International Journal of Scientific Engineering and Applied Science (IJSEAS) – Volume-7, Issue-5, May 2021
ISSN: 2395-3470
www.ijseas.com

EVALUATION OF FERROCK: A CARBON NEGATIVE SUSTAINABLE CONCRETE

Ms Amitha P Sunil, Ms MA Chinnamma

[1] Student, Department of Environmental Engineering, MCET, Desamanghalam-679532, Kerala, India

[2]Professor, Department of Environmental Engineering, MCET, Desamanghalam-679532, Kerala, India

ABSTRACT-*In this fast-growing world, people are focusing on the infrastructural development, where construction sector plays an important role. Cement is the most prominent material being used in construction that emits approximately 6-8% of the total carbon dioxide in the world during its production which is the major constituent of global warming. Cement production currently constitutes the fourth largest source of anthropogenic carbon emissions. As these emissions continue to rise, the natural world faces the threat of an unprecedented environmental catastrophe.*

Ferrock, an innovative iron-based binding compound, presents a carbon-negative alternative to cement that utilizes a variety of waste streams to produce a versatile building material.

This paper is a review over a product that is stepping towards carbon negativity and waste management. It shows the best usage of iron ore waste powder obtained during the mining process that is just dumped away from the mines, causing air pollution, health hazards and also consuming larger area. The product indirectly reduces the carbon dioxide released by its unique strength gaining mechanism, which is in contrary with that of the cement and thus stands out among many other supplements of cement. This paper includes a comprehensive literature review, and an in-depth environmental assessment of Ferrock production, from the point of its raw materials extraction, to its curing and hardening phase, and all processing steps in between. The results have been compared to a previous life-cycle analysis of OPC. This preliminary analysis finds that Ferrock has both the intriguing potential to replace OPC, and contribute significantly to the promotion of an environmentally sustainable future.

Key Words: ***Ferrock, carbon footprint, carbon negative, recycled by-product***

1.INTRODUCTION

Methods to reduce greenhouse gases like CO_2 in the atmosphere are an active research area today. Climate change has prompted scientists to search for newer alternatives in this regard in all kinds of fields. Cement in concrete, the second most used entity after water in the world today, is the fourth largest source of anthropogenic carbon emissions (Andrew, 2018). It's been called the foundation of modern civilization. The world's infatuation with this high carbon intensive material has grown to be real pandemic as the accumulation of these emissions contributes to the growing threat of global climatic catastrophe.

One of the major threats our world facing today is global warming. Amongst the greenhouse gases leading to global warming, carbon dioxide is of the maximum percentage.

The ferrock is made of 90 % recycled materials so the cost for making this will be lower than cement when manufactured as bulk. The other factor is that one of the major issues faced by human is the carbon dioxide, which is the major reason for green house effect and other chain problems like global climate change etc. Ferrock is a carbon-negative substance and it takes CO_2 for its reaction, to attain its strength, past studies says that it will take the CO_2 even after attaining the initial strength.

The objectives of this paper are:

- To analyze the suitability of ferrock as a carbon negative sustainable concrete
- To compare ferrock with Ordinary Portland Cement
- To study the properties of ferrock.

2. LITERATURE REVIEW

2.1 CEMENT

In this fast-growing world, infrastructure development is given more importance leading to a linear increase in constructions of multi-stories or high-rise buildings, roads, bridges, towers, etc... The most important material used in this construction is the cement. Cement is a binding material, a substance used for construction that hardens and adheres to aggregates to bind them together to form concrete. Cements used in construction are usually inorganic, often with a lime or calcium silicate base and can be characterized as either hydraulic or nonhydraulic, based on its ability to attain strength in the presence of water (Niveditha M et al, 2020). Portland cement which is largely used in the construction industry is an example of hydraulic cement. They set and become adhesive due to an exothermic chemical reaction between the cement and the water. The chemical reaction also called hydration of cement results in mineral hydrates. This reaction results in the hardening and strength gaining of cement (Turner, 2013).

2.1.2 CARBON FOOTPRINT

With the consumption rate of $1m^3$ per person per year concrete is the most used construction material in the world. Ordinary Portland Cement (OPC) has traditionally been used as the binder material in concrete. On the contrary OPC has carbon emissions in the range of 0.66-0.82kg of CO_2 emitted for every kilogram of OPC manufactured. The contribution of OPC is approximately 5-7% of global CO_2 emissions (Turner, 2013). The main reasons for high contribution to CO_2 emissions from the manufacture of OPC have been attributed to:

1) Calcination of limestone, one of the key ingredients, which leads to formation and release of CO_2.

2) High energy consumption during manufacturing, including heating raw materials within a rotating kiln at high temperatures in the range of 1400℃.

The estimation of CO_2 due to cement manufacturing is a more complicated problem due to the chemical liberation of CO_2 due to decomposition of limestone during calcination, variation of the limestone source and also the use of calorific wastes in cement kilns which provide energy as a substitute fuel. The reported emission factor for cement production is 0.82 kg of CO_2 /kg. The estimate includes the emissions contributed from the mining of raw materials, cement manufacturing, and all transport associated, including the freight of cement to concrete batching plants. (Laurent Barcelo et al., 2013) stated that the cement industry is a major producer of CO_2 accounting to 5-7% of man-made CO_2 emissions.

In cement manufacturing the CO_2 emissions comes majorly from the decarbonation of limestone. (Ernst Worrell et al., 2001) discussed that, the emissions of CO_2 can be reduced by the production of blended cements with fly ash and GGBS. By adopting this we can reduce both fuel and process related CO_2 emissions. M Schneider et al., (2011) observed that the reduction in energy and raw material consumption and also complying with quality, performance and cost requirement is quite a challenge.

Chen Li et al., (2011) stated that the CO_2 emission consists of emission by raw materials, fuel and electricity. The direct CO_2 emissions are 0.8 ton per ton of cement clinker, and the total CO_2 emissions are 0.66 tons CO_2 per ton of cement.

Nurdeen M Altwair et al., (2010) analysed that the solution to reduce the environmental impact is to use ‘Green concrete’ which eliminates the negative impact of the cement industry. To make a greener concrete we must replace as much as cement possible by supplementary cementitious material, especially those that are the byproducts of industrial processes such as fly-ash, rice husk ash, silica fumes etc. Ferrock is such a product which is carbon negative by nature and also which can be used as a supplement to cement which was advocated by David stone, university of Arizona in the year 2017.

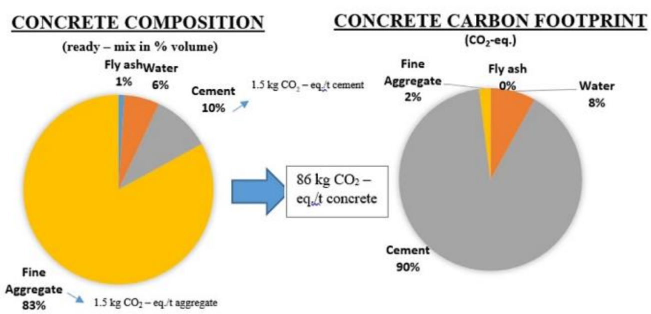

Fig 2.2 Proportion of Cement in Concrete and its carbon footpint, (Niveditha M et al.,2020)

2.1.3 OTHER ENVIRONMENTAL ISSUES BY CEMENT

As per the studies conducted by Magudeaswaran. Pet al.(2019), In addition to the generation of CO_2 the cement manufacturing process produces millions of tons of the waste product cement kiln dust each year contributing to respiratory and pollution health risks. The main environmental issues associated with cement production are consumption of raw materials and energy use as well as emissions to air. Waste water discharge is usually limited to surface run off and cooling water only and causes no substantial contribution to water pollution. The storage and handling of fuels is a potential source of contamination of soil and groundwater. Additionally, the environment can be affected by noise and odors.

The cement production needs the very high amount of energy. Energy cost represents 40% of total production costs involved in producing of 1 ton of cement. Thermal energy demand (fuel) and electrical energy demand are the most important. Specific energy consumption depends on size and plant design, raw materials properties and its moisture, specific caloric values of fuel, throughput of kiln, type of clinker and many other factors. Thermal energy demand is in range of 3000 - 6500 MJ per 1 tone of clinker, the electricity demand ranges from 90 to 150 kWh per 1 ton of cement. Emissions to air and noise emissions arise during the manufacture of cement. Furthermore, with regard to the use of waste, odors can arise, eg. from the storage and handling of waste. In this section, ranges of air pollutant emissions are presented for the process of cement production, including other process steps, such as the storage and handling of, eg. raw materials, additives and fuels including waste fuels. The main constituents of the exit gases from a cement kiln are nitrogen from the combustion air; CO_2 from calcination of $CaCO_3$ and combustion of fuel; water vapors from the combustion process and from the raw materials; and excess oxygen The green concrete concept derives from saving of various natural resources without compromising with the future generation needs, durability, low cost, recycle and reuse of waste materials without wasting space, time and money on their disposal.

Ferrock is an iron-based compound made of 90% recycled materials that have been proven to be less-expensive, 3 stronger and more flexible in its building applications than OPC. Furthermore, this unique material uses compressed carbon dioxide to expedite the curing process and requires no added heat to catalyze its chemical reaction, making it a carbon-negative alternative to OPC, Niveditha.et.al (2020)

2.2 FERROCK

Ferrock, an innovative iron-based binding compound, presents a carbon-negative alternative to cement that utilizes a variety of waste streams to produce a versatile building material. The name (Ferrock) is a reflection of its composition – largely iron-rich ferrous rock. It's actually created from waste steel dust which is normally discarded from industrial processes and silica from ground up glass more flexible and greener concrete. Figure 2.4 shows "Ferrock" green cement material.

Fig. 2.4 Ferrock

As per the available literature, ferrock is a binder. Its key ingredient is iron dust and it reacts with carbon di-oxide and rust, which creates an iron carbonate matrix to form Ferrock while it dries.

The strength gaining mechanism of ferrock is by consumption of carbon dioxide which react with the iron and forms the iron carbonate that adheres strongly to the substrate. With reference to the paper of Sumanta Das et al., (2015), Vijayan D S et al., (2019) and Niveditha M et al., (2020), the accepted reaction steps for this process are:

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

The ingredients are combined as a dry mix with a source of silica, such as fly ash or recycled glass. Oxalic acid is also added to facilitate the chemical process and then blended to create a uniform mixture (Das, Hendrix, Stone, & Neithalath, 2015; Das, Souliman, Stone, & Neithalath ,2014; Das, Stone, Convey, & Neithalath,2014; Widera, & Stone, 2016). The iron residue among the steel reacts with water and, which form an iron carbon matrix; when it dries, it exhausts rock-like qualities called Ferrock. It is also the best choice to substitute for cement. However, concrete has its own tensional limitation and poor ductility. To increase the tensile property of concrete with the help of industrial by- products. Ductility is an important characteristic of structure to resist seismic, impact and blast loading.

2.2.1 RAW MATERIALS

Ferrock is a binding material which was mainly introduced as the cement replacement. Thus, in order to obtain the binding property for the product, materials similar to cement were used and trails were done in order to obtain the same. Thus, considering the minor ingredients such as metakaolin, fly ash, limestone, oxalic acid was used along with the major ingredient iron powder, ferrock was manufactured (Niveditha M et al., 2020).

2.2.1.1 IRON POWDER

Major constituent of ferrock is the iron powder which is obtained from the wastes of steel industries and mines which in-turn does a waste management and it doesn't sum up on to the carbon dioxide content in the atmosphere during its manufacturing process. The iron powder being used is ferrock is taken from the heaps of bag house dust waste of the shot blasting operations of steel and also electric arc furnace manufacturing process of steel. This component is not economically viable to recycle and get the iron content from it thus it has been a landfill at great costs in the world. Niveditha M et al., (2020) have used the metallic iron powder of median size 19 microns which is a waste from structural steel fabrication that has been a burden in dumping it and in turn consuming lot of space. It consists of 88% Fe, 10% O and traces of Cu, Mn, Ca, etc… Iron powder is examined and

Component materials	**% by mass of total powder**							
	mixture number							
	1	2	3	4	5	6	7	8
Iron powder	64	60	62	58	69	65	67	63
Fly ash	20	20	20	20	15	15	15	15
Limestone	8	8	10	10	8	8	10	10
Metakaolin	6	10	6	10	6	10	6	10

Analysis (atomic absorption spectroscopy) shows that fully cured samples contain between 8 and 11% captured CO_2 by weight. Ferrock is therefore ‘‘carbon negative” unlike Portland cement, which during manufacture is a major source of CO_2 and other air pollutants (Niveditha M et. al., 2021)

Alejandro Lanuza Garcia et al., (2015) have tabulated the ferrock mix proportioning of the various raw materials is as shown in Table 2.3. It shows the percentage by weight of the raw materials to be used to make the component Ferrock. It also shows the specifications of the basic properties for the raw materials of Ferrock.

Table 2.3 Summary of materials used for manufacturing of Ferrock

Material	Percentage (by weight)	Specifications
Iron Powder	60	Waste metallic iron powder with a median particle size of 19.03µm
Fly Ash or Glass	20	Class F fly ash conforming to ASTM C 618 or ground glass particles
Limestone	10	Limestone powder (medium particle size of 0.7µm) Conforming to ASTM C 568
Metakaolin	8	Conforming to ASTM C 618

Weak Oxalic Acid	2	Oxalic acid has been used as catalyst in previous research

2.2.3 APPLICATIONS OF FERROCK

Ferrock in original form has 5 times more compressive strength and flexures much more before failure when compared to control mix. Therefore, suitable for earthquake resistant buildings (H.S. Mehta.et al, 2013).

It has various applications similar to normal concrete in buildings, bridges and other conventional uses of concrete. Also, as the specimen gains strength in CO_2 environments it will be very useful in polluted sites of industrial zones (Vijayan D S et al., 2019).

Further, ferrock concrete can also be used for structures in contact with sea water as this fastens the process of rusting and gives strength to ferrock. (S. Karthika et al., 2021)

While using ferrock, 8 to 11% of CO_2 emission is reduced and economical in construction. (S. Karthika et al., 2021)

3. MATERIALS AND METHODS

3.1 MANUFACTURING PROCEDURE

Although the structural applications for both materials are very similar, the manufacturing and chemical processes involved are vastly different. Cement is produced by first mining clay and limestone from rock quarries, using explosives to blast the raw material loose from the earth. The material is then hauled to a crushing facility where it is pulverized into 1-½” rocks and blended into a homogenized mixture. The mixture is temporarily stored and then hauled to a milling factory where the size is reduced to a fine powder. The raw blend is then loaded into a kiln, fired at 1400 degrees Celsius and undergoes a chemical reaction, known as calcination. On a molecular level, the calcium carbonate ($CaCO_3$), found in the limestone, begins to decompose at a high heat, releasing carbon dioxide (CO_2). In the final stage, the heated mixture is sent through a second stage of milling, in which gypsum is added to extend setting time and then sent to a storage facility where it will be stored until it is shipped to the consumer (ENGINEERING INTRO. 2012. Cement Manufacturing Process). At this stage, cement is primarily used for concrete production, which results from the mixing of cement, water and aggregates in the necessary proportions. The combination of cement with water results in an exothermic reaction due to the hydration of the principal chemical components of cement, namely, tricalcium (Ca3) and dicalcium silicate (Ca2SiO4), tricalcium aluminate (Ca3AI2O6), and tetracalcium aluminoferrite (Ca4AI2Fe2O10). These hydrated components harden into a binding material that acts as an agglutinant for the mineral structure formed by the aggregates. Cement also finds its application as a soil stabilizer in geotechnical engineering, and stabilizer for environmental applications.

In comparison, Ferrock also uses clay and limestone as part of its composition, but the ratio of clay and limestone used is much smaller compared to OPC, eight and ten percent respectively. The majority of the mixture, totaling 80%, is composed of low-value waste products. The main ingredient is metallic iron powder, which is a byproduct of shot blasting, a finishing technique for steel manufacturing. During the shot blasting process, the iron powder is ground to a micro-particle scale (~19.03µm) (Das et al., 2017), which becomes a considerable nuisance to the blasting facility because of its ineffectual applicability and the inherent respiratory hazard associated with working with such a fine material. These ingredients are combined as a dry-mix with a source of silica, such as fly ash or recycled glass (2013-2014 Program Report for Tribal eco Ambassadors). Oxalic acid is also added to facilitate the chemical process and then blended to create a uniform mixture.

It is necessary to point out that the Oxalic Acid, while small in percentage, represents an important ingredient of the mixture since it promotes the precipitation and mineralization of iron. It is in fact a well-known chemical promoter commonly used in the iron industry due to its characteristics as an iron dissolvent, which prevents oxidization and has the capacity to absorb CO_2 (by creating iron oxalate). While reacting with the Ferrock mixture, it chemically reacts with the compound and transforms it into a bonded carbonate molecule and therefore has no further threat as an emitting greenhouse gas (GHG) (Dr. Stone, 2017). With the introduction of additional aggregates, water and compressed carbon dioxide, the iron oxide begins to chemically react yielding a new compound, iron carbonate, and emits hydrogen gas as a by-product (Das etal., 2017).

The following system diagrams represent the manufacturing process for each material. It represents a visual model of the components and their interactions. The arrows represent the flow of mass, energy and the effluent by products at each stage of the manufacturing process (John Bello, 2017).

Table 3.1 Performance Comparison Between Ferrock and OPC

Parameter	Ferrock (per metric tonne of production)	OPC (per metric tonne of production)
Energy use (Total Primary Energy Consumption)	557 MJ **	5887 MJ

Water*	220 L	10,100 L
Global Warming Potential (GWP)	-50 kg CO_2-eq	1040 kg CO_2- eq

* These values include the water needed for the curing and hardening phase of the binding materials.

** The manufacturing process of Ferrock generates 17 kg of H_2, which has an energy content of 2210 MJ. Therefore, the overall process produces a net of 2210 - 557 = 1653 MJ.

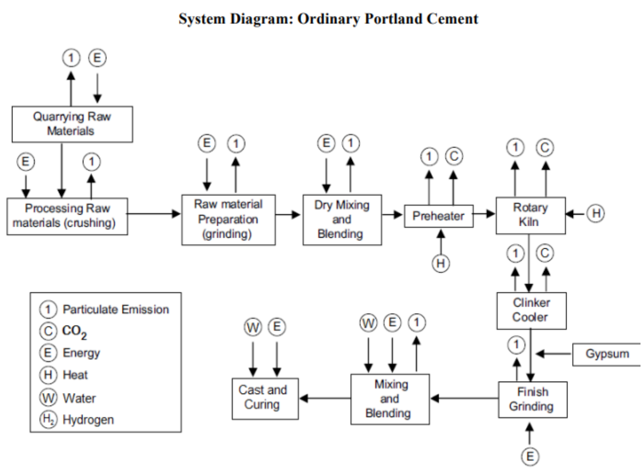

Fig. 3.2 System Diagram of Ordinary Portland Cement

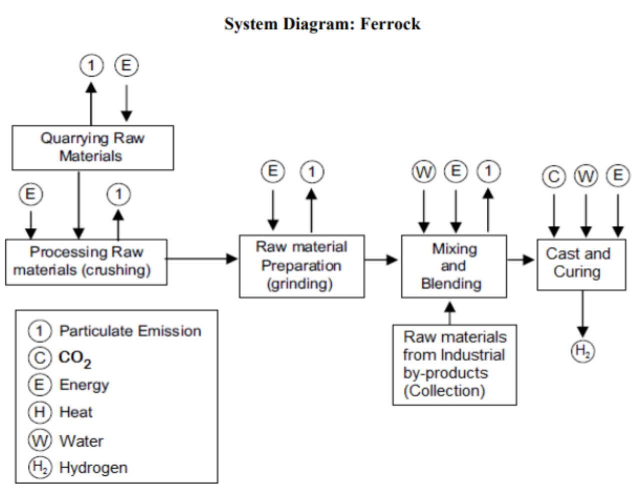

Fig. 3.3 System Diagram of Ferrock

3.2 CASTING, HARDENING AND CURING

Sumanta Das et al., (2014) conducted the curing process by demoulding immediately after the compaction, later when the samples were kept for carbon dioxide curing in plastic bags with 100% carbon dioxide at room temperature was refilled every 12hrs to maintain saturation for 1 to 4 days. Then the samples were placed in air at room temperature letting the moisture to evaporate from about 1 to 30 days. Sumanta Das et al., (2014) carried out a similar experiment as above and to determine the optimal combination of carbon curing duration and air curing durations. They observed that there was no appreciable increase in compressive strength after 4 days of carbon curing and 3 days of air curing.

The upper limit of carbonation duration was determined by a thermogravimetric analysis. Variation in carbonation durations were made and experimentally tested starting from one day carbon curing which showed very low mechanical strength. They also conducted experiment with less carbon curing duration and higher air curing duration, however it was observed that air curing was effective only with the increase in carbon curing duration, as the average pore size decreased with increased carbonation duration. And, a significant increase in strength is observed for specimens carbonated for a longer duration and when the air curing time was increased. This is due to the fact that larger pores in initial days of carbonation exert less internal moisture pressure under compression test and thus loss of moisture in air curing after lesser carbonation duration doesn’t have a larger effect on internal pressure and in turn on the compressive strength. In increased carbonation duration, pore size is reduced and thus more sensitive to compressive strength and loss of moisture during the air curing. Sumanta

Das et al., (2014) conducted the curing process of beams by initially keeping the polythene moulds in the carbon curing and then after the mould is removed the samples ae kept in 100% carbon curing for 5 days with refilling carbon dioxide for every 12 hours and then allowed to air cure for days to let the moisture evaporate. They considered this curing duration to be appropriate beyond which significant changes were not observed.

The machinery and methods used to cast an OPC-based structural material, like concrete, and a Ferrock based structural material are generally the same. However, there are variable differences between the water-solid ratio for each compound and their relationship with CO_2. Also, OPC does not produce H_2 gas during curing.

3.3 STRENGTHS

The basic important characteristic of a concrete block is the compressive strength of it to sustain all the load implied on it. Thus, while supplementing the binding material cement in the normal ordinary Portland cement concrete with the ferrock as a binding material in ferrock blended concrete should be checked with at least its compressive strengths. Vrajesh M Patel et al., (2018) in the year 2018 conducted a combination of cement and ferrock in concrete as a binding material, with supplementing cement by about 20 to 30%. Greater compressive strengths were observed at supplementation of cement by ferrock of 27%. Vijayan D S et al., (2019) conducted experiments on ferrock blended cement concrete at varied replacement by percentages with increment of 4% from 4-12%. It is concluded that 8% substitution gives better results in terms of compression, flexural and split tensile strength.

The basic mix, cement: fine aggregate: coarse aggregate was in a ratio of 1:2:3 for M20 grade cement concrete. For the strength test of ferrock incorporated concrete, the samples are prepared as follows.

In the first mix, 0% of ferrock is added by weight of cement. For the second mix, 4% of ferrock by weight of cement is used as a substitute. Similarly, 8% and 12% of ferrock powder is substituted by weight of cement. The ingredients and their exact proportions are listed in Tables 3.2 to 3.4.

Table 3.2 Proportion of mix ingredients of cubes (D.S. Vijayan et al., 2019)

Grade	No of cubes	Ferrock (%)	Cement (kg)	FA (kg)	CA (kg)	Ferrock (kg)
M20	9	0	13.89	30.55	43.05	0
	9	4	13.32	30.55	43.05	0.57
	9	8	12.512	30.55	43.05	1.11
	9	12	12.213	30.55	43.05	1.677

Table 3.3 Proportion of mix ingredients of cylinder (D.S. Vijayan et al., 2019)

Grade	No of cylinder	Ferrock (%)	Cement (kg)	FA (kg)	CA (kg)	Ferrock (kg)
M20	9	0	18.56	40.84	57.54	0
	9	4	17.817	40.84	57.54	0.742
	9	8	17.075	40.84	57.54	1.484
	9	12	16.332	40.84	57.54	2.227

Table 3.4 Proportion of mix ingredients of beams (D.S. Vijayan et al., 2019)

Grade	No of Beams	Ferrock (%)	Cement (kg)	FA (kg)	CA (kg)	Ferrock (kg)
M20	9	0	21.76	47.87	71.808	0
	9	4	20.889	47.87	71.808	0.87
	9	8	20.019	47.87	71.808	1.74
	9	12	19.148	47.87	71.808	2.611

3.3.1 COMPRESSIVE STRENGTH

The specimens are of size 150 mm x 150 mm x 150 mm for various proportions of ferrock- 0%, 4%, 8% and 12% has casted. The casted cubes are kept for curing of 7 days 14 days and 28 days. Then it was tested in compression testing machine of 2000kN, the results are shown in fig 3.4 (DS Vijayan et.al., 2019)

International Journal of Scientific Engineering and Applied Science (IJSEAS) – Volume-7, Issue-5, May 2021
ISSN: 2395-3470
www.ijseas.com

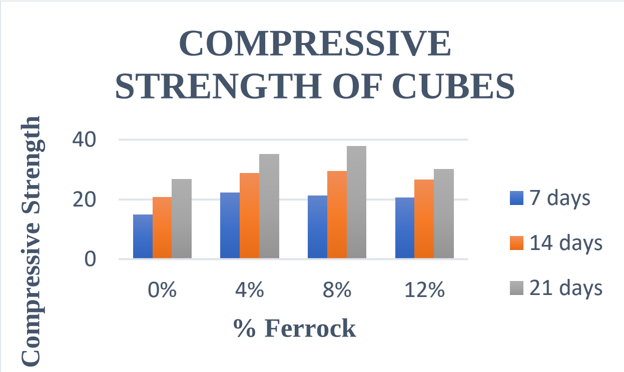

Fig 3.4 Compressive strength of concrete cubes M20 for 7, 14 & 28 days.

3.3.2 TENSILE STRENGTH

The tensile strength of concrete is one of the fundamental and necessary properties that greatly have an effect on the extent and size of cracking in structures. Moreover, the concrete is incredibly weak in tension because of its brittle nature. Hence. It's not expected to resist the direct tension. So, concrete develops cracks once tensile forces exceed its strength. Therefore, it's necessary to work out the strength of concrete to work out the load at that the concrete members might crack. The procedure supported the ASTM C496 (Standard take a look at the technique of Cylindrical Concrete Specimen) that almost like alternative codes like IS 5816 1999. Fig 3.5 shows the tensile strength test results with varying percentages of ferrock. (DS Vijayan et.al., 2019)

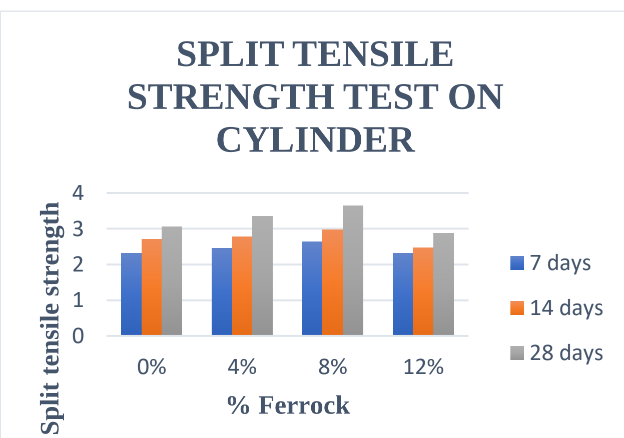

Fig 3.5 Split Tensile strength of concrete cylinder M20 for 7, 14 & 28 days.

3.3.3 FLEXURAL STRENGTH

he flexural strength of concrete beam was determined based on IS 516-1959. Place the specimen within the machine in such a way that the load is applied to the higher most surface as cast within the mould. Apply load continuously without shock and increasing at a rate of 180 kg/min and is multiplied till the specimen fails. Measure the space between the line of fracture and nearest support. The check is distributed with beam specimen to search out of the flexural strength of typical concrete and the test results are in shown Fig 3.6 (DS Vijayan et.al., 2019)

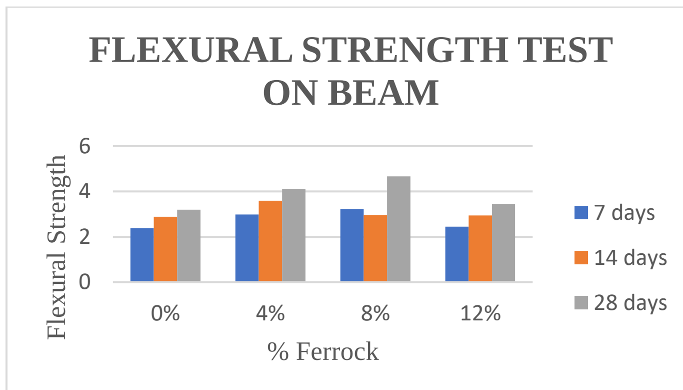

Fig 3.6 Flexural strength of concrete beam M20 for 7, 14 & 28 days.

3.4 POTENTIAL APPLICATIONS

The characteristics of Ferrock make it an extremely versatile compound. Its applications can vary based on the coarse size of the aggregates added. Using a coarse-grit aggregate it may be used slabs, blocks, other pre-cast forms and general applications. By using fine aggregates, the material becomes very malleable and can be spread on like stucco, plaster or mortar. Adding additional reinforcement, like rebar, allows for the construction of large full-sized structures (Dr. Stone, D. 2017). Like concrete, the applications of this material are limited only by its form. When cast in place, Ferrock's shorter cure time allows for compressed project construction schedules, conserving capital resources. While most contemporary building materials must be specially treated to withstand environmental degradation, Ferrock is resistant to rust, oxidation, UV radiation, rotting and corrosion. Therefore, Ferrock can be used for marine applications like breakwater, seawalls, piers, structural pilings, foundations and other structures exposed to seawater. Its environmental durability also makes its application in the manufacture of pipes that are typically used for water transmission and wastewater removal. Ferrock is not affected by the constituents of sewage water like hydrogen sulfide and sulfuric acid, which corrodes regular cement pipes. Further, since Ferrock is less brittle compared to concrete, it enables better pipe-to-pipe connection and consequently there is less damage while aligning and installing sections (Ironkast -Precedent of Ferrock).

In a large-scale application, the plausibility for sizable industrial transformation begins to take form. By constructing buildings, homes, roadways, walkways and various forms of infrastructure out of this material prospective urban-dwellings will become consumers of carbon dioxide compared to the exponential producers of present-day. While architects may quarrel with the ascetic limitations of a rustic pigment covering the majority of urban landscapes, the consequent environmental restoration associated with such an effort may entice designers to find new applications for a variety of red-Ferrock structures.

3.5 ENVIRONMENTAL IMPACT ASSESSMENT OF FERROCK PRODUCTION

The following table shows the results from weighting selected values with the proportions of each material. (Bello,2017)

Table 3.5 Environmental Impact Assessment of Ferrock

Raw Materials	GWP (kg CO_2-eq/ FU)	Energy (MJ/ FU)	Water (litres / FU)
1. RAW MATERIAL PRODUCTION			
Iron Powder	-	-	-
Fly Ash	0.72	6.03	0
Limestone	2.88	4.11	4.32
Metakaolin	31.32	180	0
Oxalic Acid	-	-	-
Carbon Dioxide	(100)	0	0
2. TRANSPORTATION			
Iron Powder	1.67	10	0
Fly Ash	0.56	26.71	0
Limestone	3.9	23.4	0
Metakaolin	6.62	81.57	0
Oxalic Acid	1.66	20.40	0
Carbon Dioxide	0.31	1.85	0
3. MANUFACTURING			
Mixing, Casting, Hardening and Curing	0	170.2	216

4. BYPRODUCT GENERATION			
Hydrogen	17 (kg H_2/ FU)	(2210) (Energy equivalent of 17 kg H_2 [22])	0
TOTAL			
1 FU	49.64 -100 = -50.36	524.34-2210 = -1685.66	220.32

4. RESULTS AND DISCUSSIONS

The studies conducted on ferrock composition gave a clear picture on the complete replacement of cement with ferrock as the binding material. The best possible proportion of ingredients are 60% iron powder, 20% fly ash, 10% metakaolin, 8% limestone, 2% oxalic acid. Analysis (atomic absorption spectroscopy) shows that fully cured samples contain between 8 and 11% captured CO_2 by weight. Ferrock is therefore ''carbon negative" unlike Portland cement, which during manufacture is a major source of CO_2 and other air pollutants.

Carbon curing duration and air curing duration was finalized to 4 days and 3 days respectively for ferrock blended concrete for better compressive strengths. The experimental works conducted on ferrock are majorly focusing on complete replacement of cement by ferrock with carbon and air curing.

Table 4.1 Curing properties

	Ferrock	OPC
Water-Solid Ratio	0.18 to 0.30	0.40 to 0.70*
CO_2	Absorbs CO_2 in a ratio of 0.1 tonnes CO_2/ tonne	No relationship during curing
H_2	17 kg H_2/ tonne produced	No relationship during curing

*This ratio is very dependent on the workability requirements of the mixture and can be easily altered by using additives to the mix, such as plasticizers or superplasticizers.

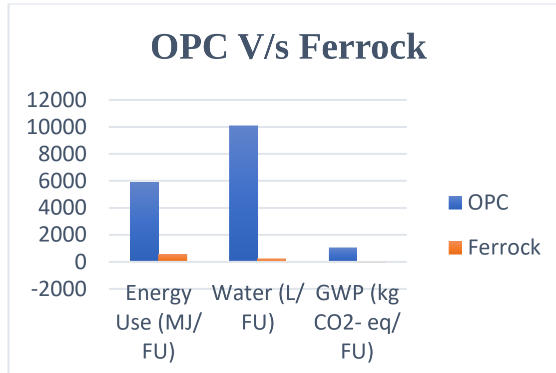

Fig. 4.1 Comparison of Ferrock and OPC, Bello (2011)

The energy-intensive manufacturing process of Ordinary Portland Cement (OPC) contributes significantly to the surging volume of accumulated Green House Gases (GHG) emissions in the atmosphere and continued natural resource depletion. Fig. 4.1 shows the comparison of OPC and ferrock in terms of energy use, water requirement, and Global Warming Potential (GWP). Due to the unique and encouraging technical characteristics, the versatile applicability and the respectively minimal impact it has on the 20 natural world throughout the first initial stages of the product's life, ferrock serves as a suitable replacement for Ordinary Portland Cement in the majority of functional applications. Even in its propriety state the quantifiable advantages of using Ferrock have been defined to be extremely enticing, but the ambiguity of its unique properties have the potential to have an even greater influence of the sustainable well-being of the environment and the prosperity of human civilization.

The compressive strength for cube of controlled mix for 7, 14 and 28 days are 14.93 N/mm2, 20.69 N/mm2 and 26.80 N/mm2 respectively. The compressive strengths for 4%, 8% and 12% ferrock concrete for 28 days are all higher than normal concrete. They are 35.13 N/mm2, 37.87 N/mm2 and 30.15 N/mm2 respectively. The splitting tensile test on cylinder for controlled mix for 7, 14 and 28 days are 2.34 N/mm2 , 2.71 N/mm2 and 3.05 N/mm2 respectively. The splitting tensile test for 4%, 8% and 12% ferrock concrete for 28 days are all higher than normal concrete. They are 3.35 N/mm2, 3.65 N/mm2 and 2.87 N/mm2 respectively. The flexural strength of control mix concrete is 7, 14 and 28 days are 2.37 N/mm2, 2.89 N/mm2 and 3.2 N/mm2 respectively. The flexural strengths for 4%, 8% and 12% ferrock concrete for 28 days are all higher than normal concrete. They are 4.1 N/ mm2, 4.67 N/mm2 and 3.45 N/mm2 respectively. From the results it is evident that the 8% ratio has improved strength when compared to the other ratios of the concrete. Flexural strength of the ferrock concrete was improved 4.1 N/mm2, 4.67 N/mm2 and 3.45 N/mm2 respectively with the 4%, 8% and 12% respectively.

From the results it is evident that the 8% ratio has improved strength when compared to the other ratios of the concrete. Test results on the compressive strength, splitting tensile test and flexural strength has revealed that the 8% ratio of the ferrock cement has better results when compared to the other ratios.

5. CONCLUSIONS

Investigation on the Ferrock as a carbon negative sustainable alternative for the cement concrete was carried out in the present work to improve the strength of the materials when used a Solid block.

Ferrock was constituted based on testing with different proportions of the raw materials. The composition of ferrock thus finalized as 60% iron powder, 20% fly ash, 10% metakaolin, 8% limestone, 2% oxalic acid in terms of rheological characteristics.

The experimental studies on the curing process suggested that carbon curing of 4 days and air curing of 3 days gives the best result of ferrock blended concrete for better compressive strengths

Test results on the compressive strength, splitting tensile test and flexural strength has revealed that the 8% ratio of the ferrock cement has better results when compared to the other ratios. Hence the test results reveal that the 8% ratio will be optimum to be used in the construction industry.

Ferrock can be used for marine applications like breakwater, seawalls, piers, structural pilings, foundations and other structures exposed to seawater as it is resistant to rust, oxidation, UV radiation, rotting and corrosion. Its environmental durability also makes its application in the manufacture of pipes that are typically used for water transmission and wastewater removal.

As it has 5 times more compressive strength and flexures much more before failure, it is suitable for earthquake resistant buildings.

It has various applications similar to normal concrete in buildings, bridges and other conventional uses of concrete. Due to its property of strength gaining in CO_2 environments, it will be very useful in polluted sites of industrial zones.

Environmental Impact Assessment studies, ferrock serves as a sustainable environment friendly replacement for Ordinary Portland Cement. While using ferrock, 8 to 11% of CO_2

emission is reduced and economical in construction, so it is carbon negative in nature.

Ferrock constructions are best suitable in the countries like India, where steel mines are present so that to use the steel waste for constructions and thus avoid the issues of waste disposal.

REFERENCES

1) Vijayan, D. S., Arvindan, S., & Janarthanan, T. S. (2020). Evaluation of ferrock: a greener substitute to cement. Materials Today: Proceedings, 22, 781-787
2) Niveditha M, Y M Manjunath , Setting H S Prasanna (2020). Ferrock: A Carbon Negative Sustainable Concrete. International Journal Of Sustainable Construction Engineering And Technology Vol. 11 No. 4 (2021) 90-98
3) Kavita Singh , Compressive Strength Study Of Green Concrete By Using Ferrock, Multidisciplinary International Research Journal of Gujarat Technological University ISSN: 2581-8880, Volume 2 Issue 2 July 2020
4) S. Karthika, A Leema Rose, G Priyadarsini, Sustainable Development on Ferrock Mortar Cubes, International Conference on Physics and Energy 2021 (ICPAE 2021)
5) Alejandro Lanuza Garcia , Ashik Thithira Achaiah , John Bello , and Thomas Donovan, Ferrock: A Life Cycle Comparison to Ordinary Portland Cement, ISE 576 - Industrial Ecology 2017
6) Tarun Parihar, Priya U. Mahato, Tejas Dilip Patil, Green Building Materials – An Approach Regarding Green Construction , International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056 Volume: 06 Issue: 04 | Apr 2019
7) Andrew, R. M. (2018). Global CO 2 emissions from cement production. Earth System Science Data, 10(1), 195
8) Phd Barbara Widera, PhD David, Analysis Of Possible Application Of Iron-Based Substitute For Portland Cement In Building And Its Influence On Carbon Emissions. The Examples Of Jizera Mountains Region And Tohono O'odham Indian Reservation
9) Magudeaswaran. P, Kiran. K , ShabeerShumsudheen , Srivignesh. N. K, Reduction In Green House Gas And Agricultural Solid Waste In Green Concrete International Journal of Advanced Research in Basic Engineering Sciences and Technology (IJARBEST) ISSN (ONLINE):2456-5717 Vol.5, Issue.5, May 2019
10) Hassan Ahmed Hassan / et al/ Alternative architecture as a new approach to achieve energy efficiency “Guiding bio-mimicry in architectural design” Engineering Research Journal 167(septamber 2020/ A1– A17) A1
11) “An In-Depth Look at Ferrock And How it Compares to Concrete.” HRL Tech, http://hrltech.com/2014/12/02/an-in-depth-look-at-ferrock-and-how-it-compares-to- concrete
12) Picasso Kumar Debnath, Ecological Construction of Low Cost Building in public and Government Sectors (A feasible solution to contaminated environment of Bangladesh)
13) Pandey Shivam, Dalvi Ankit, Chaurasia Brijesh & Patel Arshan, (2017), “A Review on the Study of Green Concrete”, International Journal of Advanced Research in Science, Engineering and Technology, ISSN: 2350-0328,Vol.4, Issue 7.
14) Priyanshu Shekhar, Rudali Nagpurkar, Bhagyashree Selore, Prashant Sonekar,

Rahul Sonaghare, Mr. Atul Gautam, (2017), " Green Concrete for Better Sustainable Development", International Research Journal of Engineering and Technology, ISSN- 2395 - 0072, Volume - 4, Issue – 3

15) Rahul Hodge, Shrikant Shitole & Deepak Yewale,(2018) "Experimental Study on Green Concrete", International Journal of Advance Research in Science and Engineering, Volume No.7, Special Issue No.3
16) H.S. Mehta, Vishal Porwal Green Building Construction for Sustainable Future, Civil and Environmental Research www.iiste.org ISSN 2224-5790 (Paper) ISSN 2225-0514 (Online) Vol.3, No.6, 2013.
17) "An In-Depth Look at Ferrock And How it Compares to Concrete." HRL Tech, http://hrltech.com/2014/12/02/an-in-depth-look-at-ferrock-and-how-it-compares-to- concrete.
18) Watts, Johnathon. (2019) "Concrete: the most destructive material on Earth." Theguardian, https://www.theguardian.com/cities/2019/feb/25/concrete-the-most-destructive-material-on-earth.
19) Turner, L. K., & Collins, F. G. (2013). Carbon dioxide equivalent (CO2-e) emissions: A comparison between geopolymer and OPC cement concrete. Construction and Building Materials, 43, 125-130
20) Suresh, D., & Nagaraju, K. (2015). Ground granulated blast slag (GGBS) in concrete–a review. IOSR journal of mechanical and civil engineering, 12(4), 76-82
21) Vrajesh P and Hardik. S, (2018), Development of Carbon Negative Concrete by Using Ferrock, International Journal of Scientific Research in Science, Engineering and Technology, 21-25
22) Lanuza, A., Achaiah, A. T., Bello, J., & Donovan, T. (2017). Ferrock, ISE 576-Industrial Ecology, 2-24
23) Widera, B., & Stone, D. (2016). Analysis of Possible Application of Iron-Based Substitute for Portland Cement In Building And Its Influence On Carbon Emissions. The Examples of Jizera Mountains Region and Tohono o'odham Indian Reservation. International Multidisciplinary Scientific GeoConference: SGEM, 2, 455-462
24) ENGINEERING INTRO. 2012. Cement Manufacturing Process. [ONLINE] Available at: http://www.engineeringintro.com/uncategorized/cement-manufacturing-process.
25) Versatile Cement. Cement Applications. Accessed April 21, 2017
26) EPA. "Creating a Carbon-Negative Building Material from Recycled Glass, Steel Dust, and Carbon Dioxide (Tohono O'odham Community College)". 2013-2014 Program Report for Tribal ecoAmbassadors.
27) Das S. et al.. "Pore- and Micro-structural Characterization of a Novel Structural Binder Based on Iron Carbonation." Science Direct. Materials Characterization, Dec. 2014. Web. 27 Feb. 2017
28) Dr. Stone, D. (2017, April 18). Inventor of Ferrock. Telephone interview.