Experimental Investigation on Eco friendly Ferrock concrete

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***Abstract*— Concrete is the most used building material for Construction works, which is responsible for 70% of the industrial carbon dioxide emission. 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. From this perspective, the green concrete concept has evolved, and more research have been done on replacement by green materials. 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 Powder, fly ash, lime Powder, metakaolin and oxalic acid. Oxalic acid acts as a catalyst and on reaction with CO2 and water produces Iron Carbonates, which is the hardened product. It can enhance the environment by absorbing the atmospheric CO2 for its hardening process. The current work was carried out by replacing the cement with 10%, 20%, 30%, 40%, 50% and 100% of ferrock in the cement mortar cubes. From results, it was found that the optimum percentage of ferrock was 30%. Then mix design for M30 grade concrete was prepared and cubes of size 15cm X 15cm X 15cm, split tensile cylinders of size 15cm diameter X 30cm height and flexural beams of size 50cm X 10cm X 10cm for both conventional concrete and ferrock cement concrete with 30% replacement of ferrock were casted. The specimens were kept in water curing for 7, 14 and 28 days and in CO2 curing for 7 and 14 days. After the curing period the specimens were tested for compressive strength, split tensile strength, flexural strength, carbonation, and carbon dioxide absorption. Then the results obtained were compared with each other.**

***Index Terms*—Ferrock, Carbon – Negative Concrete, Cement replacement, Sustainable materials, Compressive strength.**

I. INTRODUCTION

Concrete continues to be the most widely used structural material in the world, driven by rapid infrastructure growth such as roads, bridges, and high-rise buildings. However, cement the primary binder in concrete remains a major source of carbon emissions, contributing 6–8% to global CO_2 pollution, which exacerbates environmental concerns and climate change. This scenario has fueled the search for sustainable alternatives to traditional cement, with a focus on materials that repurpose waste and reduce environmental impact.Ferrock, an innovative binder discovered by Dr. David Stone, has emerged as a promising carbon-negative material. Composed mainly of iron powder, fly ash, metakaolin, limestone, and oxalic acid, Ferrock is synthesized from up to 80% recycled materials, largely utilizing industrial waste. Its strength comes from the formation of an iron carbonate matrix during curing, making it a compelling substitute for cement. Studies by Dinesh Kumar et al. (2019) showed that 8% replacement of cement with Ferrock yielded optimum strength, while Mouli Prashanth et al. (2019) demonstrated Ferrock's effective CO_2 absorption through carbonation tests. Research by S. Kartika et al. (2021) confirmed that a 10% replacement ratio further improved strength, and Nivedita M et al. (2021) optimized mix ratios and curing protocols, reporting Ferrock's superior compressive strength compared to conventional concrete.In summary, contemporary literature confirms that adopting Ferrock can significantly lower the carbon footprint of concrete construction while providing mechanical and durability benefits making it a leading solution for sustainable development in the construction sector.

II. MATERIALS AND METHODOLOGY

2.1 About
The basic materials testing, methodology and properties are discussed in this lesson. All the test are conducted as per IS specification.

2.2 Test On Materials Used
Table 2.1 shows basic material test conducted on materials to know their physical properties shows some basic testing apparatus.

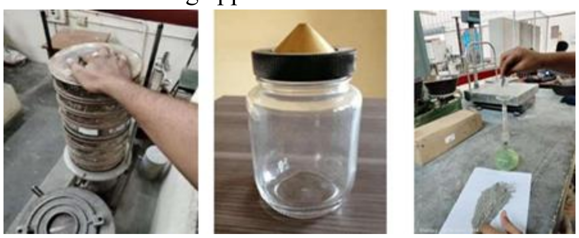

Fig 2.1 Sieve analysis, Pycnometer and Specific gravity

2.3 Mix Design
M30 grade Plain Cement Concrete was chosen. The mix design was prepared based on Indian Standard method using IS 456: 2000 and IS 10262: 2019. The mix design of normal concrete and ferrock cement concrete with 15,30 and 45 percentage ferrock and results were discussed in chapter 3.

2.4 Trail Casting
The optimum percentage of ferrock was determined by substituting 15%, 30%,60%, and 100% of ferrock by weight of cement in mortar. M30 grade Plain Cement Concrete was chosen for the present investigation. After a day specimen was demoulded and kept in the curing tank for 7 and 14 days. After the curing the cubes were tested to know their compressive strength. After the optimum percentage of ferrock obtained in trial mix, further cubes, cylinder and beams are casted for traditional concrete and concrete with optimum percentage of concrete then tested at 7,14 and 28 days. Figure 3.4 to 3.7 shows process of casting of cubes for trial mix.

Fig 2.2 Preperation of Ferrock and mixing of material

Fig 2.3 Cube casting and casting of cubes

2.5 Batching of Materials
Batching is defined as process of measuring materials by mass. Proper. It helps to get smooth surface of concrete and It increases the speed of construction and minimizes the wastage of concrete ingredients. According to mix design, the amount of cement, fine aggregate, coarse aggregate, water and ferrock were proportioned by weight. The water was measured by its volume. The weighing balance was kept clean, and its accuracy was verified on a regular basis.

2.6 Mixing
Mixing refers to complete blending of the materials which are required to produce a homogeneous concrete. Mixing of materials is essential to produce uniformity and strength in concrete. The mixing should ensure that the mass becomes homogeneous, uniform in color and consistency. There are 2 types of mixing, Hand mixing and Machine mixing. In this project hand mixing was adopted. The mixing was carried out in two stages i.e., Dry mixing and Wet mixing. Ferrock was prepared by mixing the raw materials in required proportions which were obtained from the literature review. The summary of percentage of raw materials required for the preparation of ferrock.

Table 2.1: Percentage of Raw Materials in Ferrock

Materials	Percentage of total weight of ferrock(%)
Iron powder (Fe)	60
Fly ash (Fa)	20
Metakaolin (MK)	10
Limestone powder (LP)	8
Oxalic acid	2

2.7 Casting Of Cubes
- After homogeneous mixing, Cubes are casted to determine Compression test of ferrock concrete.
- For trail, we casted 10 Cubes for 0,15,30,60 and 100% replacement of cement.
- 36 cubes of size 150mm*150mm*150mmwere

casted for 0,15,20 and 45% replacement of cement.
- Initially mould is prepared followed by greasing.
- Then concrete is filled and tampered, so that air void is removed. Then top surface is flattened by removing excess paste and proper surface is obtained.
- After a day, cubes were removed from the mould and placed it in water tank for curing. Then CST is conducted after 7, 14, 28 days. Fig 2.2 to 2.3 shows process of casting of cubes.

2.8 Casting of Cylinders
- Cylinders are casted to determine tensile strength and carbonation test of Ferrock concrete
- Total of 38 cylinders of diameter 150mm and depth 300mm were casted for 0, 15, 30 and 45% replacement of cement.
- Initially mould is prepared followed by greasing.
- Then concrete is filled and tampered, so that air void is removed. Then top surface is flattened by removing excess paste and proper surface is obtained.
- After a day, cylinders are demoulded and placed it in water tank for curing. Then STT is conducted after 7,14,28 days and Carbonation test is after 24 hours of carbon curing. Fig 2.4 shows process of casting of cylinder for trial mix.

Fig 2.4 Casting of Cylinder and Curing of Cylinder

2.9 Casting of Beams
- Beams are casted to determine flexural strength of Ferrock concrete.
- Total of 6 of 500mm X 100mm X 100mm were casted for 30% replacement of cement
- Initially mould is prepared followed by greasing.
- Then concrete is filled and tampered, so that air void is removed. Then top surface is flattened by removing excess paste and proper surface is obtained.
- After a day, beam is demoulded and placed it in water tank for curing.
- Then FST is conducted after 7,14,28 days.

2.10 Demoulding and Curing
After 24 hours the casted specimens are demoulded and then kept for water curing and carbon dioxide curing for the necessary strength tests to be carried out. The curing period was 7, 14 and 28 days. Demoulded specimen are presented.

Fig 2.5 Demoulded cubes, Demoulded Cylinders and Demoulder Beams

2.11 Laboratory Tests Conducted on Concrete
To know the properties of normal concrete and ferrock cement concrete following laboratory tests were conducted and they are as follows. Table 2.1 shows the test conducted on concrete.
1. For fresh concrete- Slump cone test
2. For Cubes- Compressive strength test
3. For Cylinders- Split tensile strength test
4. For Beams- Flexural strength test

III. RESULTS AND DISCUSSION

3.1 General
Several mechanical parameters, including workability, Compression, tensile and flexural strength, and carbon dioxide absorption of regular concrete and ferrock cement concrete, were examined in the experimental inquiry. This chapter highlights the findings from the tests mentioned above.

3.2 Basic Material Testing Results
Basic material test was conducted initially to determine physical property of specimen and results are listed in table 3.1

Table 3.1: Basic Material test result

Materials	Tests conducted	Results
Cement	Specific gravity	3.15
	Normal consistency	34%
	Initial setting time	38 min
	Final setting time	220 min
	Fineness	5%
Ferrock	Specific gravity	3.36

	Normal consistency	28%
Fine aggregate	Specific gravity	2.65
	Sieve analysis	Zone II
	Fineness modulus	3.0
	Bulk density	1450 kg/m^3
	Water absorption	1.52
Coarse aggregate	Specific gravity (20 mm)	2.68
	Water absorption	1.52
	Aggregate impact value	0.5%
	Los Angeles abrasion value	16.8%

As per IS Code guidelines, all values are within the permissible values; hence we can proceed for mix design.

3.3 Mix Design Results for Trial:

Table 3.2 shows the general details required to calculate the quantity of materials

Table 3.2: General Details

Basic Details	Value
Ordinary Portland cement	53 Grade
Water	Portable water
Maximum size of aggregate	20 mm
Fine aggregate	Grading zone II
Degree of quality of work	Good
Type of exposure	Severe

3.3.1 For 0% Cement Replacement

In this trial, mix design for normal concrete was prepared with 0% of ferrock as cementitious materials. Design is done as per IS456:2000 AND IS 10262:2019. Table 3.3 shows the result obtained for 0% cement replacement

Table 3.3 Mix Design for 0% Cement Replacement

Parameters	Value
Target strength	36.5 N/mm^2
Air content	1%
Water content ratio	0.45
Water content	186 L/m^3
Cementatious materials content	0 kg/m^3
Volume of Concrete	1 m^3
Volume of entrapped air	0.01 m^3
Volume of cement	0.144 m^3
Volume of ferrock (Cementitious material)	0
Water	0.186
Fine aggregate	0.39
Coarse aggregate	0.62
Mix proportion (C:FA:CA)	1:1.46:2.41

3.3.2 For 15% Cement Replacement

In this trial, mix design for ferrock concrete was prepared with 15% of ferrock as cementitious materials. Design is done as per IS456:2000 AND IS 10262:2019. Table 3.4 shows the result obtained for 15% cement replacement.

Table 3.4 Mix Design for 15% Cement Replacement

Parameters	Value
Target strength	36.5 N/mm^2
Air content	1%
Water content ratio	0.41
Water content	186 L/m^3
Cement content	386.50 kg/m^3
Cementatious materials content	68.20 kg/m^3
Volume of Concrete	1 m^3
Volume of entrapped air	0.01 m^3
Volume of cement	0.122 m^3
Volume of ferrock (Cementitious material)	0.021 m^3
Water	0.186 m^3
Fine aggregate	0.38 m^3
Coarse aggregate	0.62
Mix proportion (C:FA:CA)	1:1.73:2.86

3.3.3 For 30% Cement Replacement

In this trial, mix design for ferrock concrete was prepared with 30% of ferrock as cementitious materials. Design is done as per IS456:2000 AND IS 10262:2019. Table 3.5 shows the result obtained for 30% cement replacement.

Table 3.5 Mix Design for 30% Cement Replacement

Parameters	Value
Target strength	36.5 N/mm^2
Air content	1%
Water content ratio	0.41
Water content	186 L/m^3
Cement content	318.27 kg/m^3
Cementatious materials content	136.41 kg/m^3
Volume of Concrete	1 m^3
Volume of entrapped air	0.01 m^3
Volume of cement	0.010 m^3
Volume of ferrock (Cementitious material)	0.043 m^3
Water	0.186 m^3
Fine aggregate	0.38 m^3
Coarse aggregate	0.62
Mix proportion (C:FA:CA)	1:2.11:3.49

3.3.4 For 45% Cement Replacement

In this trial, mix design for ferrock concrete was prepared with 45% of ferrock as cementitious materials. Design is done as per IS456:2000 AND IS 10262:2019. Table 3.6 shows the result obtained for 45% cement replacement.

Table 3.6 Mix Design for 45% Cement Replacement

Parameters	Value
Target strength	36.5 N/mm^2
Air content	1%
Water content ratio	0.41
Water content	186 L/m^3
Cement content	250.07 kg/m^3
Cementatious materials content	204.61 kg/m^3
Volume of Concrete	1 m^3
Volume of entrapped air	0.01 m^3
Volume of cement	0.0791 m^3
Volume of ferrock (Cementitious material)	0.065 m^3
Water	0.186 m^3
Fine aggregate	0.38 m^3
Coarse aggregate	0.62
Mix proportion (C:FA:CA)	1:2.7:4.48

3.4 Compression Test Results For Trial Mix

Compression test for trial mix of various percentage i.e. 0,15,30 and 45% of cement replacement is presented in Table 3.7. CST on cube for trial mix is presented.

Table 3.7: Compression Test Results

Cement replacement (%)	Load at failure (kN)	7 days compressive strength (N/mm^2)
0	519	23.1
15	550	24.45
30	570	25.3
45	486	22

Among the CST values obtained from Table 4.11 theconcrete cubes with 30% cement replacement may have more compressive strength at 7 days compared to other percentages of cement replacement. So, the maximum percentage of ferrock was fixed to 30%. After the maximum percentage of ferrock obtained in trial mix, further cubes, cylinder and beams were casted for 0% concrete and concrete with 30 percentage of cement replacement and then tested at 7,14 and 28 days. CST on cube for trial mix is presented in table 3.7

3.5 Fresh Concrete Test Results

After mixing, Fresh concrete is tested for slump to determine its workability. For 0% replacement the slump obtained was 90 mm and for 30% replacement slump obtained was 84 mm. As per IS 1199:1959 Slump value should vary in between 75 to 100 mm for structural work, thus obtained results are satisfactory.

3.6 Compression Strength Test Results

Compression test for 0% and 30% percentage of cement replacement is shown in Table 3.8

Table 3.8: CST Result

Cement replacement (%)		Load at failure (kN)	Average compressive strength (N/mm^2)
0	7 Days	519	23.1
	14 Days	720	32
	28 Days	869	38.6
30	7 Days	551	25.3
	14 Days	778	34.6
	28 Days	892	39.5

Fig 3.1 Compressive test, Dial gauge and Cube failure

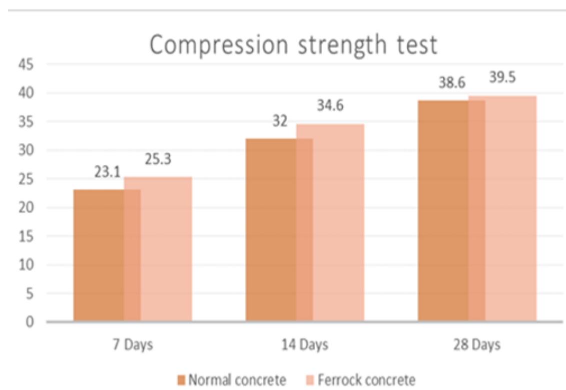

Fig 3.2: Comparison of CST value of Normal and Ferrock Concrete

It is observed that the compressive strength of ferrock cement concrete placed in water curing was greater the than ordinary conventional concrete in 7 days, 14 days and 28 days.

3.7 Split Tensile Strength Test Results

Split tensile test for 0% and 30% percentage of cement replacement is shown in Table 3.9 and split tensile test on cylinder is presented

Table 3.9: STT Results

Cement replacement (%)		Load at failure (kN)	Average split tensile strength (N/mm^2)
0	7 Days	95.6	1.41
	14 Days	121	2.68
	28 Days	137	3.53
30	7 Days	200	1.69
	14 Days	251	2.97
	28 Days	283	3.81


Fig 3.2 Split tensile test, Dial gauge, Cylinder after failure

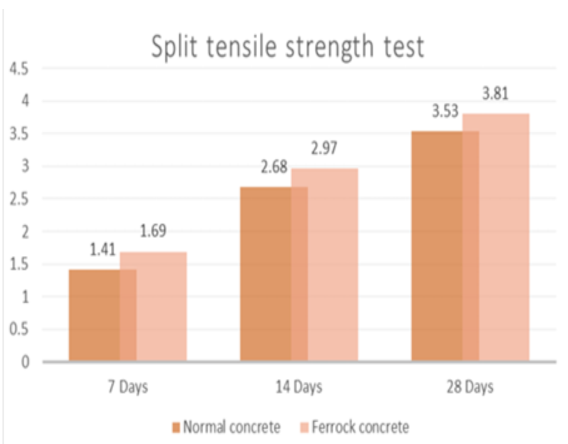

Fig 3.3 Comparison of STS Value of Normal and Ferrock Concrete

From the fig 3.3 it is observed that the STS of ferrock cement concrete placed in water curing was greater the than ordinary conventional concrete in 7, 14 and 28 days

3.8 Flexural Strength Test Results

Flexural strength test for 0% and 30% percentage of cement replacement is presented in Table 3.10. Flexural tensile test on beam is shown in fig 3.4.

Table 3.10: FST Results

Cement replacement (%)		Load at failure (kN)	Average flexural z strength (N/mm^2)
0	7 Days	217	4.38
	14 Days	282	5.63
	28 Days	317	6.31
30	7 Days	228	4.57
	14 Days	291	5..82
	28 Days	337	6.74


Fig 3.4 UTM Test and Beam after failure

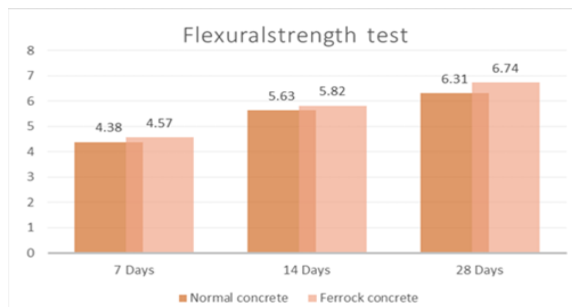

Fig 3.5: Comparison of Flexural Strength of Normal and Ferrock Concrete

From the fig 3.5 it is observed that the FST result of ferrock cement concrete placed in water curing was greater the than ordinary conventional concrete in 7 days, 14 days and 28 days.

3.9 Carbon Dioxide Absorption Test Results

Carbon dioxide absorption test for 30% percentage of cement replacement is shown in table 3.11. Carbon dioxide absorption test on cylinders is shown in fig 3.11.

Table 3.11: Carbon Dioxide Absorption Test Results

Percentage of cement replacement (%)	Weight in (kg)			Percentage of Co$_2$ = $\frac{W1-W2}{W2}\times 100$
	W1	W2	W3	
30	12.4	12.9 3	0.53	4.09
	12.3 8	12.9 5	0.57	4.40

Fig 3.6 Carbon dioxide Curing and Phenolphthalein Solution

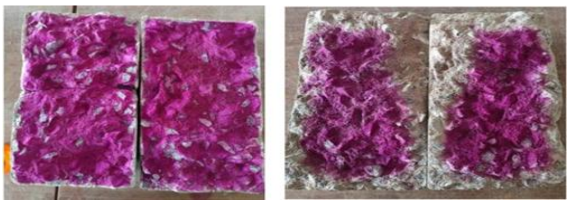

Fig 3.7 Carbonation Test result for Normal and Ferrock cement

From carbonation test it was observed that the normal concrete cylinders did not absorb any CO2 as shown in fig 4.17 but the ferrock cement concrete cylinders had absorbed considerable amount of CO2 as shown in fig 4.18. When the phenolphthalein solution came in contact with the surface of normal concrete cylinders the entire surface of the concrete turned into pink color. The presence of pink color indicated the non-carbonated part i.e.; CO2 was not absorbed that portion. When the phenolphthalein solution came in contact with the surface of the ferrock cement concrete cylinders there was absence of pink color in some portion of the cylinders. The non -presence of pink color indicated the carbonated part i.e.; CO2 was absorbed in that portion. The average CO2 absorption of the specimens was found to be 4.25%.

IV. CONCLUSION

In the current work, ferrock was investigated as a cement substitute in concrete after test results were obtained.

- From the experimental results, the optimum percentage of ferrock was found to be 30% for the best behaviour in compression.
- It was observed that the CST, STS and FST of ferrock cement concrete placed in water curing was greater the than ordinary conventional concrete in 7 days, 14 days and 28 days.
- From the carbonation test it was evident that the ferrock cement concrete specimens had absorbed considerable amount of CO_2 from CO_2 curing.
- From carbon dioxide absorption test it was observed specimens had absorbed average of 4.58% of CO_2 in 14 days of curing period.
- By replacing cement with ferrock, the rate of emission of CO2 due to cement production in the industry is reduced.
- Ferrock is best suitable for PCC. If ferrock is used in RCC suitable precautions should be taken as ferrock absorbs CO2 during the hardening process.
- Thus, ferrock is a better partial substance as replacement of cement in concrete
- Ferrock is therefore a preferable partial material to use in concrete instead of cement.

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