavating and crushing limestone, which is sintered with clays in a kiln at temperatures reaching 1450°C to produce clinker. This process directly releases CO2 during calcination of CaCO3 into CaO and indirectly releases CO2 due to the use of fossil fuels to heat the kiln to high temperatures. The clinker is ground up to produce cement, which is ultimately mixed with aggregates and water to produce concrete. If society is going to transition to a carbon-neutral or carbon-negative future, which is essential if global warming is to be limited to 1.5-2.0°C, alternative construction materials and processing routes must be developed. Currently, the most common approach to reducing the carbon footprint of concrete is to partially replace Portland cement with industrial wastes such as fly ash and slag and by also by doing modification in manufacturing processes. One of the modification can be done in curing process, instead of curing with ordinary method ie. With water the concrete blocks can be cure with carbon dioxide (CO2) and it performs better. A durable replacement for OPC-based concrete, with modified concrete sequesters CO2 during curing, and it can be designed for desire compressive strength, abrasion resistance and freeze-thaw cycling resilience that are equal to, or better than, that of traditional concrete. Although this technique is limited to concrete block (precast blocks) only due to complex process.

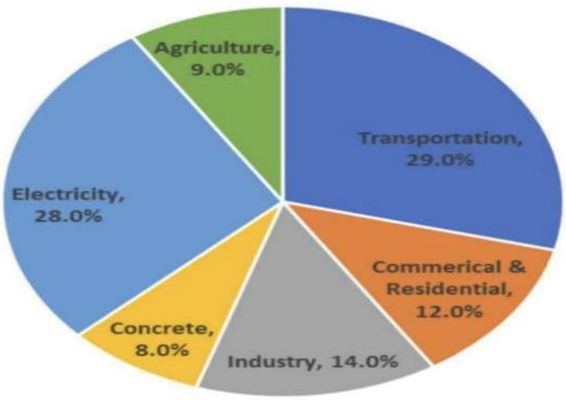

Figure No: 1.1 Carbon Emission due to Different Industries.

3. METHODOLOGY

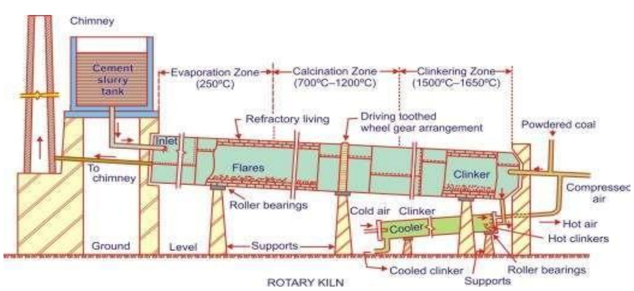

Figure No.3.1: Cement Manufacturing Process.

3.1 Cement Manufacturing Process.

Cement is nothing but a binding media which holds the sand and aggregate together. Cement is manufacture using some raw material (lime) and by adapting proper processes (Calcination, Grinding with gypsum etc.)

Detail description of these processes is as follows.

3.1.1 Raw Materials for Cement Manufacturing.

The first step in the manufacture of cement is to combine a variety of raw ingredients so that the resulting cement will have the desired chemical composition. These ingredients are ground into small particles to make them more reactive, blended together, and then the resulting raw mix is fed into a cement kiln which heats them to extremely high temperatures.

Since the final composition and properties of cement are specified within rather strict bounds, it might be supposed that the requirements for the raw mix would be similarly strict. As it turns out, this is not the case. While it is important to have the correct proportions of calcium, silicon, aluminum, and iron, the overall chemical composition and structure of the individual raw ingredients can vary considerably. The reason for this is that at the very high temperatures in the kiln, many chemical components in the raw ingredients are burned off and replaced with oxygen from the air.

Table3.1: Lists of Some Of The Many Possible Raw Ingredients That can be Used to Provide Each Of the Main Cement Elements in Cement.

Calcium	Silicon	Aluminum	Iron
Limestone	Clay	Clay	Clay
Marl	Marl	Shale	Iron ore
Calcite	Sand	Fly Ash	Mill scale
Aragonite	Shale	Aluminum	Shale
Shale	Fly Ash		Blast furnace dust
	Slag		

3.1.2 Raw Material Processing.

Portland cement is by far the most common type of cement in general use around the world. This cement is made by heating limestone (calcium carbonate) with other materials (such as clay) to 1450 °C in a kiln, in a process known as calcinations, whereby a molecule of carbon dioxide is liberated from the calcium carbonate to form calcium oxide, or quicklime, which is then blended with the other materials that have been included in the mix to form calcium silicates and other cementitious compounds. The resulting hard substance, called 'clinker', is then ground with a small amount of gypsum into a powder to make 'Ordinary Portland Cement', the most commonly used type of cement (often referred to as OPC). Portland cement is a basic ingredient of concrete, mortar and most non-specialty grout. The most common use for Portland cement is in the production of concrete. Concrete is a composite material consisting of aggregate (gravel and sand), cement, and water. As a construction material, concrete can be cast in almost any shape desired, and once hardened, can become a structural (load bearing) element.

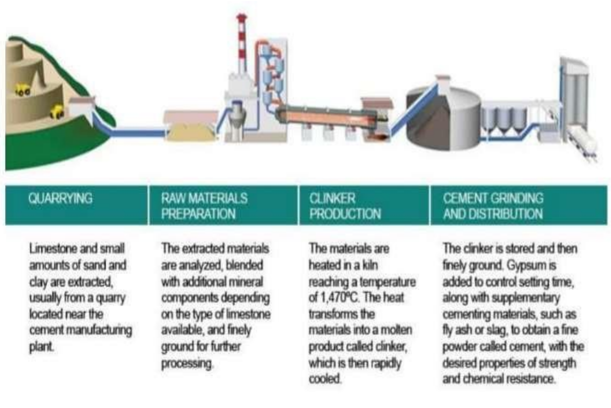

Figure No.3.2 Cement raw materials processing.

3.2 Sources carbon emission during cement production.

During cement production there is a lot of use of energy which leads to carbon emission which is explain below.

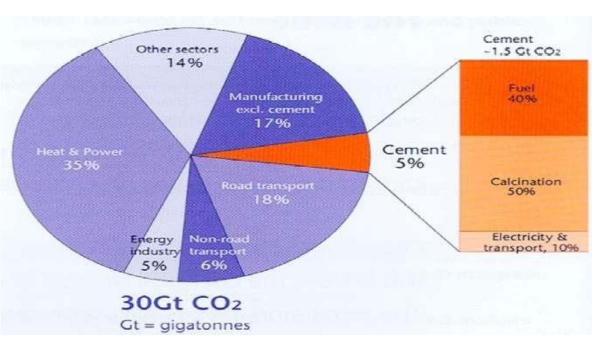

Figure No.3.3 Carbon Emission at to Different Stages of cement manufacturing.

3.2.1 Carbon Emission Due To Burning Of Fossil Fuel.

As seen earlier cement manufacturing processes involves lot of different processes right from the miming to the heating of raw material at high temperature. These all processes required lot energy and this much amount of energy is obtained by burring of fossil fuel, this burning leads carbon emission. As above fig shows around 40% of carbon emission (CO_2) happens due to burning of fuel.

3.2.2 Carbon Emission Due To Calcination Processes.

50% of carbon emission happens due to processes of calcination. It is the decomposition of calcium carbonate (limestone) to calcium oxide (lime) and carbon dioxide, in order to create cement. During this chemical reaction biproduct called Carbon dioxide (CO_2) gas is released.

$$\text{(Lime with Clay, Silt, Iron oxide etc.)} \xrightarrow{1400^{oC}} \text{Clinker} \xrightarrow{\text{Grind}} \text{Powder Cemen}$$

$$5CaCO_3 + 2SiO_2 \longrightarrow (3CaO, SiO_2) + (2SiO_2) + 5CO_2$$

1 Tone of cement manufacturing = 1 Tone of Carbon dioxide (CO_2)

3.2.3 Carbon Emission Due to Miscellaneous Processes.

Around 10% of carbon emission is happens due to some miscellaneous processes like transportation, Electricity and few operations.

3.3 Modification in the Process Of Cement Manufacturing.

As at different stages of cement manufacturing process there's a emission of carbon to avoid this or to reduce this carbon emission there is a need of slightly modification in every process.

Following modifications can be done in the processes of cement manufacturing.

3.3.1 By Lowering The Temperature Of Calcination Process.

Geopolymer cement is one of material developed by, French material scientist joshep Davidaveds using Fly Ash- rich in Silica and Aluminum, Sodium Hydroxide or Potassium Hydroxide, Sodium Silicate or Potassium Silicate to break down calcium carbonate that make a reaction to takes place at lower resulting in claimed 80% emission in CO_2 emission.

3.3.2 Using CO_2 In Cement Manufacturing Process.

Using CO2 source from industries emitters establishing gas supply to concrete sites the by injecting this CO2 in fresh concrete where concrete under goes the mineralization processes becomes permanently embedded that's lockup the CO_2 leads to increases the concrete strength, around 15 Kg of co2 can be saved for every 1 cubic meter of concrete and between 20 to 23 Kg in pre-cast component.

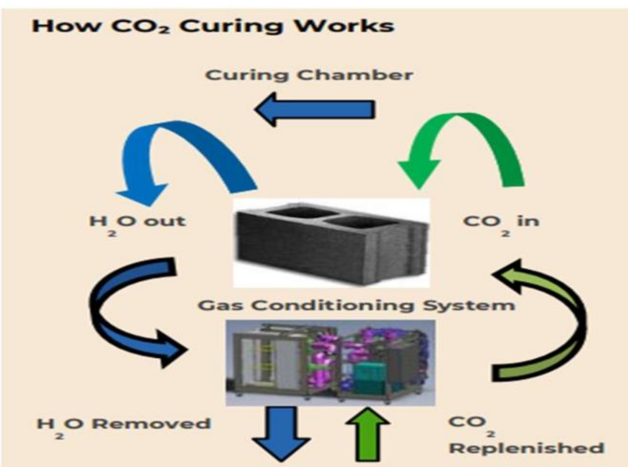

Figure No.3.4 CO_2 Curing Action.

3.3.3 Using Mineral Waste as Raw Material.

Using a process called carbonation activation theneed for cement in a concrete can be eliminate. Part of cement can be replace by extra cementitious material which generally waste from concrete industry such as GGBS i.e. Ground Granulated Blast Furnace Slag (GGBS) which is one of biproduct of steel industry, around 269 million tones of blast furnace slag is produce worldwide per year. The concrete mix obtained from this process can use be use to manufacture pre cast blocks which can cure using CO2 and that curing processes solidify the CO2 and bind it together with steel slag granular which gives concrete it's strength.2Kg of CO2 can be capture in standard size concrete block. The optimum % replacement may vary based on the properties of GGBS and ingredients used.

Some part of cement can also be reduce by materials like fly ash which leads to decrease in cement requirement in construction helps to reduce carbon footprint of cement.

Fig.3.5 Reduction In Carbon Emission Due To Addition of GGBS.

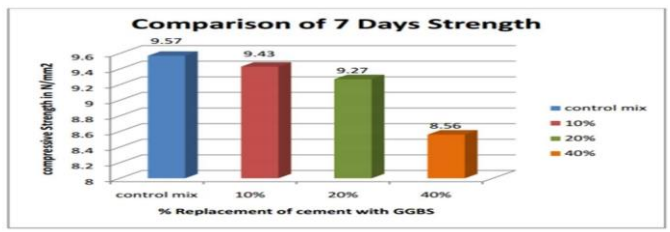

Figure No.3.6 Comparison Of 7 Days Compressive Strengths Of Mixes With 0%(Control Mix), 10% 20% And 40%.

As above graph shows the variation of 7 days strength of concrete due to addition of GGBS. It clearly shows that 7day strength is not as good as original concrete mix but this changes rapidly after 28 days which is shown in graph below.

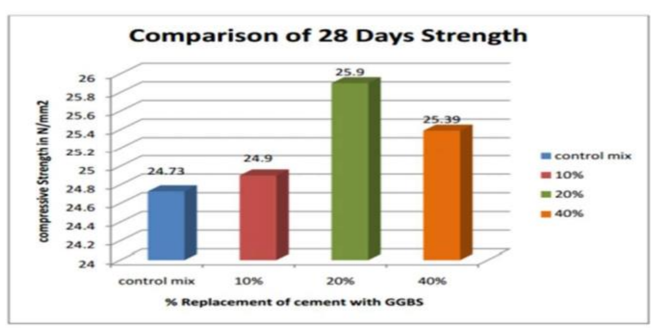

Figure No. 3.7 Comparison of 28 days compressive strengths of mixes with 0%(controlmix), 10% 20% and 40%.

Above graph shows the variation of concrete strength with respect to addition of GGBS in different percentage and it clearly shows that the strength of concrete increase with addition of GGBS in optimum quantity.

3.3.4 Using Magnesium Base Cement.

Manufacturing high-strength cement from widely abundant seawater-derived magnesium (Mg) feedstocks. In contrast to conventional Portland cement, which starts with carbon-containing limestone as the source material, the proposed process uses membrane-free electrolyzersto facilitate conversion of carbon-free magnesium ions (Mg2+) in seawater into magnesium hydroxide (Mg(OH)2) precursors for production of Mg-based cement. After a low-temperature carbonation curing step converts Mg(OH)2 into magnesium carbonates through reaction with carbon dioxide (CO2), the resulting Mg-based binders can exhibit compressive strength comparable to that achieved by Portland cement after curing for only two days. Although the proposed “cement-from-seawater” process requires similar energy use per ton of cement as existing processes, its potential to achieve a carbon-negative footprint makes it highly attractive to decarbonize one of most carbon intensive industries.

4. CONCLUSIONS

- Cement industry contributes 8% of global carbon emission which is around 1.6 million metric ton per year.
- The partial replacement of cement in concrete with some extra cementitious materials like fly ash, GGBS in concrete mixes has shown enhanced performance in terms of strength and durability. This is due to the presence of reactive silica in GGBS which offers good compatibility also leads to increase in carbon negativity of concrete (cement).
- Adaption of simple modifications in manufacturing processes and in raw material of cement can helps to reduce carbon emission from cement industry. Following are the modifications which can be done in order to achieve carbon negativity of cement.
  - Replacing some part of cement by extra cementitious material like GGBS, Fly ash etc.
  - By lowering the temperature of Calcination processes.
  - Using CO_2 for curing purpose of concrete.
  - Using Magnesium base cement instead of Calcium base cement.
- Producing less carbon footprint cement is need of on growing construction industry and environment.

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