Ferrock A Carbon Negative Sustainable Concrete: A Review

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Abstract:
Cement industry further going to grow at high speed with Government of India giving boost to infrastructure projects and housing facilities. As per the World business council for sustainable development (WBCSD, 2005) the cement industry produces 5% of global man-made carbon dioxide, a major gas contributing to climate change and responsible for global warming. A product called Ferrock was created as a result, concentrating on the reduction of carbon emissions as well as the utilization of waste materials for a better environment. This study examines this product that moves in the direction of waste reduction and carbon neutrality. It demonstrates the most effective use of iron ore waste powder obtained during the mining process, which is often dumped outside of the mines and causes air pollution, health risks, and bigger area use. By having a strength-gaining mechanism that is unlike cement's and unique among cement supplements, the product indirectly lowers the carbon dioxide discharged into the atmosphere. For greater strength in terms of compression and tensile strengths and to achieve desired qualities, ferrock is subjected to a curing process that includes carbonation and air curing over a range of days. Because it uses waste effectively and has a negative carbon footprint, ferrock is a more promising environmentally friendly binding material.

Keywords: Ferrock, waste management, cement replacement, and carbon negative are other related terms.

1. Introduction

Around 8% of all carbon dioxide (CO2) emissions worldwide are attributed to cement manufacture. Given how these emissions add up to an increasing threat from global climate change, the world's obsession with carbon-intensive products and methods has intensified into a true epidemic. Concrete has historically played a crucial role in the exponential growth of the world's largest cities and continues to be the product of choice for more industrial development. To preserve a competitive edge in a developing green market, contractors have been pushed to consider alternate building materials as academics uncover more knowledge about the environmental damage caused by the manufacture of concrete. In comparison to OPC, the iron-based compound known as Ferrock has been shown to be less expensive, stronger, and more flexible in building applications. It is composed of 95% recycled resources. Additionally, this special substance employs compressed carbon dioxide to hasten the curing process and doesn't need additional heat to catalyze its chemical reaction, making it a carbon-negative substitute for OPC. Since Ferrock is still a secret blend, a lot of the material outlining its workings and effects is written from an early stage of development. However, the information that is readily available highlights a number of this material's advantageous traits. The first of two white papers, which was written by Dr. David Stone, the inventor of the substance, and a number of engineers from Arizona State University, describes the flexural strength and general durability of the compound in comparison to OPC. They came to the conclusion that "the critical crack tip opening displacement (CTODC) and the fracture toughness of the iron-based binders were significantly higher than those of the OPC matrices [2]." Porosity is another advantageous property of the iron-based material in contrast to OPC, which can be reviewed in Dr. Stone's second white paper titled, Pore- and Micro-structural Characterization of a Novel Structural Binder based on Iron Carbonation[3]. A brief essay by the Environmental Protection Agency titled, Creating a Carbon-Negative Building Material from Recycled Glass, Steel Dust, and Carbon Dioxide, provides additional details regarding the advantages of using recycled materials as substitute ingredients for the production of binding materials. Except for iron powder, all of the components required for the manufacturing of Ferrock are common industrial products. A scientific paper titled, Sustainability of Construction Materials, notably chapter because of its focus on clinker material manufacturing, serves as the primary source of literature for fly ash and silica fume used in this study. The technical features of composite cements, other low clinker cement combinations, and their components are all thoroughly reviewed in this chapter. It also examines the emissions connected to these materials. The Natural Stone Council's limestone material fact sheet, which includes a review of the products, applications, performance, physical attributes, and environmental data concerning this material, offers information regarding the environmental effects of limestone. More general data on the GWP, water, and energy consumption consequences of limestone, silica fume, and fly ash were also obtained from a separate study by Rod Jones, Michael McCarthy, and Moray Newlands. Due of its duration in the general market, research materials on Ordinary Portland Cement are much more accessible. Additionally, the components of OPC are also conventional materials that have undergone in-depth analysis, making their statistical information easily accessible. Reviewing section will provide more details about the recent literature for Ferrock and OPC.

2. Carbon Footprint

Concrete is the most frequently used construction material in the world, being consumed at a rate of 1 m3 per person year. Historically, concrete has been bound together by ordinary Portland cement (OPC). On the other hand, OPC produces carbon emissions that vary from 0.66 to 0.82 kg of CO2 for every kilogram produced. According to Turner (2013), OPC accounts for between 5 and 7 percent of worldwide CO2 emissions. The following have been identified as the primary causes of the substantial contribution to CO2 emissions from the production of OPC:

Limestone, one of the essential elements, is calcined, causing the creation and release of CO2.

High energy consumption is involved in the manufacturing process, which includes heating raw materials to temperatures around 1400°C in a revolving kiln. Because of the chemical liberation of CO2 caused by the calcination of limestone, variations in the source of limestone, and the use of calorific wastes as a fuel substitute in cement kilns, the estimation of CO2 due to cement manufacturing is a more challenging problem. 0.82 kg of CO2/kg has been reported as the emission factor for the manufacturing of cement. The estimate takes into account all connected transportation, including the freight of cement to concrete batching facilities, as well as the emissions produced by raw material mining, cement manufacturing, and all associated transportation. According to (Laurent Barcelo et al., 2013), the cement sector is a significant source of CO2 emissions, accounting for 5-7% of all man-made CO2 emissions. The decarbonation of limestone is the primary source of CO2 emissions in the cement making process. The manufacturing of blended cements with fly ash and GGBS can minimize CO2 emissions, according to (Ernst Worrell et al., 2001). By doing this, we can lower the CO2 emissions caused by both the fuel and the process. M. Schneider et al. (2011) noted that it can be difficult to meet quality, performance, and cost requirements while also reducing the consumption of energy and raw materials. The innovative use of industrial waste, such as flyash and GGBS, in cement manufacturing provides a solution to the environmental crisis and the issue of waste disposal. According to an analysis by Nurdeen M. Altwair et al. (2010), using "Green concrete" to build structures avoids the detrimental effects of the cement industry. In order to produce greener concrete, as much cement as feasible must be replaced with supplemental cementitious materials, particularly those that are by-products of industrial operations such fly ash, rice husk ash, silica fumes, etc. According to Chen Li et al. (2011), the CO2 emission is made up of emissions from fuel, electricity, and raw materials. The total CO2 emissions are 0.66 tons per ton of cement, with direct CO2 emissions per ton of cement clinker being 0.8 tons. The process of particularization is the opposite of generalization. After obtaining a workable customized chain, it is detailed into the matching mechanical device in a skeleton drawing.

3. Literature Review

In this study, **David Stone** et al. report on the pore and micro structure characteristics of a novel binding material based on the carbonation of leftover metallic iron powder. The main component of the binder is metallic iron powder, which is followed by silica and alumina additions that help favorablereaction product production. The bulk of concrete applications can be met using compressive strengths. Mercury intrusion porosimetry is used to analyze the material's pore structure, and electron microscopy is utilized to characterize the material's microstructure. With an increase in carbonation time from 1 day to 4 days, there is a reduction in both the total porosity and the average pore size.

The prospect of carbonating used metallic iron powder to create environmentally friendly concrete binders is explored in this paper by **Sumanta Das** et al. The key idea of this study was that metallic iron will, in the presence of aqueous CO2, react under regulated conditions to produce complex iron carbonates with binding properties. The specimens carbonated for 4 days show mechanical properties that are comparable to those of companion regular Portland cement systems, which are most frequently used as the binder in building and infrastructure construction. The compressive and flexural strengths of optimized iron-based binder systems increase with carbonation duration.

Ali and Koranne investigated how stone dust and fly ash interacted with expansive soil and how that affected the properties of the soil. They demonstrated a notable improvement in the properties of expansive soil as well as a considerable reduction in swelling nature when fly ash and stone dust are combined in equal amounts.

According to research by **Surya R**, Ferrock is a green concrete that reduces CO2 emissions by 30%. Utilizing green concrete products will not only lessen environmental impact and CO2 emissions but also save production costs.

Through trials, **Nivedita M**. created Ferrock using various ratios of basic components. Cement can be replaced partially or entirely with ferrock. The results of experimental research on the CO2 curing process were recommended to be optimal with carbon curing lasting 4 days and air curing lasting 3 days.

A lasting advance in the building sector would result from **Kotla Janardhan Reddy's** compression testing, which revealed that Ferrock concrete was stronger than OPC. By substituting a partial component for cement in concrete, it will also help the environment.

In this essay, **Shivani A.B.** examined the environmental effects of both Ferrock and OPC, focusing in particular on their involvement in carbon pollution, water use, and energy consumption. Contrary to OPC, which can only be water cured, Ferrock cement concrete was CO2 as well as water cured. Concrete made with Ferrock cement benefits more from CO2 curing than water curing. Ferrock is a superior partial material to cement in concrete in terms of environmental sustainability.

4. Ferrock

When David Stone was a PhD student, he experimented with iron rust and the modifications it makes to original material. It was during this time that he developed this exclusive blend. Iron dust, a byproduct of the iron industry that cannot be recycled traditionally and cannot be economically extracted to yield iron, is the main component. As the iron dust dries, it combines with carbon dioxide and other particles to generate Ferrock[1], which is a matrix made of iron carbonate.

The following reaction steps are recognized for this process:

$$Fe + 2CO_2 + H_2O \longrightarrow Fe^{2+} + 2HCO_3^- + H_2$$

$$Fe^{2+} + 2HCO_3 \longrightarrow FeCO_3 + CO_2 + H_2O$$

Finally, the net reaction is:

$$Fe + CO_2 + H_2O \longrightarrow FeCO_3 + H_2$$

Even though the fundamental reaction scheme appears clear and simple, the reaction's kinetics and the rate at which the product is formed are sometimes too slow to be of any use for advantageous industrial applications. In order to manage corrosion rates, dissolving agents (organic) that have a high reducing power and complexing capacity must be used since they have the potential to increase the rate of iron corrosion. Here, for optimum binding and performance needs, we employ ingredients like metakoalin, limestone, flyash, and iron dust. The optimal combination of materials, according to the literature that is currently accessible, is iron dust (60%), fly ash (20%), metakoalin (12%), and limestone (8%). Fully cured samples had between 8 and 11% of collected CO2 by weight, according to analysis (atomic absorption spectroscopy). In contrast to Portland cement, which during production is a significant generator of CO2 and other air pollutants, ferrock is "carbon negative." Contrary to cement, which utilizes water during the process of acquiring strength, or curing, raw components are only moved between locations and mixed here.

5. Technical Properties

Ferrock has similar functional characteristics in terms of its fresh-state behavior and workability, in addition to its special chemical characteristics as a carbon sink that produces valuable hydrogen gas as a byproduct. Additionally, the iron-based binder cures in a smaller amount of time than OPC; it takes 4 days for carbonation versus 28 days for hydration for cement to set. Based on the quality of the compressed carbon dioxide, the curing process for Ferrock may theoretically be sped up even more. [13]

A comparison with the pore structure of 28-day-cured OPC pastes defines additional characteristics by demonstrating that, whereas the overall pore volume was lower in iron-carbonated binders, the critical pore sizes were bigger. This explains why the permeability of Ferrock at 4 days after carbonation (k = 2.5 x 10-16 m2) is much higher than at 28 days after cement paste curing (k = 6.17 x 10-20)[14].

Additionally, investigations demonstrate that the iron-based binder is chemically stable in saltwater settings and does not degrade. Results actually demonstrate that Ferrock has the ability to incorporate some salt, particularly chlorine ions, into the mineral structure. This ability to trap some harmful pollutants, including arsenic, appears to exist. [2]

6. Raw Materials

Ferrock is a binding substance that was primarily developed to replace cement. In order to obtain the product's binding property, cement-like components were employed, and trials were conducted to achieve the same. In order to create ferrock, secondary materials including metakaolin, fly ash, limestone, and oxalic acid were combined with the main ingredient, iron powder.

By weight, the percentage of material

Waste metallic iron powder with a median particle size of 19.03 m makes about 60% of the iron powder.

Fly Ash or Ground Glass Particles 20% Class F Fly Ash Meeting ASTM C 618

10% Limestone Powder that complies with ASTM C 568 and has a mean particle size of 0.7 m

Metakaolin 8% in accordance with ASTM C 618

2% Weak Oxalic Acid Oxalic acid has been utilized as a catalyst in earlier studies.

7. Curing Process

After the samples were maintained for carbon dioxide curing in plastic bags with 100% carbon dioxide at ambient temperature, they were replenished every 12 hours to maintain saturation for 1 to 4 days. Sumanta Das et al. (2014) carried out the process by demoulding right away after the compaction. The samples were then left in room-temperature air for 1 to 30 days to allow any remaining moisture to evaporate. To find the ideal mix of carbon curing length and air curing durations, Sumanta Das et al. (2014) conducted an experiment similar to the one described above. After 4 days of carbon curing and 3 days of air curing, they saw that there was no discernible increase in compressive strength. A thermogravimetric analysis was used to establish the maximum time for carbonation. Beginning with one day of carbon curing, which demonstrated very poor mechanical strength, various carbonation durations were constructed and experimentally evaluated. They also performed experiments with lower carbon curing durations and higher air curing durations, however it was found that air curing was only successful with higher carbon curing durations since the average pore size shrank as carbonation duration increased. And when the specimens were air-cured for a longer period of time and carbonated for longer periods of time, a considerable improvement in strength was seen. This is because, during the initial days of carbonation, larger pores exert less internal moisture pressure during compression tests, and as a result, moisture loss during air curing after shorter periods of carbonation does not have a significant impact on internal pressure, which in turn does not affect compressive strength. Pore size is smaller and more sensitive to compressive strength and moisture loss during air curing at higher carbonation levels. Sumanta Das et al. (2014) carried out the curing of beams by first keeping the polythene molds in the carbon curing, and after the mould is removed, the samples are kept in 100% carbon curing for 5 days with refilling carbon dioxide every 12 hours, and then allowed to air cure for days to let the moisture evaporate. They deemed this healing period to be appropriate because no major alterations were seen after it.

8. Advantages

1. Ferrock is primarily an environmentally friendly martial. Additionally, the generation of hydrogen gas as a by-product of Ferrock manufacturing gives an intriguing prospect for additional applications of this material, particularly as the energy industry searches for alternative fuel sources. Hydrogen gas is one of the best fuels for facilitating the switch away from fossil fuels due to its ability to burn cleanly.
2. By controlling the curing conditions with a repeatable precast technique, it is possible to extract the effluent hydrogen more easily. The precast building could be put inside a vacuum-sealed chamber where a CO2 source would catalyze the chemical reaction. The H2 gas that was released would then be drawn via the chamber's ducting and compressed into useable cylinders. The commercial potential for Ferrock is made to appear endless by offering it as a potential producing source for this high-value fuel.

9. Conclusions

An overview of the development, properties, advantages and disadvantages of using Ferrock in place of concrete has been outlined. Further, based on the literature study, the following general conclusions have been drawn.

1. With a 30% decrease in CO2 emissions from the concrete industry, green concrete has a lower impact on the environment.
2. The heat and fire resistance of green concrete is excellent.
3. Concrete recycling has resulted in greater usage of waste materials by the industry, including ceramic wastes and aggregatesby 30%.
4. Green concrete is therefore more energy-efficient and cost-effective.

Therefore, it is certain that using concrete products like green concrete in the future will not only minimize CO2 emissions and environmental impact but also be cost-effective to produce. We can not only achieve environmentally friendly and sustainable concrete but also achieve a green concrete industry.

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