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# Experimental Study on Mechanical Properties of Ferrock Concrete

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**Abstract -** Concrete, as one of the most widely utilized construction materials, contributes significantly to global carbon dioxide ($CO_2$) emissions, with cement manufacturing accounting for approximately 8% of global emissions. Ferrock, an emerging sustainable alternative to traditional cement, offers a promising solution to mitigate this environmental impact. Composed of iron powder, fly ash, metakaolin, and limestone powder, Ferrock exhibits pozzolanic properties and actively captures $CO_2$ during its curing process, addressing both waste utilization and carbon sequestration. This research investigates the mechanical and durability properties of Ferrock concrete through a comprehensive suite of tests, including compressive strength, split tensile strength, flexural strength, etc. Additionally, sorptivity and microstructure analysis are conducted to assess its porosity and long-term durability. The findings aim to provide valuable insights into the potential of Ferrock concrete as a sustainable and eco-friendly substitute for conventional cement in construction applications, contributing to the advancement of green building materials and sustainable development practices.

***Key Words*:** ferrock, mechanical properties, microstructural analysis, sustainability, durability.

## 1. INTRODUCTION

Despite being the most widely used building material, concrete production has a significant environmental impact The production of conventional Portland cement is a major contributor to climate change, accounting for approximately 8% of global CO2 emissions. In response, alternative materials like Ferrock have garnered attention due to their carbon-negative properties and sustainability. Ferrock is primarily composed of iron dust, fly ash, metakaolin, and limestone powder, with a substantial portion originating from steel industry waste. Unlike traditional cement, Ferrock reduces its environmental footprint by absorbing $CO_2$ during the curing process. To evaluate Ferrock's viability as a partial cement substitute, further research is necessary to assess its durability and mechanical characteristics. This study aims to investigate how the incorporation of Ferrock affects the concrete's critical mechanical properties, including flexural, split tensile, and compressive strengths. Additionally, the rate of water absorption through capillary action will be measured using sorptivity tests. Microstructural analysis employing microscopy techniques can provide insights into Ferrock concrete's internal bonding mechanisms. The results demonstrate that the incorporation of Ferrock significantly enhances the concrete's mechanical properties and durability. The optimal mix, with a 12.5% Ferrock replacement, exhibits improved compressive, split tensile, and flexural strengths. However, higher Ferrock content leads to reduced strength, indicating diminishing returns beyond this level. The mix also displays low water absorption and excellent resistance to moisture ingress. Scanning electron microscopy analysis reveals a denser microstructure with enhanced bonding, facilitated by pozzolanic reactions. These findings will encourage the adoption of sustainable building materials and reduce the reliance on conventional cement by highlighting the viability of using Ferrock in construction.

### 1.1. OBJECTIVE

The primary purpose of this study is to assess the viability of utilizing Ferrock as a sustainable alternative to traditional Portland cement in concrete. Specifically, the investigation aims to experimentally measure and compare the mechanical properties of Ferrock-based concrete, including compressive strength, tensile strength, flexural strength, and modulus of elasticity, with those of conventional concrete. Additionally, the study will evaluate the durability of Ferrock concrete when exposed to various environmental factors, such as water absorption. A microstructural analysis of Ferrock concrete will also be conducted to find the bonding mechanisms and internal structure that contribute to its mechanical performance. Finally, the study will compare the overall performance of Ferrock concrete with that of traditional Portland cement concrete, focusing on both mechanical and environmental considerations.

### 1.2. FERROCK

The iron powder used in this study is a waste product obtained from steel mills during the processing of scrap steel from other industries. It was sourced from an iron and steel facility located in Kottayam. Fly ash, a fine pozzolanic powder, is a byproduct of coal combustion in power plants and contains aluminous and siliceous materials. Oxalic acid is employed as an accelerator for the setting reaction without adversely impacting the strength. Metakaolin, a mineral admixture, is incorporated into ordinary Portland cement concrete to enhance its mechanical properties and durability.

**Table -1:** Raw materials used for ferrock manufacturing

| | | |
|---|---|---|
| 1 | Iron dust | 60% |
| 2 | Fly ash | 20% |
| 3 | Limestone | 10% |
| 4 | Metakaolin | 8% |
| 5 | Oxalic acid | 2% |

## 2. Methodology

### 2.1 MATERIAL COLLECTION AND PREPARATION

Gather the components needed to make ferrock concrete, such as fly ash, limestone, metakaolin, iron dust and oxalic acid. To guarantee that these components fulfill the precise particle size and quality requirements needed for the best possible performance in the concrete mix, process them using techniques like crushing and sieving.

### 2.2 MIX DESIGN

Develop an optimized concrete mix design by carefully adjusting the proportion of ferrock used as a partial replacement for cement, ensuring the mixture meets the desired strength, durability, and performance characteristics while maximizing sustainability.

### 2.3 CASTING

Cast concrete specimens using cylinder, cube, and beam molds, applying the developed mix formulation, and maintaining consistency throughout the mixing, casting, and curing stages to prepare the samples for evaluation.

### 2.4 TESTS FOR MECHANICAL PROPERTIES

Fabricate concrete specimens using cylinder, cube, and beam molds, applying the developed mix formulation, and maintaining consistency throughout the mixing, casting, and curing stages to prepare the samples for evaluation.

### 2.5 TESTS TO EVALUATE DURABILITY

Water absorption and sorptivity tests will be conducted on the concrete samples to evaluate their durability. These assessments examine the concrete's resistance to water infiltration, moisture ingress, and chloride-induced corrosion, ensuring its durability and suitability for diverse applications.

### 2.6 ANALYSE MICROSTRUCTURE

Microstructural analysis of the sample can provide valuable insights into the concrete's microscopic characteristics, aiding the understanding of its composition, pore structure, and potential factors impacting performance and durability.

### 2.7 COPMPARE WITH CONVENTIONAL CONCRET

This study examines the mechanical and durability properties of Ferrock-cement concrete, comparing its performance to that of conventional concrete to gain insights into the material's behavior and performance.

## 3. Mix Proportions

The impact of employing Ferrock as a partial cement replacement was examined through the creation of four distinct M25 concrete mixtures with a water-to-cement ratio of 0.45. Ferrock was used to substitute 10%, 12.5%, and 15% of the cement content. To evaluate how these replacements influence the workability, compressive strength, and durability of concrete, M25 concrete specimens in the form of 150 x 150 x 150 mm cubes and 500 x 100 x 100 mm beams were produced. The specimens were stored in a standard curing environment to assess whether Ferrock could serve as a practical, sustainable alternative to conventional concrete materials without compromising performance.

**Table -2:** Mix proportions

| Mix | OPC (kg) | Ferrock | Fine aggregate (kg) | Coarse aggregate (kg) | Water (kg/m) |
|---|---|---|---|---|---|
| 0% | 438 | 0 | 674 | 1167 | 197 |
| 10% | 394.2 | 43.8 | 674 | 1167 | 197 |
| 12.5% | 383.25 | 54.75 | 674 | 1167 | 197 |
| 15% | 372.3 | 65.7 | 674 | 1167 | 197 |

## 4. Mixing and Casting

The concrete batches were mixed using a thoroughly cleaned and dried drum to ensure no contamination from previous mixes. To create a uniform the aggregates were first stirred for three minutes in the drum. After adding cement and water, the mixture was mixed for two more minutes before the slump test was conducted. To prevent aggregate segregation and to aid in the release of air bubbles while keeping the aggregates in suspension, the specimens were vibrated using a vibrator with a controlled vibration time after the casting process. Following a 24-hour period, the specimens were taken out of the molds and allowed to cure in water at 23°C until the testing period. Three 150x150x150 mm cubes were used to determine the average compressive strength, and two 150 x 300 mm cylinders were used to determine the splitting tensile strength and 500x300x100mm beams for flexural strength

## 5. Results and Discussions

### 5.1 Initial Tests

Cement-53 grade Ordinary Portland Cement is used in this project. Various tests, including the Fineness, Soundness, and Consistency tests as well as the Initial Setting times, are conducted for accuracy.

**Table -3:** Properties of cement

| | |
|---|---|
| Fineness | 4.53 |
| Soundness | 2 mm |
| Consistency | 34% |
| Initial Setting time | 44 min |
| Specific gravity | 3.14 |

Coarse aggregate - One of the key components of concrete that gives the structure its strength is aggregate

**Table -4:** Properties of coarse aggregate

| | |
|---|---|
| Fineness Modulus | 6.01% |
| Specific Gravity | 2.7 |
| Water absorption | 1.5 |

Fine Aggregate: We did tests such as Fineness modulus, Specific Gravity, water content

**Table -5:** Properties of fine aggregate

| | |
|---|---|
| Fineness modulus | 2. |
| Specific Gravity | 2.66 |
| Water absorption | 4.16% |

FERROCK CONCRETE: Initial Tests were conducted to find the suitability of ferrock concrete.

**Table -6:** Properties of ferrock concrete

| | |
|---|---|
| Fineness | 2 % |
| Soundness | 2 mm |
| Consistency | 36 % |
| Initial Setting time | 48 min |

**Fig -1**: a) fineness, b) soundness c) consistency d) initial setting time e) specific gravity

### 5.2 Experimental Results and Discussion

#### 5.2.1 Compressive strength

The compressive strength of concrete mixtures that partially substitute ferrock (FKC) for cement is assessed in this study. Before testing, the samples were cured in water for seven and twenty-eight days. All samples were applied a uniformly distributed load. The average values are provided after three specimens were tested from each mixture at each testing age. The test results conducted at 7 and 28 days revealed significant variations in performance, which were closely tied to the specific FKC ratios used in the mixtures. Below is a discussion of the main conclusions and underlying variables that affected compressive strength.

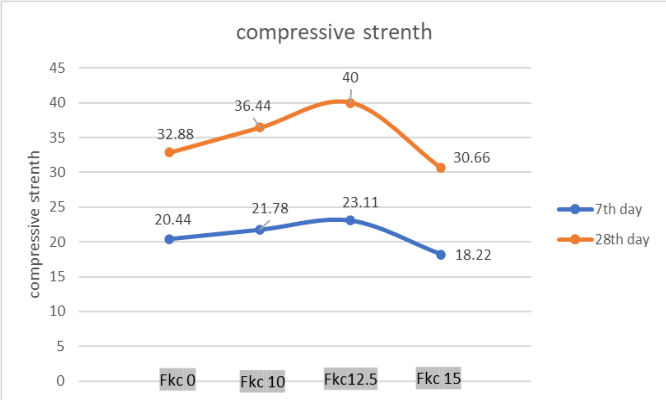


**Fig -2**: a) Compressive testing machine b) graph showing variation in compressive strength

The graph shows the Ferrock concrete's compressive strength at 7 and 28 days. In this case, ordinary concrete with 0% Ferrock replacement is represented by Fkc 0, and concrete with 10%, 12.5%, and 15% Ferrock replacement is indicated by Fkc 10, Fkc 12.5, and Fkc 15. The findings validate the appropriate strength growth over curing time, demonstrating a constant increase in compressive strength from 7 days to 28 days across all mix variations. The strength of the control mix, Fkc 0, was 20.44 MPa after 7 days and 32.88 MPa after 28 days, representing a 60.8% strength rise. The 7-day strength was 21.78 MPa with 10% Ferrock replacement rising to 36.44 MPa at 28 days, indicating a 67.3% gain. The greatest strength was demonstrated by the 12.5% replacement mix, which improved by 73% over time, reaching 23.11 MPa at 7 days and 40 MPa at 28 days. The 7-day strength was lower at 18.22 MPa at 15% Ferrock replacement, however it increased by 68.3% to 30.66 MPa at 28 days. According to these results, the optimum mix is 12.5% Ferrock replacement (Fkc 12.5), which yields the best compressive strength at 7 and 28 days. Better particle packing and stronger bonding between Ferrock and the cement matrix are responsible for the strength enhancement. But after this point, excessive replacement (Fkc 15) causes the concrete structure's compressive strength to decrease, either as a result of more voids or weakened interlocking. This suggests that although Ferrock increases concrete strength to a certain extent, performance may suffer if it is used in excess of 12.5% replacement.

### 5.2.2 Split Tensile Strength

The split tensile strength of concrete mixtures that partially substitute ferrock (FKC) for cement is assessed in this study. In a split tensile strength test, a cylindrical concrete specimen is positioned horizontally between the platens of a compression testing apparatus. The test results conducted on 28 days revealed significant variations in performance. Below is a discussion of the main conclusions and underlying variables that affected compressive strength. figure3 displays the average splitting tensile strength values at 28 days for the various mix configuration.

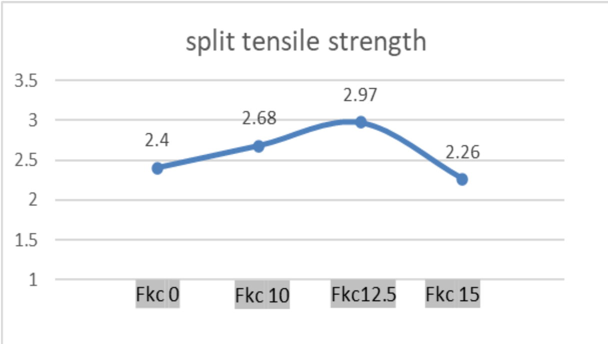


**Fig -3**: a) Split tensile cracking b) graph showing variation in split tensile strength

The control mix (FKC 0) had a split tensile strength of 2.4 MPa, whereas the mix with 12.5% Ferrock replacement (FKC 12.5) showed the highest strength at 2.97 MPa. The tensile strength values followed a similar trend to the compressive strengths, indicating that Ferrock improves both properties up to a certain replacement level. However, at 15% replacement (FKC 15), the strength decreased to 2.26 MPa, suggesting that excessive Ferrock replacement negatively affects the concrete's tensile performance. The study concluded that the increase in tensile strength for Ferrock-based mixes could be attributed to improved bonding between aggregates and the binder matrix. The optimal performance at 12.5% replacement may be due to enhanced particle packing and better interfacial adhesion. However, beyond this limit, the mix likely becomes weaker due to excess Ferrock altering the cementitious matrix.

### 5.2.3 Flexural Strength

The flexural strength of concrete mixtures that partially substitute ferrock (FKC) for cement is assessed in this study. In flexural strength test, a concrete beam specimen placed on two supports and a testing machine is used to apply a load to the center. The load is gradually increased until the beam fractures, and the maximum stress is measured to determine the flexural strength. The test results conducted at 28 day revealed significant variations in performance, which were closely tied to the specific FKC ratios used in the mixtures. Below is a discussion of the main conclusions and underlying variables that affected flexural strength.

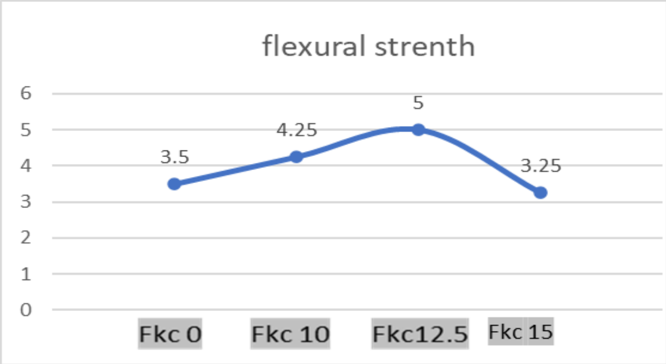


**Fig -4**: a) Bar diagram showing variation in split tensile strength b) Split tensile test

The graph presents the flexural strength of M25 concrete with varying levels of Ferrock as a partial cement replacement. The mixes FKC 0, FKC 10, FKC 12.5, and FKC 15 represent 0%, 10%, 12.5%, and 15% Ferrock replacement, respectively. The control mix (FKC 0) exhibited a flexural strength of 3.5 MPa, serving as the baseline. When 10% Ferrock (FKC 10) was incorporated, the strength increased to 4.25 MPa, indicating an improvement in the concrete's ability to resist bending. The highest flexural strength was observed in FKC 12.5 (5 MPa), suggesting that 12.5% Ferrock replacement is the most effective proportion for enhancing flexural performance. However, beyond this limit, the strength declined to 3.25 MPa for FKC 15, showing that excessive Ferrock content reduces the material's ability to resist bending forces. The improvement in flexural strength at 10% and 12.5% replacement can be attributed to better bonding between particles and enhanced microstructural integrity, which contribute to a stronger load distribution. However, at 15% replacement, the cementitious matrix may weaken, leading to reduced strength.

### 5.2.4 Water Absorption Test

The water absorption test for concrete cubes is conducted to assess the material's porosity and permeability, key factors in its durability. Concrete cubes, typically 150 mm x 150 mm x 150 mm, are cast and cured for 28 days. After curing, the cubes are weighed to determine their initial dry weight. The cubes are then submerged in water for 24 hours to absorb moisture. After removal, they are wiped dry and reweighed to obtain the final weight. The water absorption percentage is calculated to evaluate the concrete's ability to absorb water, which can indicate its overall durability. Water absorption of fkc12.5 =2.59%

### 5.2.5 Sorptivity Test

In this test, a concrete sample is placed in a pan and exposed to a liquid on one side. The liquid level is maintained constant to prevent changes caused by pressure differences. At regular intervals, the mass of the concrete sample is measured. The amount of liquid absorbed by the concrete is then divided by the surface area that came into contact with the liquid. A graph is plotted, showing the rate of absorption versus the square root of time. The slope of this graph represents the sorptivity value. A lower sorptivity value indicates better quality material.

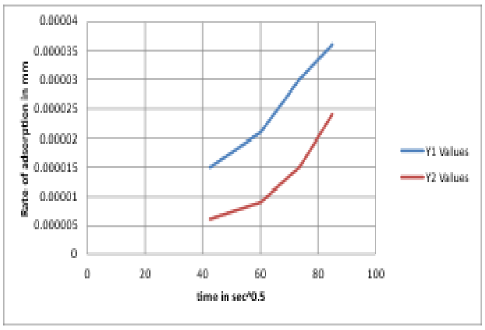


**Fig -5**: a) Sorptivity test b) Graph showing the rate of absorption vs time for M25 concrete and 12.5% ferrock concrete

The graph compares the sorptivity of M25 concrete and 12.5% Ferrock-replaced concrete over time. The M25 concrete (blue line) shows a higher adsorption rate, indicating greater permeability and water absorption. This suggests it has more capillary pores, making it more vulnerable to moisture-related damage. In contrast, Ferrock concrete (red line) exhibits a lower sorptivity, implying a denser structure with better resistance to water penetration. Reduced sorptivity enhances durability, making Ferrock concrete more suitable for environments exposed to moisture. Overall, the results indicate that Ferrock replacement improves concrete performance by reducing water absorption and increasing structural longevity.

### 5.2.6 Microstructural Analysis

The SEM analysis of Ferrock concrete with 12.5% cement replacement reveals a dense and well-packed microstructure, indicating strong interparticle bonding. compared to traditional cement, Ferrock appears to have a denser matrix, which may result in higher compressive strength and durability.The presence of irregularly shaped, tightly packed Ferrock particles suggests enhanced mechanical interlocking, while the visible formation of reaction products, such as iron carbonate ($FeCO_3$) and calcium-silicatehydrate (C-S-H) gel, confirms the pozzolanic and carbonation reactions contributing to strength development.

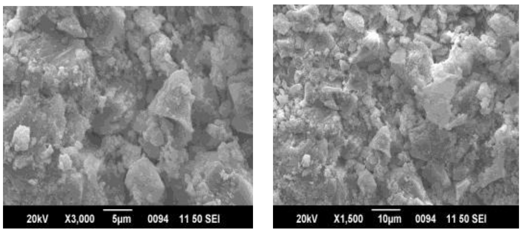


**Fig -6**: SEM images of fck12.5

## 3. CONCLUSIONS

The primary objective of the project is to investigate the feasibility of using Ferrock as sustainable alternative to partially replace traditional Portland cement in concrete. The key findings of the study are summarized as follows:

- The experimental results demonstrate that the partial replacement of cement with Ferrock (FKC) significantly affects the mechanical properties and durability of concrete. Among the different mix ratios tested, the optimum Ferrock replacement level was found to be 12.5%.
- After 28 days, the control mix (0% Ferrock) had a compressive strength of 32.88 MPa. The mix with 12.5% Ferrock reached the highest compressive strength of 40 MPa at 28 days, representing a 73% increase. The compressive strength dropped after this, with 15% Ferrock replacement underscoring the diminishing returns that occur when Ferrock content rises above 12.5%.
- Similar trends were observed in the split tensile strength and flexural tests, with the 12.5% Ferrock mix exhibiting the highest strength on 28 days.
- The water absorption test for FKC 12.5 %yielded a water absorption of 2.59%, indicating that the mix has good resistance to moisture ingress. This is further supported by the sorptivity test, which demonstrates the concrete's ability to resist liquid absorption.
- The SEM analysis revealed that the 12.5% Ferrock mix has a denser, well packed microstructure with improved interparticle bonding.The presence of reaction products such as iron carbonate ($FeCO_3$) and calcium-silicate-hydrate (C-S-H) gel confirmed the pozzolanic reactions, contributing to the improved strength and durability of the Ferrock-based concrete.

Ferrock concrete, incorporating up to 12.5% Ferrock as a cement substitute, shows significant improvements in compressive, tensile, and flexural strength. The optimal mix (FKC 12.5) enhances bonding and microstructure, contributing to stronger, more durable concrete. However, higher Ferrock content (above 12.5%) leads to reduced strength, emphasizing the importance of careful mix design. These findings suggest that Ferrock concrete is a promising, sustainable alternative to traditional concrete, with potential for further exploration in construction applications.

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