EXPERIMENTAL INVESTIGATION OF FERROCK BY COMPLETE AND PARTIAL REPLACEMENT OF CEMENT IN CONCRETE

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Abstract - *Cement is a major binding component in concrete. It is of great importance in construction industry. Even though cement has these prominent properties, it emits carbon dioxide. So ferrock is used as an alternative for cement. Ferrock is an innovative iron-based binding compound, which presents a carbon-negative alternative to cement that utilizes a variety of waste streams to produce a versatile building material. Ferrock is a binder that is a blend of iron oxide powder, fly ash, lime powder, metakaolin and oxalic acid. Oxalic acid act as a catalyst. Iron oxide reacts with carbon dioxide and water produces iron carbonate. It can enhance the environment by absorbing the atmospheric carbon dioxide for its hardening process. By the use of ferrock the rate of emission of most dangerous greenhouse gases are reduced. During the curing process, carbon dioxide is used instead of traditional water curing. This helps in reducing the usage of water.*

Key Words: Ferrock, oxalic acid, carbon dioxide absorption, carbon, cement replacement, waste management, carbon negative

1. INTRODUCTION

Infrastructure development is resulting in a linear increase in the construction of multi-stories or high- rise buildings, roads, bridges, towers, etc. The foremost vital material utilized in this construction is that the cement. Cement is that the binding material accustomed to gain strength so as to sustain the weight applied on that, it is associated by artificial means of factory-made product that releases carbon dioxide within the method of its manufacture that contributes to the entire atmosphere by more or less about 6 to 8%. This proposes to gauge the power of ferrock to be used jointly as the simplest doable substitutes for cement in concrete. It is mostly associated with iron based binding compound that utilises different type of waste materials to make a carbon negative artefact.

1.1 Significance

Cement in concrete is that, the second most used entity when. Water in the world nowadays, is that the fourth largest supply of phylogenies carbon emissions. The worlds infatuation with this high carbon intensive material has full-grown to be real pandemic, because the accumulation of those emissions contributes to the growing threat of worldwide climatically catastrophe.

Ferrock is associated with an iron-based binding compound that is manufactured from 95% of recycled materials that are tried to be less-expensive, stronger and additional versatile in its building applications than ordinary Portland cement. Ferrock in original type has 5 time's additional compressive strength and flexures far before failure in comparison to manage the combination of control mix. For winding up the overall replacement of cement the most demand may be a 100% greenhouse emission atmosphere for curing. Furthermore, this building material uses compressed carbon dioxide to expedite the curing process and requires no added heat to catalyse its chemical reaction making it a carbon negative alternative to ordinary Portland cement. Ferrock is a binder that is a blend of iron oxide, fly ash, lime powder, metakaolin and oxalic acid. Oxalic acid act as a catalyst and on reaction with carbon dioxide and water produces iron carbonates, which is the hardest. Ferrock involves a curing process. Ferrock is thus a more promising eco-friendlier binding material in terms of its carbon negativity and in best usage of the waste.

1.2 Objectives

- To determine the compressive strength of Ferrock
- To determine the mechanical properties of ferrock cement concrete using water curing and carbon dioxide curing.
- To determine durability properties of ferrock cement concrete using water curing and carbon dioxide curing.
- To compare curing of ferrock cement concrete using water curing and carbon dioxide curing.

1.3 Scope

- Ferrock production shows an intriguing opportunity for future applications, especially as the energy industry looks for alternative sources offuel.

- Ferrock have been represented as an extremely enticing, but the ambiguity of its unique properties has the potential to have a much greater impact on the sustainable well-being of the abode and the prosperity of human advancement.

- Focussing on carbon emission reduction as well as utilization of waste materials to produce a better environment.

- Development of new engineered cementitious material which has more future opportunities.

2. FERROCK

Ferrock is a better alternative to conventional concrete. It acts as a waste management tool, wherever within the waste is being best utilized. The raw materials which is employed in the production of ferrock when used in different proportions to get the best use of it in terms of strength. The major ingredient in the ferrock is the iron oxide powder. Other components of ferrock are used based on its comparison with that of cement as this product is an alternative to cement in many purposes, and also its compatibility with other materials for construction. The strength gaining mechanism of ferrock is by consumption of carbon dioxide that reacts with the iron and forms the iron carbonate that adheres powerfully to the substrate. Now, in case of ferrock the curing process conducted is carbon dioxide curing. It is noted that carbon curing of 4 days and air curing of 3 days will give best test result. Water is simply for transferring and intermixture of the raw materials in contrast to cement that uses it throughout its strength gaining activity, the curing process.A product named ferrock is a binder material used as a partial or complete replacement to cement in concrete. Ferrock was measured based on its testing with different proportions of the raw materials. The composition of ferrock was concluded as 60% iron powder, 20% flyash, 10% metakaolin, 8% limestone, 2% oxalic acid in terms of rheological characteristics.The pore and micro structural properties of the better performing material was concluded as ferrock.

3. FERROCK CEMENT CONCRETE

In order to contrast the environmental effects of ordinary Portland cement and ferrock especially aiming on their contribution to carbon pollution, water use, energy consumption. By substituting partially ferrock with cement in varied proportions as 4%, 8%, 12% in concrete optimum ratio of replacement which would give better strength in terms of sustainability. And hence a new product called Ferrock Cement Concrete evolved.

In the first mix 4% ferrock by weight of cement (96%) is used as a substitute. Similarly 8% ferrock by weight of cement (92%) is used as a substitute and also 12% of ferrock by weight of cement (88%) is used as a substitute. The maximum strength of concrete is obtained at 8% of replacement of ferrock by weight of cement. Ferrock cement concrete is a stronger binding material that helps to increase the bond strength of the concrete mix without any failure. The strength gaining mechanism of ferrock cement concrete is by both air curing and water curing. Air curing is mainly done by using carbon dioxide gas in an air tight container or plastic cover and carbon dioxide gas is introduced in it.

4. MATERIALS USED

4.1 Ferrock

1. Iron oxide powder
2. Flyash (Class F)
3. Limestone Powder
4. Metakaolin
5. Oxalic acid

Table -1: Percentage of materials added in ferrock

Materials	Percentage{byweight}
Iron oxide powder	60%
Flyash	20%
Limestone Powder	10%
Metakaolin	8%
Weak Oxalic Acid	2%

Iron oxide powder: Iron oxide particles as produced for the construction industry, are 10 times finer than cement particles. When added into a concrete mix, the iron oxide particles actually surround and coat the cement particles. This is why integral colour is dosed or metered based on the cement content, not on the amount of sand, stone or water. Iron oxide powder is examined and stated that they are elongated and angular in shape. However, the large surface area helping it to provide greater reactivity.

Fig -1: Iron oxide powder

Fly Ash: Fly ash is a by-product or a waste product, hence use of fly ash concrete reduces CO2 and is thus is environment friendly. It has good cold weather resistance and non-shrink material. Fly ash concrete has great workability as well and allows for a lower water-cement ratio similar slumps compared to the ordinary concrete. It reduces heat of hydration, cracks, permeability, bleeding. It is cost-effective substitute for Portland cement.

Fig -2: Flyash

Limestone powder: Addition of limestone powder provides easier grindability, reduced water demand, increased strength and less bleeding in concrete. Limestone due to its reactive nature provides nucleation sites for clinker hydration products, and reduces heat of hydration. Bending of Limestone in cement will reduce the emission of CO_2 and addition of limestone will improve workability of cement. Limestone powder is a by-product of the limestone quarry, and it has been used in cement-based materials. Limestone can be formed from marine organisms, lacustrine and evaporate depositional environments.

Fig -3: Limestone powder

Metakaolin: Metakaolin is a high-quality pozzolanic material. Metakaolin is one of the most widely used admixtures these days. It helps concrete to obtain both higher performance and economy. It is produced from high Kaolin. Metakaolin consist of silica and alumina in an active form and as other mineral admixtures, it reacts with calcium hydroxide at room temperature and form calcium silicate hydrate-gel which increases the density of concrete and reduces porosity.

Fig -4: Metakaolin

Oxalic Acid: Oxalic acid is a weak acid and is reported to act as an accelerator for cement hydration reaction. This may also be helpful in the formation of a protective electrical double-layer film around the cement particle during gel state.

Fig -5: Oxalic acid

Carbon dioxide: The curing of concrete elements by diffusing carbon dioxide into it under controlled pressure and temperature is one of the popular methods of accelerated curing. In ferrock concrete and ferrock cement concrete CO_2 curing is more beneficial. Iron oxide powder reacts with carbon dioxide to form iron carbonate which gives binding ability to ferrock.

The accepted reaction steps for this process are: Fe

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

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

The net reaction then is

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

Fig -6: Carbon dioxide gas

4.2 Cement

In this project work, 53 grade of Ordinary Portland Cement is used. As per the Indian Standard the different tests are done for the accuracy such as Fineness Test, Consistency Test, Specific Gravity, Intial and Final Setting time.

Fig -7: Cement

4.3 Aggregate

Aggregate is one of the most important ingredient of the concrete which is responsible to provide the strength to the structure. To get the best result we used angular aggregateand as the Indian Codal Provisions we did the tests such Specific Gravity, Fineness modulus. Fine aggregate used is M Sand. Coarse aggregate of 20mm size is used.

Fig -8: Fine and coarse aggregate

5 TEST ON FERROCK

5.1 Specific gravity

Specific gravity is defined as the ratio between weight of a given volume of material and weight of an equal volume of water. To calculate specific gravity for any material, we have to use water. But water reacts with cement and forms calcium oxide. So that we are using Kerosene. It doesn't react with cement. The specific gravity of the ferrock mix obtained after testing was 1.36 which is less compared to ordinary Portland cement.

5.2 Fineness of ferrock mix

The fineness of ferrock mix was determined using 90 micron sieve and found that 0 percent of the particles retained within the 90 micron sieve.

6 MIX DESIGN

6.1 Coventional Concrete

W/C ratio = 0.50

Mix Ratio = 1:1.9:3.1 (cement: sand: aggregate)

6.2 Ferrock

W/C ratio = 0.5

Mix Ratio = 1:1:2 (ferrock:sand:aggregate)

7 CASTING AND TESTING OF SPECIMENS

7.1 Coventional Concrete

Casted conventional concrete of M25 mix design and the mix raito is 1:1.9:3.1 (cement:sand: aggregate). After mixing the conventional concrete mix was casted into moulds of different cubes, cylinders and beams and Compressive strength test, Splitting tensile strength test, Flexural strength test on conventional concrete are tested. Conventional concrete is cured using water.

Fig –9: Casting of conventional concrete

7.2 Ferrock Concrete

Casted ferrock concrete of M25 mix design and the mix ratio is 1:1:2 (ferrock:sand: aggregate). After mixing the ferrock mix was casted into moulds of cube size 150mm*150mm*150mm. Ferrock concrete is cured using carbonation. CO_2 gas is passed through the mix for curing using special setups. By absorbing carbon dioxide for long time, the ferrock material will get strengthened more. Curing process is one of the major difference between conventional concrete and ferrock concrete. In conventional concrete lots of water is being used for mixing and curing process. But in ferrock concrete water usage for curing is less.

Fig -10: Casting of ferrock concrete

7.3 Ferrock Cement Concrete

In the basic mix, cement:fine aggregate:coarse aggregate was in a ratio of 1:1.9:3.1 for M25 grade concrete. In the first mix, 4% of ferrock by weight of cement is used as substitute. Similarly, 8% and 12% of ferrock powder is substituted by weight of cement. With the help of mix ratio the weight of all materials are calculated for mixing concrete in required volumes for all the specimens of cube size 150mm*150mm*150mm size, split tensile cylinder size 300mm*150mm and flexural beam of 100mm*150mm*150mm has been casted as per decided percentage substitution.The casted specimen have been kept for 24hrs in a dry place for making harden concrete and the removed from mould. After remolding the specimens it has to keep curing in water and carbon dioxide for 7,14,28 days. After curing the specimen is taken out from curing tank and dried for few hours to remove the moisture content. The dried specimen is to be tested for compressive strength, split tensile and flexural strength. The results of substituted specimens have been compared to conventional concrete without substitution. It has given a value at which percentage of ferrock in concrete reaches its maximum strength. The optimum dosage has been noted from the experimental result.

Fig -11: Casting of ferrock cement concrete

8 TEST ON SPECIMENS

8.1 Conventional concrete

Table -2: Coventional concrete test values

TESTS	DAY 7	DAY 14	DAY 28
Compressive Strength Test (N/mm^2)	23.55N/mm^2	24.44N/mm^2	26.22N/mm^2
Splitting Tensile Strength Test(N/mm^2)	2.12N/mm^2	2.2N/mm^2	2.55N/mm^2
Flexural Strength Test (N/mm^2)	2.35N/mm^2	2.81N/mm^2	3.3N/mm^2

8.2 Ferrock concrete

Table -3: Compressive strength test values of ferrock

TESTS	DAY 7	DAY 14	DAY 28
Compressive Strength Test (N/mm^2)	2.3N/mm^2	2.57N/mm^2	2.68N/mm^2

8.3 Ferrock Cement concrete

Table -4: Compressive strength test values of ferrock cementconcrete in CO_2 curing

Percentage replaced (%)	Compressive strength after 7 days (N/mm²)	Compressive strength after 14 days (N/mm²)	Compressive strength after 28 days (N/mm²)
4%	21.86	27.83	35.24
8%	22.13	29.24	36.94
12%	21.1	26.43	32.61

Table -5: Compressive strength test values of ferrock cementconcrete in water curing

Percentage replaced (%)	Compressive strength after 7 days (N/mm²)	Compressive strength after 14 days (N/mm²)	Compressive strength after 28 days (N/mm²)
4%	20.1	26.1	34.2
8%	20.16	28.2	35.3
12%	19.3	25.1	30.01

Table -6: Splitting Tensile strength test values of ferrock cement concrete in CO_2 curing

Percentage replaced (%)	Compressive strength after 7 days (N/mm²)	Compressive strength after 14 days (N/mm²)	Compressive strength after 28 days (N/mm²)
4%	2.52	2.83	3.24
8%	2.63	2.94	3.42
12%	2.41	2.56	2.75

Table -7: Splitting Tensile strength test values of ferrock cement concrete in water curing

Percentage replaced (%)	Compressive strength after 7 days (N/mm²)	Compressive strength after 14 days (N/mm²)	Compressive strength after 28 days (N/mm²)
4%	2.14	2.32	3.1
8%	2.5	2.81	3.4
12%	2.11	2.32	2.51

Table -8: Splitting Tensile strength test values of ferrockcement concrete in CO_2 curing

Percentage replaced (%)	Compressive strength after 7 days (N/mm²)	Compressive strength after 14 days (N/mm²)	Compressive strength after 28 days (N/mm²)
4%	2.94	3.23	4.24
8%	3.24	3.76	4.42
12%	2.41	2.96	3.45

Table -9: Flexural strength test values of ferrock cement concrete in water curing

Percentage replaced (%)	Compressive strength after 7days (N/mm²)	Compressive strength after 14 days (N/mm²)	Compressive strength after 28 days (N/mm²)
4%	2.15	3.01	4.02
8%	3.11	3.53	4.01
12%	2.22	2.53	3.1

9 DURABILITY TEST

9.1 Water Absorption Test

Moisture penetration is one of the factors affecting the durability of concrete. Concrete as a porous material which can allow water to migrate through it, corroding steel reinforcement, bringing in harmful chemicals. So it is a predominant factor to be determined to asses the quality of concrete. For water absorption test, cube specimen of size of 150mm*150mm*150mm was casted and immersed in water and carbon dioxide curing for 28 days. The specimens are ovendried for 24 hours at the temperature of 110 degree Celsius until the mass becomes constant and again weighed at room temperature.

% water absorption = (W1 – W2) / W2 *100
W1 = oven dried weight of specimen
W2 = final weight of specimen

Table -10: Water absorption test values in carbon dioxide curing

Sl.No.	Before immersion (kg)	After immersion (kg)	Percentage loss in weight
1	8.310	8.415	1.26
2	8.211	8.302	1.11
3	8.101	8.302	1.50

Table -11: Water absorption test values in water curing

Sl.No.	Before immersion (kg)	After immersion (kg)	Percentage loss in weight
1	8.150	8.310	1.96
2	8.112	8.232	1.48
3	7.99	8.119	1.61

9.2 Sulphate Test

5% sodium sulphate (Na_2SO_4) by volume solution were prepared and three cubes of size 150mm*150mm*150mm were immersed in solution after 28 days curing in water and carbon dioxide for taking 28 days after taking intial weights. The cubes were weighted and tested on compression testing machine after 28 days.

% loss in weight = (W1 – W2) / W2 *100
W1 = oven dried weight of specimen
W2 = final weight of specimen

Table -12: Sulphate test values in carbon dioxide curing

Sl.No.	Before immersion (kg)	After immersion (kg)	Percentage loss in weight
1	8.337	8.373	0.431
2	8.327	8.363	0.432
3	8.405	8.441	0.421

Table -13: Sulphate test values in water curing

Sl.No.	Before immersion (kg)	After immersion (kg)	Percentage loss in weight
1	8.404	8.440	0.428
2	8.334	8.370	0.431
3	8.324	8.360	0.432

10 CONCLUSIONS

Our study compares the environmental impacts of ordinary Portland cement and ferrock (iron oxide powder-60%, flyash-20%, metakaolin -12%, and limestone-8%) focussing specially on their contributionto carbon pollution, water use and energy consumption.By substituting cement with ferrock in varying proportions as 4%, 8%, and 12% in concrete we are trying to find the optimum ratio of replacement which would give desired results in both strength(compressive, split tensile & flexural strength).In all the test results 8% shows the good result in strength. It is also seen that Specific gravity of ferrock mix is less than specific gravity of cement.Ferrock cube achieved amaximum compressive strength of 2.68 N/mm^2only. This is due to the variation in particle sizeof iron powder and environmental condition. From the test results it is seen that mechanical strength of ferrock cement concrete is greater than that of conventional concrete. In ferrock cement concrete, 8% replacement of cement shows increase in strength. The ferrock cement concrete was both water cured and Carbon dioxide cured. CO_2 curing is better than water curing in ferrock cement concrete. To save the environment, ferrock is the better partial substance as replacement of cement in concrete.

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