

Effect of Iron Powder on Partial Replacement of Fine Aggregate in Concrete

Aman Raj, Keshav Sharma, Ankit

Department of Civil Engineering, Vellore Institute of Technology, Vellore, Tamil Nadu-632014

*Email: amanraj2162@gmail.com

Abstract – Concrete is the main building material used worldwide. This project is an experimental study on the effects of cast iron powder as a partial replacement of sand (fine aggregate) in concrete. The effects of the iron powder on the concrete's workability, strength (i.e., compressive strength, split tensile strength and flexural strength), durability via dry and wet strength test and water absorption test were studied. Along with these, analysis in the form of X-Ray diffraction (XRD) test was also conducted. For the aforementioned studies, we replaced the fine aggregate with iron powder in concrete by four different percentages i.e., 0%, 15%, 30% and 45%. Slump cone test was performed to study the impact on the freshened concrete tests. The slump value continuously declined with the increased iron powder percentages from 37 mm in 0% mix to 9 mm in 45% mix. The strength tests on hardened concrete were conducted on varied concrete specimens of different percentages for the following durations: 7, 14 and 28 days. Cubes, cylinders and prisms were casted for compressive, split-tensile and flexural strength tests. It was observed that the compressive strength, split-tensile and flexural strength increased till 30%, 45% and 45% of partial replacement of fine aggregate with iron powder. Also, water absorption test displays that it increased till 30% and then decreased. From all the tests and analysis, we determined that the optimum percentage of partial replacement is 30%. Apart from these tests and analysis, this project deals with showcasing the importance and benefits of using materials to improve the properties of conventional concrete and their impact on the environment.

Keywords– Iron Powder, Ferric Oxide, Workability, Mechanical Properties, X-Ray diffraction.

I. INTRODUCTION

Concrete is the most widely used building material worldwide. It is a heterogeneous compound made up of cement, fine aggregate, coarse aggregates and water. Concrete is a very durable material which continuously gains strength over the years. River sand is widely used as fine aggregate in concrete mixes throughout India and the world. Sand fills about 35% of the total aggregate volume in concrete mix and since concrete demand is on an increase, the sand mining is also on an increase. River sand mining has led to increase in sea-level rise, increase in salinity which in turn is affecting the groundwater reservoir system. Continuous exploitation and overuse of this natural and conventional resource has very drastic consequences on our rivers. It is expected that demand of raw materials for concrete will double in the next two to three decades given the present rate of consumption. Over the past few years, researchers have been experimenting on different materials in order to find an alternate to sand that can be incorporated in concrete without affecting its original properties. Natural crushed rock sand, copper slag, waste foundry sand, coal ash, recycled sand etc., have been used in concrete as fine aggregate. We in this project have chosen iron powder, an industrial waste, to replace fine aggregate and study its effect.

II. OBJECTIVE

We divided our study into various aspects in order to fulfill our objectives. Firstly, we assigned ourselves with the task of studying the bad consequences of IP on the environment and human health if left idle. Secondly, Mix design of M35 concrete was to be done which forms the basis for our experiments conducted. Mix design for controlled mix (0%), and with partial replacement of FA with IP (15%, 30% and 45%) by weight was done. Thirdly, casting as per the mix design. Fourthly, in order to study the effect and use of IP as partial replacement of FA we performed fresh and hardened concrete tests. Durability test were also to be conducted on controlled and modified concrete mix to analyse the effect of cast iron powder. Followed by performing a chemical analysis on concrete to identify the mineral composition of concrete mixes upon replacement. Finally, after all the work was done, we conclude our study by determining the optimum percentage of cast iron powder to be used as replacement of fine aggregate in concrete.

III. BACKGROUND

India is a developing country with the world's second highest population aspiring for a brighter future. Since its

independence, India has focused on infrastructural development which has caught speed since 1991 Economic Reforms. With projects such as National Highway Project, Delhi-Mumbai Industrial Development Corridor, Dedicated Freight Corridor, Bharatmala Pariyojana, Smart City Project, UDAN (Ude Desh Ka Aam Naagrik) and many more, the country's dependence on building material mainly concrete has increased. Hence, demand for raw materials specially river sand is on high levels. Environmental bodies and governments have imposed sanctions in order to curb excessive mining. Some Indian state governments have started to import sand from other countries for concrete production which proves our aforementioned points.

Iron powder is a very dangerous industrial waste for the environment and human life if left idle posing multiple irreparable damages. On one hand, sand which is used as fine aggregate in concrete is becoming scarce due to human overexploitation and government sanctions. While on the other hand, iron waste in the form of Construction & Demolition waste, scraps, powder pose a huge environmental danger. It is always said in the time of crisis, opportunity lies and we have decided to merge these two in order to find a solution. Hence, in this project, we have replaced fine aggregate with cast iron powder in concrete in order to determine the optimum percentage of replacement and analyze how it effects concrete.

IV. PROJECT DESCRIPTION

Our project works on the basic principle of partially replacing FA by IP and studying all the changes it makes in concrete. We are studying its impact on concrete's workability, strength and durability by conducting different tests. Slump cone test is conducted to test the workability of the mixes. We conducted Compressive strength, Split-tensile strength and Flexural strength tests using CTM and Flexural Testing Machine in order to compare between the strength values of the controlled mix and modified mixes. Durability tests via water absorption test and dry & wet strength test were performed on the mixes for comparison purposes. A chemical analysis was conducted with the help of XRD test on concrete specimens to identify the crystalline composition and products responsible for the aforementioned test results. All of these tests and analysis were done in order to achieve our goal of determining the optimum percentage of IP to replace FA in concrete.

Our set of goals are listed below in points:

1. Studying the bad consequences of iron powder on the environment and human health if left idle.
2. Mix design of M35 concrete-controlled mix (0%), partial replacement of fine aggregate with iron powder (15%, 30% and 45%) by weight.

3. Studying the effect and use of cast iron powder as partial replacement of fine aggregate by conducting fresh and hardened concrete tests.
4. Conducting durability test on controlled and modified concrete mix to analyse the effect of cast iron powder
5. Performing chemical analysis on concrete to identify the mineral composition of concrete mixes upon replacement.
6. Determination of the optimum percentage of cast iron powder to be used as replacement of fine aggregate in concrete.

V. TECHNICAL SPECIFICATION

DIMENSIONS OF MOULDS USED FOR STRENGTH TESTS & DURABILITY TESTS:

C - 100mm*100mm*100mm

CM - 100mm*200mm

P-100mm*100mm*500mm

FORMULAE USED FOR CALCULATIONS:

1. Specific gravity of FA = $\frac{W2-W1}{(W2-W1)-(W3-W4)}$

W1=Weight of empty pycnometer

W2=Weight of pycnometer & dry FA

W3=Weight of pycnometer, FA & water

W4=Weight of pycnometer & water

2. Fineness modulus (FM) = Total of Cumulative Percentage of Passing(%) / 100

3. Specific gravity of Cement = $\frac{W2-W1}{(W2-W1)-(W3-W4)} * 0.79$

W1=Weight of empty flask

W2=Weight of flask & cement

W3=Weight of flask, cement & kerosene

W4=Weight of flask & kerosene

0.79= specific gravity of kerosene

4. Specific gravity of Coarse aggregate = $\frac{W4}{(W3-(W1-W2))}$

Weight of aggregates + wire bucket in water (W1)

Weight of wire bucket in water (W2)

Weight of surface dried saturated aggregates (W3)

Weight of oven dried Aggregate (W4)

Weight of aggregates in water (W1 - W2)

5. Compressive strength = $\frac{\text{Load}}{C/s \text{ Area}}$

6. Split tensile strength = $\frac{2 * \text{maximum load}}{\text{Length} * \text{Diameter}}$

7. Flexural strength = $\frac{\text{Load} * \text{Length} / \text{Breadth} * (\text{Diameter})^2}{\text{if } a > 13.3\text{cm}}$

= $\frac{3 * \text{Load} * a / \text{Breadth} * (\text{Diameter})^2}{\text{if } 11\text{cm} < a < 13.3\text{cm}}$

8. Water absorption = $\frac{\text{Oven dried weight} - \text{Water weight}}{\text{Water weight}} * 100$

VI. DESIGN APPROACH AND DETAILS

1. Materials & Methods

The materials used in this project include the following:

- Cement

We used locally available Zuari Cement OPC (Ordinary Portland Cement) Grade 53. We conducted test in order to determine the specific gravity of cement using Le-Chatelier's vessel and found out it to be 3.02 (well within the approval range of 2.90-3.15).

2. Fine Aggregate

We used natural sand with particle size of less than 2.36 mm after proper sieving it from the sand available in our laboratory. The specific gravity was found to be 2.67 (well within the approval range of 2.50-3.00) and fineness modulus of 2.392 after the respective tests were conducted using Pycnometer and Sieves. Fineness modulus indicates that we used fine sand.

3. Coarse Aggregate

The Coarse aggregate used for concrete mix was within the particle size range of 10-20 mm after proper sieving them through 10 mm, 12.5 mm and 20 mm sieves. We used the laboratory available coarse aggregate of specific gravity of 2.73 (well within the approval range of 2.50-3.00) after determining it using the water bucket apparatus.

4. Water

Potable water was used for concrete mixing and curing process.

5. Iron Powder

We procured cast iron powder for this study from Shiva Traders, Chennai, Tamil Nadu-632057. Its physical properties and mineral composition are displayed in the following tables:

Table –I: Physical Properties of Cast Iron Powder

PROPERTY	VALUE
Apparent Density (g/cm ³)	7.24
Specific Gravity	7.1
Melting Point (°C)	1538
Boiling Point (°C)	2861
Magnetic Attraction	Nonmagnetic
Power Rate	0.2V
Moisture Content (%)	40
Young's Modulus (GPa)	211
Particle Size	0.01 mm

Table –II: Mineral Composition of Cast Iron Powder Grade : E250A

CHEMICAL COMPOUND	WEIGHT(%)
TiO ₂	0.69
SiO ₂	2.42
Al ₂ O ₃	1.86
Fe ₂ O ₃	89.4
CaO	0.45
MnO	2.21
MgO	0.23
Na ₂ O	0.67
K ₂ O	1.68
P ₂ O ₅	0.37
Cu	0.003
Ni	0.002

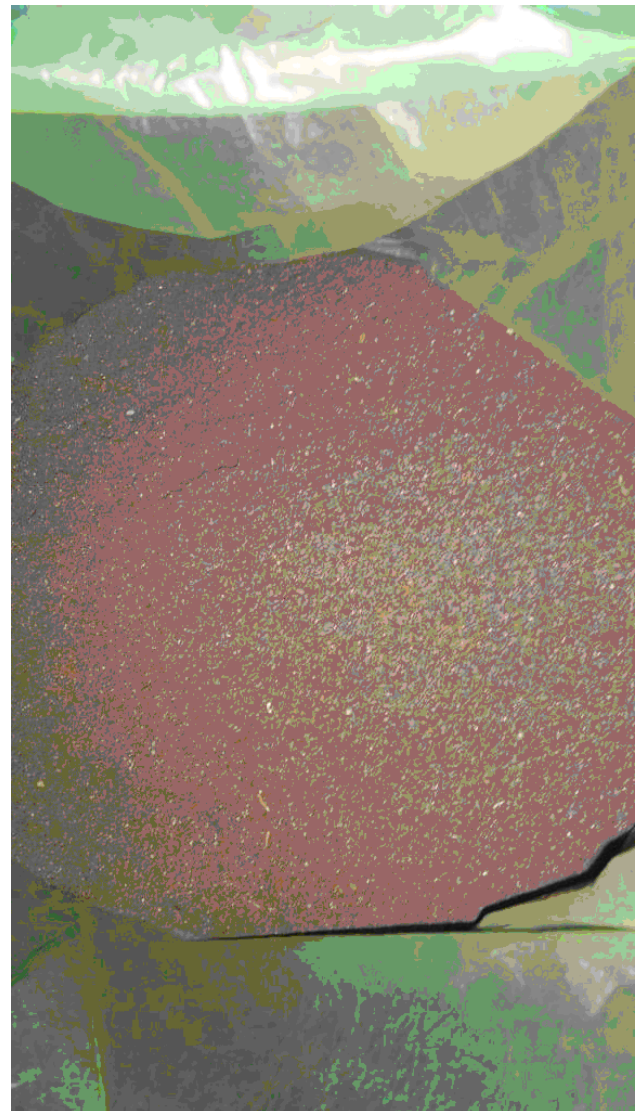


Fig.1. Cast Iron Powder.

We used different equipment for different purposes including batching, mixing, casting and testing. Plastic trays, trowels, sieves, electrically operated weighing scale, measuring cylinder as per recommended IS codes were used for the batching (by weight) process. We used drum mixer for preparing our controlled and modified concrete mixes. After mixing was complete, we poured our mix on metal sheet for casting. We used trowels, tamping rod, cube moulds of size 100mm*100mm*100mm, cylinder moulds of size 100*200mm (for strength test) and 150mm*300mm (for durability test) & 100mm*100mm*500mm sized prism moulds for casting (after lubricating them with available grease). After casting the mix in the moulds, we left them idle for 24 hours in open environment. After 24 hours, we demoulded them using 12mm*13mm, 14mm*15mm and 16mm*17mm sized spanners. After demoulding the specimens, we cured them using ponding process in the laboratory for duration of 7, 14 and 28 days. For testing,

we used the slump cone, CTM (Compressive Testing Machine), Flexural Testing Machine, Hot Air Oven and Bucket.

We went for chemical analysis- XRD test. After testing of our specimens in CTM and Flexural Testing Machine, we collected the broken parts and chips of them in small plastic zip lock pouches and send them for XRD test.

We received the raw XRD data files and processed them further for our analysis using PowDLL Converter, XPERT software, ORIGIN software, MS EXCEL and JCPDS database.

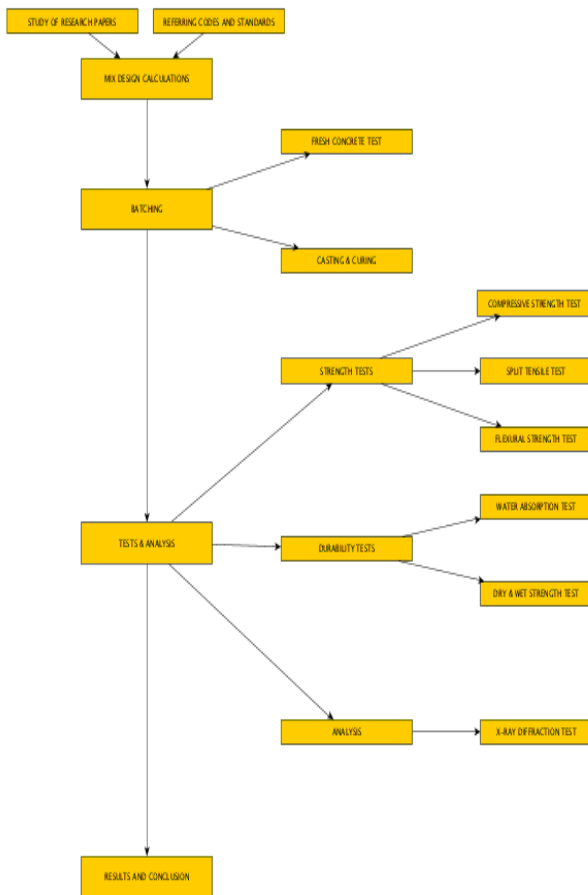


Fig.2. Methodology Flowchart.

The flowchart is explained as follows: -

1. Mix Design Calculations

After referring multiple research papers, we have calculated our mix design proportions for the required grade concrete by considering IS code 456:2000 and IS10262. The detailed mix design is mentioned below:
M35 CONCRETE MIX DESIGN BY IS METHOD

A-1) Design stipulations

M35 - 1:1.56:2.5

Characteristics compressive strength 28 days : 35N/mm²

Target mean strength : $f'_{ck} = f_{ck} + 1.65 s$

(s =5 from is 10262-table 1)

$$f'_{ck} = 35 + 1.65 * 5 = 43.25 \text{ N/mm}^2$$

maximum size of aggregates : 20 mm

workability, slump : 50 to 75mm

Type of exposure : moderate

A-2) Test data for materials

Type of cement : 53 grade (OPC)

Specific gravity of cement : 3.02

Specific gravity of coarse aggregates : 2.73

Specific gravity of fine aggregates : 2.67

Specific gravity of Cast iron powder : 7.1

A-3) Selection of water/cement ratio

From IS 456-2000 table 5 maximum W/C ratio = 0.45

A-4) Estimation of mixing water

a) Weight of water for 20 mm aggregates and slump 25-50 mm = 186 litre.

b) Weight of water for 100 mm slump (increased by 3% for additional 25 mm

slump as per is 10262 clause 4.2) = 197 litre.

A-5) Estimation of weight of cement

Weight of cement = wt. of water/water cement ratio

Weight of cement = $197.16 / 0.45 = 438.13 \text{ kg/m}^3$

Minimum content as per is 456 for severe exposure = 320kg

$438.13 > 320\text{kg}$ hence ok

A-6) Calculating proportion of coarse and fine aggregates

From IS 10262 table 3
Volume of coarse aggregates corresponding to 20mm size and fine aggregates zone 1 = 0.61m³

Volume of fine aggregates = $(1 - 0.61) = 0.39 \text{ m}^3$

A-7) Mix Calculations

a) Volume of concrete = 1m³

b) Volume of cement = $(\text{mass of cement} / \text{specific gravity}) * (1/1000)$

$$= (438.13 / 3.02) * (1/1000) = 0.145 \text{ m}^3$$

c) Volume of water = $(\text{mass of water} / \text{specific gravity}) * (1/1000)$

$$= (197.16 / 1.00) * (1/1000) = 0.197 \text{ m}^3$$

d) Volume of all in aggregates = $\{a - (b+c)\}$

$$= 1 - (0.145 + 0.197) = 0.658 \text{ m}^3$$

e) Weight of coarse aggregates

$$= 0.658 * 0.61 * 2.73 * 1000 = 1095.77 \text{ kg}$$

f) Weight of fine aggregates

$$= 0.658 * 0.39 * 2.67 * 1000 = 685.18 \text{ kg}$$

As mentioned earlier about the categories in our project, the calculations for strength tests are

Volume of 1 cube = $100 * 100 * 100 = 0.001 \text{ m}^3$

Volume of 3 cubes = $3 * 0.001 = 0.003 \text{ m}^3$

Volume of 36 cubes = $36 * 0.001 = 0.036 \text{ m}^3$

Volume of 1 cylinder = $3.14 * (50)^2 * 200 = 0.00157 \text{ m}^3$

Volume of 2 cylinders = $2 * 0.00157 = 0.00314 \text{ m}^3$

Volume of 16 cylinders = $16 * 0.00157 = 0.02512 \text{ m}^3$

Volume of 1 prism = $100 * 100 * 500 = 0.005 \text{ m}^3$

Volume of 2 prisms = $2 \times 0.005 = 0.01 \text{ m}^3$

Volume of 16 prisms = $16 \times 0.005 = 0.08 \text{ m}^3$

The following tables showcase the number of specimens casted, mix and partial replacement calculations for strength tests.

Table –III: Specimens casted for Strength Tests

AGE/PERCENTAGE	0%	15%	30%	45%
7 DAYS	3 C, 2 CM, 2P	3 C, 2 CM, 2P	3 C, 2 CM, 2P	3 C, 2 CM, 2P
14 DAYS	3 C	3 C	3 C	3 C
28 DAYS	3 C, 2 CM, 2P	3 C, 2 CM, 2P	3 C, 2 CM, 2P	3 C, 2 CM, 2P

Table –IV: Mix Calculations Required for Specimens casted for Strength Tests

MATERIAL/SPECIMEN	CUBE	CYLINDER	PRISM	TOTAL
CEMENT	$= 438.13 \times 0.036 \times 1.1 = 17.35 \text{ KG}$	$= 438.13 \times 0.02512 \times 1.1 = 12.11 \text{ KG}$	$= 438.13 \times 0.08 \times 1.1 = 38.56 \text{ KG}$	$= 68.02 \text{ KG}$
WATER	$= 197.16 \times 0.036 \times 1.1 = 7.81 \text{ L}$	$= 197.16 \times 0.02512 \times 1.1 = 5.44 \text{ L}$	$= 197.16 \times 0.08 \times 1.1 = 17.35 \text{ L}$	$= 30.6 \text{ L}$
COARSE AGGREGATE	$= 1095.77 \times 0.036 \times 1.1 = 43.39 \text{ KG}$	$= 1095.77 \times 0.02512 \times 1.1 = 30.28 \text{ KG}$	$= 1095.77 \times 0.08 \times 1.1 = 96.43 \text{ KG}$	$= 170.1 \text{ KG}$
FINE AGGREGATE	$= 685.18 \times 0.036 \times 1.1 = 27.13 \text{ KG}$	$= 685.18 \times 0.02512 \times 1.1 = 18.93 \text{ KG}$	$= 685.18 \times 0.08 \times 1.1 = 60.3 \text{ KG}$	$= 106.36 \text{ KG}$

Table –V: Partial Replacement Calculations Required for Specimens casted Strength Test

NAME/PERCENTAGE	0%	15%	30%	45%
FINE AGGREGATE	26.59 KG	22.6 KG	18.61 KG	14.62 KG
IRON POWDER	0 KG	3.99 KG	7.98 KG	11.97 KG
TOTAL	26.59 KG	26.59 KG	26.59 KG	26.59 KG

Similarly, now for our durability tests,
 Volume of 1 cube = $100 \times 100 \times 100 = 0.001 \text{ m}^3$

Volume of 3 cubes = $3 \times 0.001 = 0.003 \text{ m}^3$

Volume of 6 cubes = $6 \times 0.001 = 0.06 \text{ m}^3$

The following tables showcase the number of specimens casted, mix and partial replacement calculations for durability tests.

Table –VI: Specimens casted for Durability Tests

TEST NAME	AGE/PERCENTAGE	0%	15%	30%	45%
WATER ABSORPTION TEST	28 DAYS	3 C	3 C	3 C	3 C
DRY AND WET STRENGTH TEST	28 DAYS	6 C	6 C	6 C	6 C

Table –VII: Mix Calculations Required for Specimens casted for Durability Tests

MATERIAL/SPECIMEN	CUBE	TOTAL
CEMENT	$= 438.13 \times 0.036 \times 1.1 = 17.35 \text{ KG}$	$= 17.35 \text{ KG}$
WATER	$= 197.16 \times 0.036 \times 1.1 = 7.81 \text{ L}$	$= 7.81 \text{ L}$
COARSE AGGREGATE	$= 1095.77 \times 0.036 \times 1.1 = 43.39 \text{ KG}$	$= 43.39 \text{ KG}$
FINE AGGREGATE	$= 685.18 \times 0.036 \times 1.1 = 27.13 \text{ KG}$	$= 27.13 \text{ KG}$

Table -VIII: Partial Replacement Calculations Required for Specimens casted for Durability Tests

NAME/PERCENTAGE	0%	15%	30%	45%
FINE AGGREGATE	26.59 KG	22.6 KG	18.61 KG	14.62 KG
IRON POWDER	0 KG	3.99 KG	7.98 KG	11.97 KG
TOTAL	26.59 KG	26.59 KG	26.59 KG	26.59 KG

2. Batching, Casting and Curing

After knowing the properties of cement, fine aggregate, coarse aggregate and iron powder, we went for batching by weight. We casted specimens at four different proportions i.e.; 0%, 15%, 30% and 45% where % represents the partial replacement of fine aggregate with cast iron powder for strength and durability tests. Electrically operated drum mixer was used for mixing process. After proper mixing, we poured our mix on a metal sheet and performed the slump cone test to analyse the consistency and workability of freshly made concrete before it sets.

Slump cone test was carried out for every batch prepared to check the uniform quality of concrete. Slump cone with smaller diameter of 100mm, larger diameter of 200mm and height of 300mm and tamping rod of 16mm diameter and 60mm length were used for the test. The Procedure is as follows: -

- We place the slump cone on the metal sheet with one person holding it firmly by standing on its two foot pieces. The slump cone is filled with concrete in 3 layers with each layer being tamped 25 times using tamping rod. The strokes given should be distributed uniformly over the cross section of each layer.
- After filling the slump cone to the top, the excess concrete is stroked off using the trowel. The mould is removed immediately by raising it in the vertical direction in 3 to 7 seconds.
- After removing the mould, we measure the slump value by determining the vertical difference between the top of the mould and the displaced original center of the top surface of the specimen.
- We also determine the pattern of the slump i.e., true, shear or collapse. If it is not true, then the test is repeated.
- After this, we poured the fresh concrete in respective moulds which were initially lubricated with grease. During the process of filling the moulds, tamping is necessary to provide the uniform distribution of materials. For that, minimum of 25 to 30 tamps per layer should be performed (3 layers in total).
- Moulds are kept in open atmosphere for 24 hours without any disturbance for proper drying. After 24 hours, specimens are demoulded, marked with different notations and kept in curing tank for required number of days. Number of specimens and curing days are based on the test which should be performed on respective specimen. After curing duration is over, the specimens are kept for driving in the environment for about an hour. After an hour, the specimens are tested. We casted 36 cubes, 16 cylinders and 16 prisms for strength tests and 36 cubes for durability tests.

3. Tests and Analysis

Physical tests which were performed on the specimens are basically characterized in two different categories- Hardened Concrete test and Durability test.

For hardened concrete tests-compressive strength, split-tensile and flexural strength tests were performed. For this, 3 specimens each of cube and 2 specimens each of cylinder and prism respectively were tested after being cured for different durations (7, 14 and 28 days) at varied proportions (0%, 15%, 30% & 45%). The procedures for the different strength tests are as follow:

3.1 Compressive Strength Test

- After drying, the specimens are ready for testing. CTM is used for this test.
- The machine surfaces are wiped clean with the help of broom. We place the cube in CTM with the sides which aren't uneven such that the load is applied uniformly to the opposite sides.
- Steel plates can be used to raise the height of the specimen. Load rate of 2.5 KN/s is applied until the resistance of the cube specimen to the increasing load

break down, a 'beep' sound starts to play with the maximum load value being shown on the machine's control panel.

- We note down the Maximum Load 'P' value and calculate the strength.

3.2 Split tensile Strength Test

- After drying, the specimens are ready for testing. CTM is used for this test.
- The machine surfaces are wiped clean with the help of broom. We place the cylinder in CTM along their length in such a manner that the load is applied uniformly to the opposite sides.
- Steel plates and wooden strips can be used to raise the height of the specimen and to ensure uniform application of load. Load rate of 2.5 KN/s is applied until the resistance of the cylinder specimen to the increasing load break down, a 'beep' sound starts to play with the maximum load value being shown on the machine's control panel.
- We note down the Maximum Load 'P' value and calculate the strength.

3.2 Flexural Strength Test

- After drying, the specimens are ready for testing. Flexural Testing Machine is used for this test. We mark the prism to denote its span length by removing 5mm from both the sides.
- The machine surfaces are wiped clean with the help of broom. We place the prism in machine along the span length in such a manner that the load is applied uniformly to the opposite sides.
- Loading and supporting rollers capable of rotation and inclination are already incorporated in the machine to ensure uniform loading on the prism. Load rate of 3 KN/s is applied until the resistance of the prism specimen to the increasing load break down, the machine displays the peak load, peak stress, pace and shape of the specimen on the control panel.
- We note down the Peak load value, measure the 'a' value using scale or measuring tape and calculate the strength.

For durability tests-water absorption test and dry and wet strength test were performed. For water absorption and dry and wet strength test, total of 12 and 24 cubes were casted respectively for all percentages. The procedures for different durability tests conducted are as follow:

Water Absorption Test

- After curing duration of 28 days is over, concrete cube is dried and weighed using weighing machine. After weight is noted (W1), the cube is kept in hot air oven at 105 degrees centigrade for 72 hours.
- After 72 hours, the cube is immersed in distilled water for a duration of 24 hours.

- After 24 hours, we clean the surface of the cube with an absorbent cloth and weigh it again. (W2). With both the weights known, we calculate the water absorption rate.

Dry & Wet Strength Test

- We divide our concrete cubes into batches-one for dry strength and one for wet strength test.
- After curing duration of 28 days is over, we put the cubes (for dry strength test) in hot air oven at 105 degrees centigrade for 24 hours. After 24 hours are over, we take out the sample, keep it for some time to cool off and go for testing using CTM.
- For wet strength test, cubes are cured for 28 days. The process of testing is similar as that of Compressive Strength.
- The machine surfaces are wiped clean with the help of broom. We place the cylinder in CTM along their length in such a manner that the load is applied uniformly to the opposite sides.
- Steel plates and wooden strips can be used to raise the height of the specimen and to ensure uniform application of load. Load rate of 2.5 KN/s is applied until the resistance of the cylinder specimen to the increasing load break down, a ‘beep’ sound starts to play with the maximum load value being shown on the machine’s control panel.
- We note down the Maximum Load ‘P’ value and calculate the strengths.

For chemical analysis, we sent the samples of specimen for XRD test

XRD tests were performed to identify the mineral composition of concrete. Furthermore, it tells us about how the lattice is formed (the nature of binding among the different components of concrete), structure of the lattice and the main compounds responsible for the particular strength results.

Performing XRD analysis

This test method is performed by directing an x-ray beam at a sample and measuring the scattered intensity as a function of the outgoing direction. Once the beam is separated, the scatter, also called a diffraction pattern, indicates the sample’s crystalline structure. The Rietveld refinement technique is then used to characterize the crystal structure which most likely provided the observed pattern. When one examines a material using X - ray diffraction, one obtains a XRD spectra.

We received the raw XRD data files and processed them further for our analysis using PowDLL Converter, XPERT software, ORIGIN software, MS EXCEL and JCPDS database.



Fig.3.Powdered samples for XRD test

4. Results and Conclusion

After conducting our tests and getting our analyses done, we got our required results. We discussed among ourselves and concluded our study.

3.2 Codes and Standards

We referred the following codes and standards for our project.

- IS 456-2000: Plain and Reinforced Concrete-Code of Practice (Fourth Revision)
- IS 10262-2009: Concrete Mix Proportioning-Guidelines (First Revision)
- IS 2386 (Part III)-1963: Methods of Test for Aggregates for Concrete Part III Specific Gravity, Density, Voids, Absorption and Bulking (Eight Reprint March 1997)
- IS 7320-1974: Specification for Concrete Slump Test Apparatus(Fourth Reprint November 2000)
- IS 1199-1959: Methods of Sampling and Analysis of Concrete (Eleventh Reprint November 1991)
- SP:23-1982: Handbook on Concrete Mix
- IS 516-1959: Methods of Tests for Strength of Concrete(Eighteenth Reprint June 2006)
- IS 10086-1982:Specification for Moulds for use in test of Cement and Concrete
- ASTM C1585-13:Standard Test Method for Measurement of Rate of Absorption of Water by Hydraulic-Cement Concretes

VII. RESULT & DISCUSSION

1. Slump Cone Test

We conducted slump cone test to observe the effect of cast iron powder on the workability of our freshly made concrete. The test was conducted for each batch casted using the slump cone of smaller diameter of 100mm, larger diameter of 200mm and height of 300mm and tamping rod of 16mm diameter and 60mm length. The results are shown in the following table and represented in the following graph.

Table –IX: Slump Cone Test Results

IRON POWDER PERCENTAGE	SLUMP VALUE	PATTERN	NATURE OF WORKABILITY
0%	37	True	Low
15%	26	True	Low
30%	17	True	Very low
45%	9	True	Very low

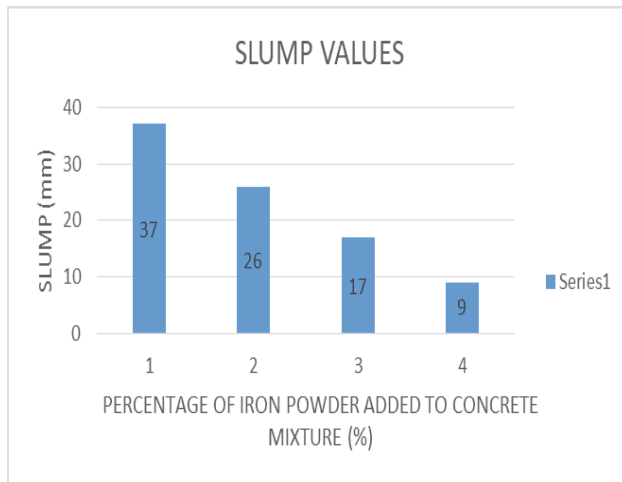


Fig. 4 .Graph displaying Slump values of concrete mixes with different iron powder percentages

The slump value gradually reduced upon the addition of iron powder in the mix which displays the reduction in the workability of the mixes. 37 mm slump of controlled mix reduces to a very low slump value of 9mm in concrete mix with 45% iron powder. Iron powder act as water repellent, increasing the excreting water phenomenon and making the concrete difficult to mix. Due to this the fresh concrete becomes dry which in return makes it hard and elastic. Hence, leading to a decrease in the workability.

2. Strength Tests

We conducted Compressive Strength test, Split-tensile Strength test and Flexural Strength test on concrete cubes, cylinders and prisms casted with varying iron powder percentages. The results are showcased as below:

3.2 Compressive Strength Test

We tested 36 concrete cubes for compressive strength test in CTM after 7, 14 and 28 days of curing. For each percentage of cast iron powder, we casted 9 cubes (3 for each duration). The results are displayed in the following table.

Table -:X: Compressive Strength Test Results

NAME	IRON POWDER %	AGE OF CUBE	C/S AREA (mm ²)	LOAD RATE (KN/s)	LOAD (P) (KN)	COMPRESSIVE STRENGTH (N/mm ²)	AVERAGE COMPRESSIVE STRENGTH (N/mm ²)	
MOC 1.1	0%	7 DAYS	10000	2.5	245	24.5	24.2	
MOC 1.2			10000	2.5	239	23.9		
MOC 1.3			10000	2.5	242	24.2		
MOC 2.1		14 DAYS	10000	2.5	268	26.8	27.0	
MOC 2.2			10000	2.5	273	27.3		
MOC 2.3			10000	2.5	269	26.9		
MOC 3.1		28 DAYS	10000	2.5	337	33.7	34.2	
MOC 3.2			10000	2.5	340	34.0		
MOC 3.3			10000	2.5	349	34.9		
MOC 4.1		15%	7 DAYS	10000	2.5	253	25.3	24.9
MOC 4.2				10000	2.5	246	24.6	
MOC 4.3				10000	2.5	248	24.8	
MOC 5.1	10000		2.5	302	30.2	30.9		
MOC 5.2	14 DAYS		10000	2.5	313		31.3	
MOC 5.3	10000	2.5	312	31.2				
MOC 6.1	28 DAYS	10000	2.5	369	36.9	36.8		
MOC 6.2		10000	2.5	376	37.6			
MOC 6.3		10000	2.5	359	35.9			
MOC 9.1	30%	7 DAYS	10000	2.5	257	25.7	26.1	
MOC 9.2			10000	2.5	262	26.2		
MOC 9.3			10000	2.5	264	26.4		
MOC 8.1		14 DAYS	10000	2.5	387	38.7	39.5	
MOC 8.2			10000	2.5	392	39.2		
MOC 8.3			10000	2.5	406	40.6		
MOC 7.1		28 DAYS	10000	2.5	403	40.3	39.9	
MOC 7.2			10000	2.5	395	39.5		
MOC 7.3			10000	2.5	399	39.9		
MOC 10.1	45%	7 DAYS	10000	2.5	301	30.1	29.6	
MOC 10.2			10000	2.5	293	29.3		
MOC 10.3			10000	2.5	294	29.4		
MOC 11.1	14 DAYS	10000	2.5	340	34.0	33.7		
MOC 11.2		10000	2.5	332	33.2			
MOC 11.3		10000	2.5	339	33.9			
MOC 12.1	28 DAYS	10000	2.5	395	39.5	39.1		
MOC 12.2		10000	2.5	386	38.6			
MOC 12.3		10000	2.5	392	39.2			

The following graphs display the comparison of compressive strengths of different concrete mixes against different iron powder percentages and ages.

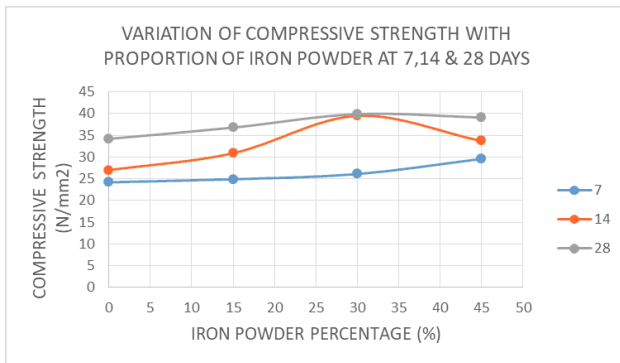


Fig.5 Graph displaying variation of compressive strength with proportion of iron powder at 7,14 and 28 days

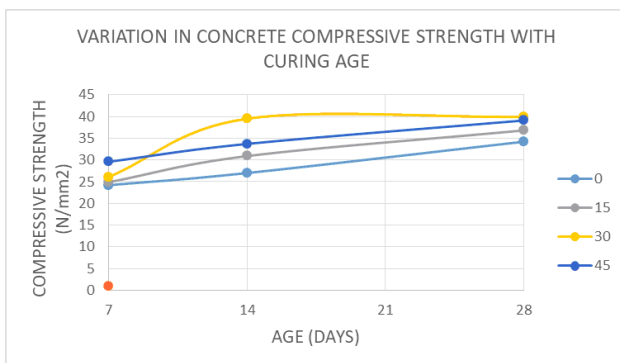


Fig.6 Graph displaying variation in concrete compressive strength with curing age

It is clearly visible from the above graphs that the mix with 30% iron powder in it gives the best average compressive strength. MOC 8 and MOC 7 have highest average compressive strengths of 39.5 N/mm² and 39.9 N/mm² on 14th and 28th days of testing. Whereas, MOC 11 have highest average compressive strength of 29.6 N/mm² on 7th day of testing.

The increase in the strength may be attributed to the nano-filler effect of the cast iron powder in concrete. Upon addition of iron powder, the particles improve the bond between the aggregate and cement matrix by filling the voids between them. Due to its small particle size of 0.01 mm, there is better compaction of the microstructure as a whole and making the mix denser. When there is better compaction, there are lesser air voids and hence higher strength (1% air entrainment reduces up to 5% of strength).

However, the strength trends to reduce after 30 percent as seen from our results. This points out the fact that although iron powder has high iron oxide (89.4%), it can't fully take on the role of sand which is rich in silica (load bearing material in concrete). When sand is 45% replaced, the silica content reduces, hence the strength reduces. Hence, it can be said that the optimum percentage for replacement of fine aggregate with iron powder is 30 percent.

3.2 SPLIT TENSILE STRENGTH TEST

We tested 16 concrete cylinders for split-tensile strength test in CTM after 7 and 28 days of curing. For each percentage of cast iron powder, we casted 4 cylinders (2 for each duration). The results are displayed in the following table.

Table -:11 Split-Tensile Strength Test Results

NAME	IRON POWDER %	AGE OF CYLINDER	DIAMETER (mm)	DEPTH (mm)	LOAD RATE (KN/s)	MAXIMUM LOAD (P) (KN)	SPLIT-TENSILE STRENGTH (N/mm ²)	AVERAGE SPLIT TENSILE STRENGTH (N/mm ²)
MOCM 1.1	0%	7 DAYS	100	200	2.5	88	2.80	2.77
MOCM 1.2			100	200	2.5	86	2.74	
MOCM 2.1		28 DAYS	100	200	2.5	75	2.39	2.29
MOCM 2.2			100	200	2.5	69	2.20	
MOCM 3.1	15%	7 DAYS	100	200	2.5	72	2.29	2.26
MOCM 3.2			100	200	2.5	70	2.23	
MOCM 4.1		28 DAYS	100	200	2.5	84	2.68	2.58
MOCM 4.2			100	200	2.5	78	2.48	
MOCM 5.1	30%	7 DAYS	100	200	2.5	86	2.74	2.80
MOCM 5.2			100	200	2.5	90	2.87	
MOCM 6.1		28 DAYS	100	200	2.5	73	2.32	2.26
MOCM 6.2			100	200	2.5	69	2.20	
MOCM 7.1	45%	7 DAYS	100	200	2.5	83	2.64	2.61
MOCM 7.2			100	200	2.5	81	2.58	
MOCM 8.1		28 DAYS	100	200	2.5	88	2.80	2.90
MOCM 8.2			100	200	2.5	94	2.99	

Graphs display the comparison of split-tensile strengths of different concrete mixes against different iron powder percentages and ages.

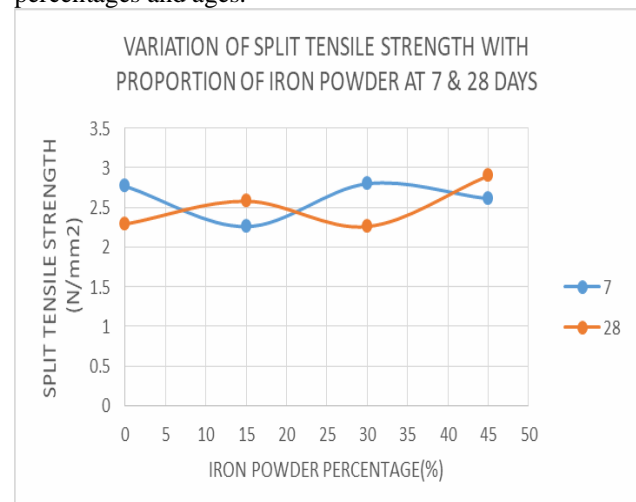


Fig.7 Graph displaying variation of split-tensile strength with proportion of iron powder at 7 and 28 days

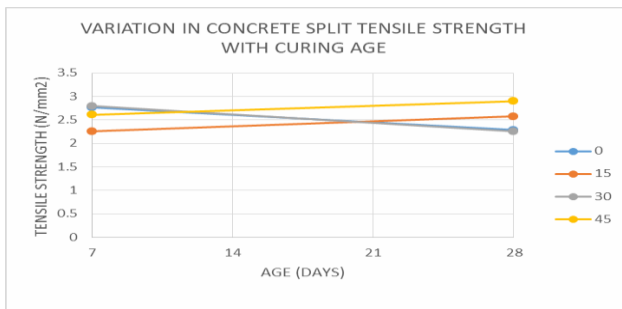


Fig.8 Graph displaying variation in concrete split tensile strength with curing age

We got the highest split-tensile strength of 2.80 N/mm² and 2.90 N/mm² respectively on 7th and 28th day of testing for 30% and 45% iron powder mix respectively. Variations as displayed by the graphs point out the fact that the materials are weak in tension. As the iron powder content is increased in the subsequent mixes, the fines content also rises leading to an increase in water demand and reduced aggregate-cement paste bond. Hence, there are such variations in these results making it difficult to determine the optimum percentage of replacement.

7.2.3 FLEXURAL STRENGTH TEST

We tested 16 concrete prisms for flexural strength test in Flexural Testing machine after 7 and 28 days of curing. For each percentage of cast iron powder, we casted 4 prisms (2 for each duration). The results are displayed in the following table.

Table – XII: Flexural Strength Test Results

NAME	IRON POWDER %	AGE OF PRISM	SIZE (mm)	SPAN LENGTH (mm)	MAXIMUM LOAD (P) (KN)	LOAD RATE (KN/s)	POSITION OF 's' (mm)	FLEXURAL STRENGTH (N/mm ²)	AVERAGE FLEXURAL STRENGTH (N/mm ²)
MOP 1.1	0%	7	100*100*500	400	13.28	3.0	148	5.31	5.32
MOP 1.2			100*100*500	400	13.34	3.0	142	5.34	
MOP 2.1		28	100*100*500	400	15.2	3.0	148	6.08	6.04
MOP 2.2			100*100*500	400	15	3.0	146	6.00	
MOP 3.1	15%	7	100*100*500	400	13.87	3.0	133	5.55	5.54
MOP 3.2			100*100*500	400	13.82	3.0	135	5.53	
MOP 4.1		28	100*100*500	400	16.98	3.0	136	6.79	6.77
MOP 4.2			100*100*500	400	16.88	3.0	134	6.75	
MOP 5.1	30%	7	100*100*500	400	14.71	3.0	154	5.88	5.90
MOP 5.2			100*100*500	400	14.77	3.0	158	5.91	
MOP 6.1		28	100*100*500	400	17.78	3.0	151	7.11	7.12
MOP 6.2			100*100*500	400	17.83	3.0	153	7.13	
MOP 7.1	45%	7	100*100*500	400	15.2	3.0	168	6.08	6.00
MOP 7.2			100*100*500	400	14.8	3.0	164	5.92	
MOP 8.1		28	100*100*500	400	18.6	3.0	158	7.44	7.48
MOP 8.2			100*100*500	400	18.8	3.0	154	7.52	

The following graphs display the comparison of flexural strengths of different concrete mixes against different iron powder percentages and ages.

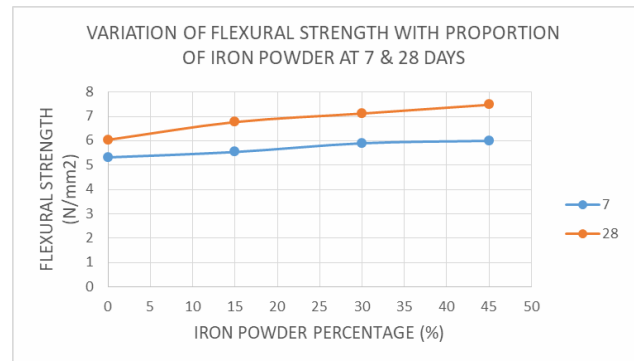


Fig.9. Graph displaying variation of flexural strength with proportion of iron powder at 7 and 28 days

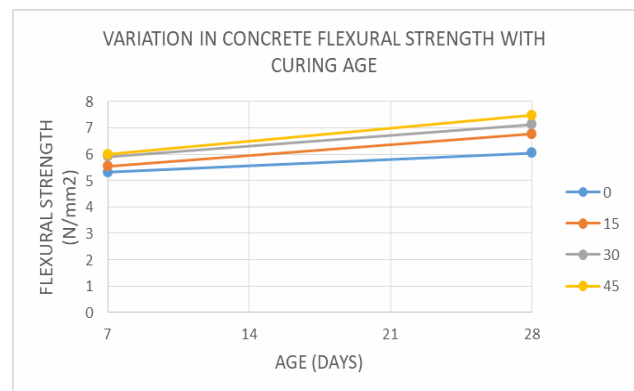


Fig.10 Graph displaying variation in concrete flexural strength with curing age

The results display that the flexural strength of the concrete mixes increased with an increase in the iron powder percentage. MOP 7 and MOP 8 pose the highest average flexural strengths of 6 N/mm² and 7.48 N/mm² on 7th and 28th days of testing. This showcase that concrete mix with 45% iron powder has the highest flexural strength making it the optimum percentage of replacement.

3. Durability Tests

We casted cubes and cylinders with different iron powder percentages and tested them for different durability tests as per IS codes. The results are show below.

3.2 Water Absorption Test

12 concrete cubes of 100mm*100mm size were casted and tested after 28 days of curing. For each percentage of cast iron powder, we casted 3 cubes. The results are displayed in the following table.

Table –XIII: Water Absorption Test Results

NAME	WEIGHT OF CUBE BEFORE OVEN DRYING (W1) AT 105C FOR 72 HOURS (KG)	WEIGHT OF CUBE AFTER IMMERSING IN WATER (W2) FOR 24 HOURS (KG)	WATER ABSORPTION %	AVERAGE WATER ABSORPTION %
DM0 1.1	2.414	2.519	4.35	4.43
DM0 1.2	2.413	2.521	4.48	
DM0 1.3	2.412	2.520	4.48	
DM15 1.1	2.474	2.596	4.93	4.89
DM15 1.2	2.475	2.593	4.77	
DM15 1.3	2.472	2.595	4.98	
DM30 1.1	2.565	2.696	5.11	5.05
DM30 1.2	2.568	2.700	5.14	
DM30 1.3	2.566	2.692	4.91	
DM45 1.1	2.649	2.772	4.64	4.66
DM45 1.2	2.647	2.770	4.65	
DM45 1.3	2.651	2.775	4.68	

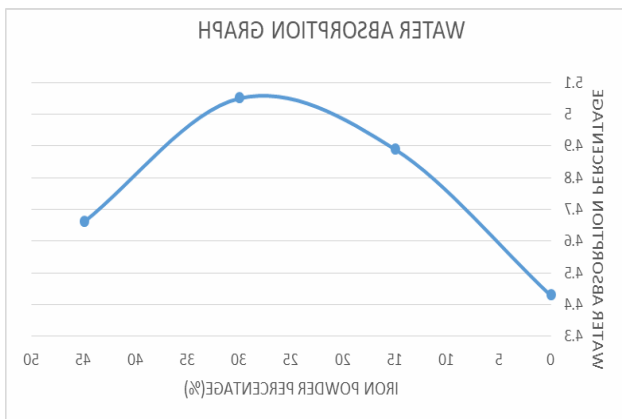


Fig. 11. Graph displaying variation in water absorption rate of different concrete mixes

The water absorption rate shoots up to a value of 5.05% for 30% iron powder embedded concrete mix from a value of 4.43% of the controlled mix. After this, the value diminishes to 4.66% for concrete mix with 45% iron powder.

As we know that the water holding capacity(absorption) of concrete can be related to the phenomenon of capillarity. The reason behind the variation of water absorption percentage due the partial replacement of iron powder can be depicted as, the radius of voids is getting reduced with the addition of iron powder in the concrete mix from 0 to 30%, (from the capillarity relation) water absorption would increase in this range and highest at 30%. With the addition of further iron powder after 30%, the voids are nearby filled i.e., saturation is reached which in turn leads to the spilling of water. hence, the water absorption value decreases.

3.2 Dry & Wet Strength Test

24 concrete cubes of 100mm*100mm size were casted and tested after 28 days of curing(wet) in CTM. 12 cubes were oven dried for 1 extra day before testing their dry strength. For each percentage of cast iron powder, we casted 6 cubes (3 for wet and 3 for dry strength test). The procedure for this test is available in Appendix. The results are displayed in the following table.

Table 14 Dry and Wet Strength Test Results

NAME	C/S AREA (mm ²)	LOAD RATE (KN/s)	LOAD (P) (KN)	COMPRESSIVE STRENGTH (N/mm ²)	AVERAGE COMPRESSIVE STRENGTH (N/mm ²) & TYPE
DM0 1.4	10000	2.5	360	36.0	36.0 W
DM0 1.5	10000	2.5	361	36.1	
DM0 1.6	10000	2.5	359	35.9	
DM0 1.7	10000	2.5	385	38.5	38.8 D
DM0 1.8	10000	2.5	387	38.7	
DM0 1.9	10000	2.5	392	39.2	
DM15 1.4	10000	2.5	389	38.9	38.9 W
DM15 1.5	10000	2.5	391	39.1	
DM15 1.6	10000	2.5	387	38.7	
DM15 1.7	10000	2.5	444	44.4	44.4 D
DM15 1.8	10000	2.5	440	44.0	
DM15 1.9	10000	2.5	448	44.8	
DM30 1.4	10000	2.5	392	39.2	39.6 W
DM30 1.5	10000	2.5	395	39.5	
DM30 1.6	10000	2.5	401	40.1	
DM30 1.7	10000	2.5	448	44.8	44.8 D
DM30 1.8	10000	2.5	445	44.5	
DM30 1.9	10000	2.5	45.1	45.1	
DM45 1.4	10000	2.5	316	31.6	31.1 W
DM45 1.5	10000	2.5	318	31.8	
DM45 1.6	10000	2.5	299	29.9	
DM45 1.7	10000	2.5	328	32.8	32.3 D
DM45 1.8	10000	2.5	325	32.5	
DM45 1.9	10000	2.5	316	31.6	

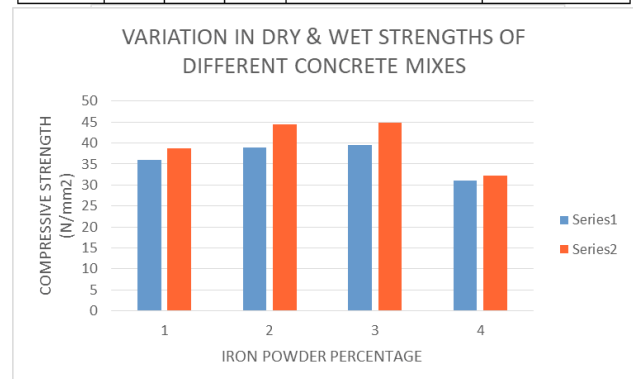


Fig.12. Graph displaying variation in dry & wet strengths of different concrete mixes

From the graphical and tabular representation of our results, we can easily point out the fact that dry strength is more than the wet strength. Strength can be related to modulus of elasticity which is defined as the ratio of

stress to strain. The load rate that is the stress is constant for all testing at 2.5 KN/s, hence it is the strain that plays a major role in determining it. The modulus of elasticity also depends upon the state of wetness of concrete when other conditions being the same. Wet concrete will show higher modulus of elasticity than dry concrete. This is in contrast to the strength property that dry concrete has higher strength than wet concrete. The possible reason is that wet concrete being saturated with water, experiences less strain for a given stress and, therefore, gives higher modulus of elasticity, whereas dry concrete shows higher strain for given stress on account of less gel water and inter-crystal adsorbed water.

VIII. ANALYSIS

We performed XRD test as a part of our chemical analysis on our specimens.

XRD is non-destructive test method used to analyse the structure of crystalline materials. XRD analysis, by way of the study of the crystal structure, is used to identify the crystalline phases present in a material and thereby reveal chemical composition information. This laboratory based technique helps in the identification of crystalline materials and analysis of unit cell dimensions. Identification of phases is achieved by comparison of the acquired data to that in reference databases. X-ray diffraction is useful for evaluating minerals, polymers, corrosion products, and unknown materials.

Performing XRD analysis

This test method is performed by directing an x-ray beam at a sample and measuring the scattered intensity as a function of the outgoing direction. Once the beam is separated, the scatter, also called a diffraction pattern, indicates the sample's crystalline structure. The Rietveld refinement technique is then used to characterize the crystal structure which most likely provided the observed pattern. When one examines a material using X - ray diffraction, one obtains a XRD spectra.

XRD tests were performed to identify the mineral composition of concrete. Furthermore, it tells us about how the lattice is formed (the nature of binding among the different components of concrete), structure of the lattice and the main compounds responsible for the particular strength results.

After testing our specimens in CTM and Flexural Testing Machine for different strength tests, we collected small bits and chips of them in small plastic zip lock pouches and sent them to the XRD lab.

We received raw XRD files from the lab and started our analysis. The procedure is as follows:

1. We used PowDLL Converter to convert our .rd file into .raw file.
2. We opened XPERT Software, browse our .raw file choose View option, opened Panel & Default

Settings Analysis Search & Match Execute Search & Match Restrictions Edit Restriction set Periodic Table choose compound and click ok, then click Add rest to none close the dialogue box and click on Search

3. We choose the highest score of a compound name and double clicked on it.
4. We also chose the highest I(Intensity) Value and highest 2θ value.
5. Open .raw file in Notepad and close it
6. Open MS EXCEL, choose Data option from text.txt file fixed with next scroll choose values next finish form table of 2 columns
7. We pasted our values in ORIGIN software, we get graph with the peak 2θ values.
8. Again open MS EXCEL to calculate the d value using the Bragg's equation. ($n\lambda = 2d\sin\theta$)
9. We opened the JCPDS software, used the 'd' value(which we got from 3 peak 2θ values) to get the JCPDS number from the JCPDS database. This JCPDS number displays the existence of a particular compound in the concrete mix with JCPDS card.

'd' Value denotes the Atomic space and θ the angle between the lattice points. Joint Committee on Powder Diffraction Standards (JCPDS) database is a database of standard XRD reference patterns for various materials.

Our individual samples with their graphs(XRD Spectra) and JCPDS cards are shown below: XRD ANALYSIS: A small amount of powder sample is put into an aluminum sample holder and the surface is finished smoothly. The holder is then placed into the X-Ray diffractometer. The samples are scanned by an X-Ray diffractometer using CuK radiation at 40 kV / 20 mA, CPS = 1k, width 2.5, speed 2° / min and scanned with an angle of 2θ from $3 - 70^\circ$. The analysis is stepped at 0.04 degree increments and continued for a period of 3 seconds. In X-Ray diffraction, X-Rays are scattered by atoms in a pattern that indicates lattice spacing of elements present in the material analyzed. Once the X-Ray analysis is completed, the scans are analyzed using Jade 7 - X-Ray Diffraction (XRD) software.

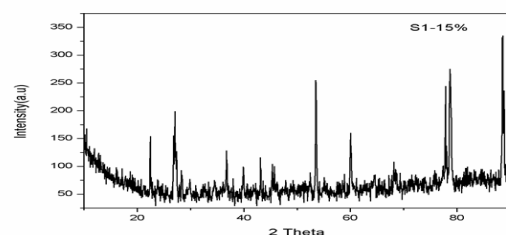


Fig.13. Graph plotted between I values and 2θ values of S1-15% IP 7 days

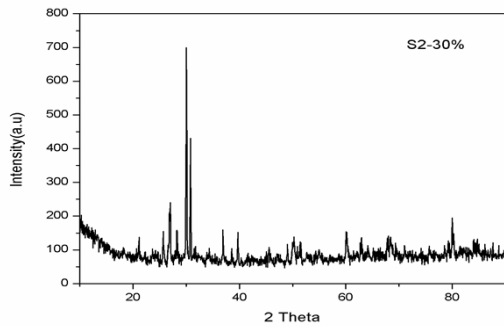


Fig.14 Graph plotted between I values and 2θ values of S2-30% IP 7 days

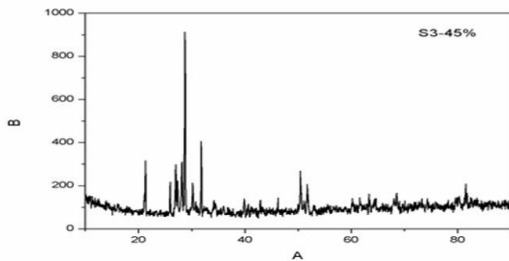


Fig.15 Graph plotted between I values and 2θ values of S3-45% IP 7 days

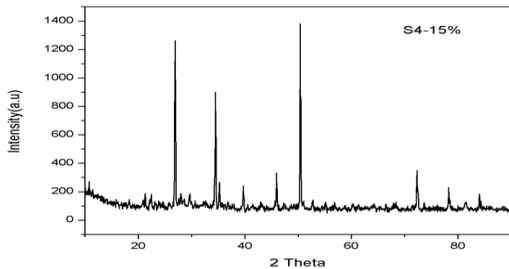


Fig.16 Graph plotted between I values and 2θ values of S4-15% IP 14 DAYS

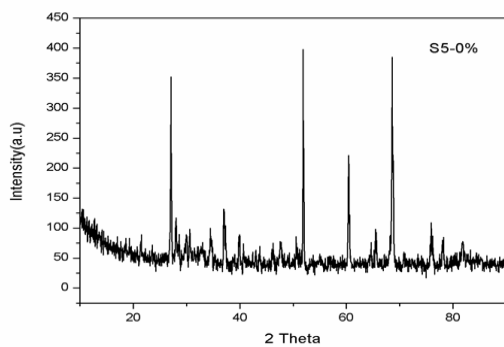


Fig.17 Graph plotted between I values and 2θ values of S5-0% IP-28 DAYS

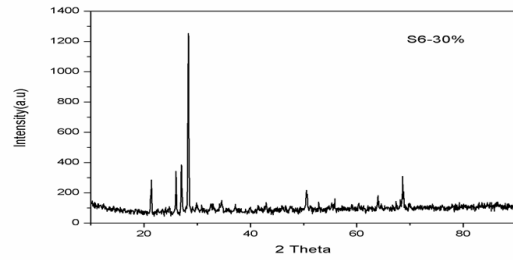


Fig.18 Graph plotted between I values and 2θ values of S6-30% IP-14 DAYS

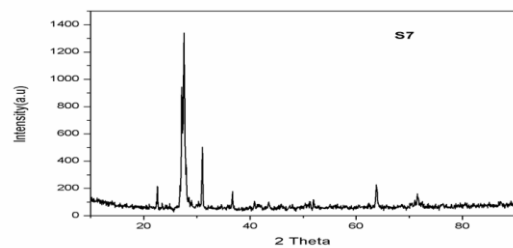


Fig.19 Graph plotted between I values and 2θ values of S7-45% IP-14 DAYS

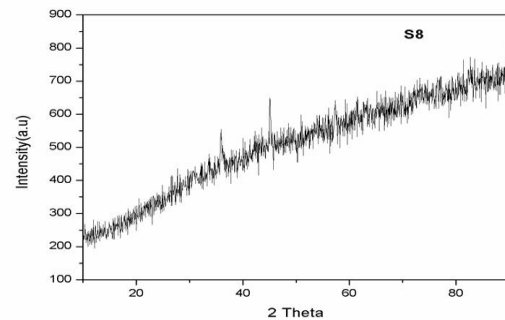


Fig.20 Graph plotted between I values and 2θ values of S8 IP

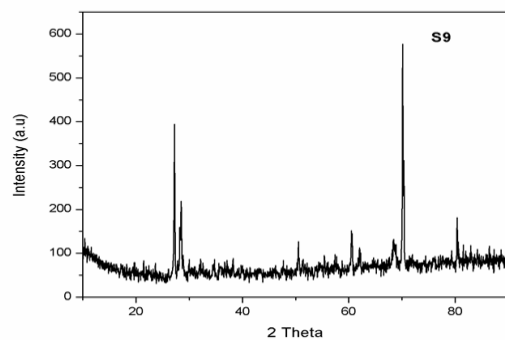


Fig.21 Graph plotted between I values and 2θ values of S9-15% IP-28 DAYS

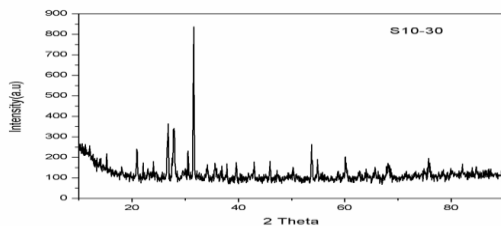


Fig.22 Graph plotted between I values and 2θ values of S10-30% IP-28 DAYS

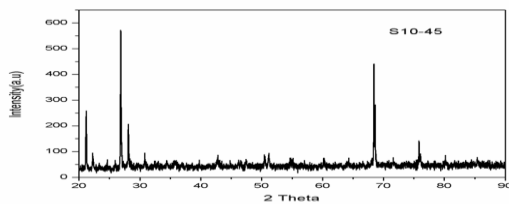


Fig.23 Graph plotted between I values and 2θ values of S11-45% IP-28 DAYS

For easier understanding, the results are displayed in the following table.

Table -:15 XRD Test Results

SAMPLE	JCPDS NUMBER	CHEMICAL NAME	CHEMICAL COMPOUND	SYSTEM
S1-15% IP-7 DAYS	52-1258	CALCIUM ALUMINIUM IRON OXIDE	$\text{Ca}_3\text{Al}_2\text{Fe}_2\text{Si}_2\text{O}_{19}$ $\text{Ca}_3.18\text{Fe}1.54\text{Al}1.34\text{O}_{28}$	ANORTHIC (A)
S2-30% IP-7 DAYS	49-1586	CALCIUM ALUMINIUM IRON OXIDE	$\text{Ca}_3\text{Al}_2\text{Fe}_2\text{Si}_2\text{O}_{19}$	HEXAGONAL (H)
S3-45% IP-7 DAYS	25-0120	CALCIUM ALUMINIUM IRON OXIDE	$\text{Ca}_3\text{Al}_2\text{Fe}_2\text{Si}_2\text{O}_{19}$	HEXAGONAL (H)
S4-15% IP-14 DAYS	52-1258	CALCIUM ALUMINIUM IRON OXIDE	$\text{Ca}_3\text{Al}_2\text{Fe}_2\text{Si}_2\text{O}_{19}$	HEXAGONAL (H)
S5-0% IP-28 DAYS	30-0040	CALCIUM ALUMINIUM IRON OXIDE	$\text{Ca}_3\text{Al}_2\text{Fe}_2\text{O}_{12}$	HEXAGONAL
S6-30% IP-14 DAYS	52-1258	CALCIUM ALUMINIUM IRON OXIDE	$\text{Ca}_3\text{Al}_2\text{Fe}_2\text{Si}_2\text{O}_{19}$	HEXAGONAL (H)
S7-45% IP-14 DAYS	70-1499	CALCIUM ALUMINIUM IRON OXIDE	$\text{Ca}_3\text{Al}_2\text{Fe}_2\text{O}_{12}$	HEXAGONAL
S9-15% IP-28 DAYS	70-1498	CALCIUM ALUMINIUM IRON OXIDE	$\text{Ca}_3\text{Al}_2\text{Fe}_2\text{O}_{12}$	HEXAGONAL
S10-30% IP-28 DAYS	49-1586	CALCIUM ALUMINIUM IRON OXIDE	$\text{Ca}_3\text{Al}_2\text{Fe}_2\text{Si}_2\text{O}_{19}$	HEXAGONAL
S11-45% IP-28 DAYS	25-0120	CALCIUM ALUMINIUM IRON OXIDE	$\text{Ca}_3\text{Al}_2\text{Fe}_2\text{Si}_2\text{O}_{19}$	HEXAGONAL (H)

The peak intensities at different angles are compared with a database of different minerals and compounds. Similarly, compounds with peak intensities matching those of the scans are identified and the compounds present in the samples are also determined. The peak indicates that the iron content is of crystalline nature and the broad parts indicate that the elements are amorphous in nature. The broadening portion of the curve represents the particles in diffraction pattern.

XRD Test gives the mineral composition of the sample under observation in the form of graphs shown above and JCPDS software gives us the Chemical name, formula and the structure of the lattice formed. After studying them, we can easily conclude our study by determining

the reasons behind our strength and durability test results. Adding to that, it helps us to find out the optimum percentage of partial replacement.

IX. CONCLUSION

After conducting the aforementioned experiments, we came up with the following conclusions.

1. After conducting Slump Cone Test, we noticed a gradual decrease in the slump value upon the addition of iron powder in the mix (37 mm in 0% to 9 mm in 45% iron powder embedded concrete). This displays the reduction in the workability of the mixes. Iron powder makes fresh concrete dry, causing it to become hard and elastic which is the sole reason behind the decrease in workability.
2. We noticed that the compressive strength (28 days) of concrete increases with the addition of iron powder from 34.2 N/mm² to 39.9 N/mm² i.e., from 0% to 30%. The compressive strength drops upon any further increase of iron powder which is showcased by the strength of 39.1 N/mm² of 45% Iron powder embedded concrete.
3. The split-tensile strength results lead to a little bit of confusion as 30% iron powder embedded concrete boasts better results at 7th day of testing while 45% iron powder embedded concrete gives better results at 28th day of testing.
4. The flexural strength of concrete continue to increase with the addition of iron powder in it. 45% iron powder gives the maximum strength of 6 N/mm² and 7.48 N/mm² at 7th and 28th day of testing.
5. The increase in flexural strength was found to be pronounced than compressive and split-tensile strength.
6. The reason behind the increase in strengths can be related to the particle size of iron powder. As it is smaller than sand, they were able to fill the voids between sand particles similar to the way sand particles fill the void between coarser aggregates thus resulting in less voids and higher density and strength. In the case of the iron powder, the increase in strength may be attributed to the modest increase in fineness of particles especially in the smaller diameter particles. In addition, because the particle size is smaller than sand, the surface area will be larger. Because of higher surface area of iron powder compared to sand, the concrete is expected to have higher strength due to more bonded areas with hydrating cement.
7. From the Water Absorption test and Dry & Wet strength test results, it is concluded that the mix with 30% iron powder gives the best results.
8. From the strength tests and durability tests results, we can conclude by saying that the optimum percentage of replacement is 30%.
9. Although the iron powder generally has less silicon oxide content compared to sand and that not all iron powder may react chemically with cement, the filler effect will bring improvements in the concrete. This is clearly visible with our XRD test results.

10. Finally, it can be concluded iron powder can be used as a partial substitute for natural sand to prepare concrete. It reduces the consumption of sand, solves the environmental pollution problem of iron powder, and encourages the development of eco-friendly projects. It is also important to note that full replacement of sand by IP isn't possible because it is beneficial only till the optimum percentage of 30%, after which it degrades and deteriorates the mix. Also, the weight of the concrete increases with the increase in percentage of IP.

APPENDIX

ID	Chemical Name	Chemical Formula	3 Strongest Lines	Sys
89-2827	Brownmillerite, Fe-rich, syn, Iron Alum-	Fe _{1.33} Al _{0.67} Ca ₂	2.66 7.30 2.69	O
77-0676	Calcium Iron Aluminum Oxide	Ca ₇ 12 Fe _{0.88} Fe ₂	10.7 2.61 2.60	A
74-1346	Brownmillerite, Iron Aluminum Calcium O-	Fe Al O ₃ (Ca O) ₂	2.64 2.67 1.93	O
74-0933	Iron Aluminum Calcium Oxide	Fe ₂ O ₃ Al ₂ O ₃ (-	2.64 2.67 1.93	O
71-0967	Brownmillerite, Calcium Iron Aluminum O-	Ca ₂ Fe Al O ₅	2.66 2.69 1.94	O
70-1459	Calcium Iron Aluminum Oxide	Ca ₂ Fe _{1.28} Al _{0.72}	2.65 2.79 7.29	O
70-1496	Calcium Aluminum Iron Oxide	Ca ₂ Fe _{1.40} Al _{0.60}	2.66 2.69 1.94	O
52-1258	Calcium Iron Aluminum Oxide	Ca ₃ 18 Fe _{15.48} Al-	2.61 1.53 2.88	A
49-1598	Calcium Aluminum Iron Oxide	Ca ₄ Al ₄ Fe ₈ O ₁₉	2.68 2.52 1.70	H
49-0038	Calcium Aluminum Iron Oxide	Ca ₄ Fe ₄ Al ₄ O ₉	2.68 2.13 1.64	A
42-1489	Calcium Aluminum Iron Oxide	Ca ₂ Al _{1.38} Fe _{0.62}	2.63 2.65 1.91	O
38-0469	Hibonite-SH, ferroan, Calcium Aluminu-	Ca (Al , Fe) ₁₂	2.67 2.51 2.13	H
35-0040	Calcium Aluminum Iron Oxide	Ca ₃ (Al , Fe) ₂	2.65 2.89 2.54	R
30-0226	Brownmillerite, syn, Calcium Aluminum I-	Ca ₂ (Al , Fe +3-	2.64 7.25 1.82	O
25-0120	Calcium Aluminum Iron Oxide	Ca ₄ Al ₄ Fe ₄ O ₁₉	2.67 2.53 1.42	H
21-0830	Calcium Aluminum Iron Oxide	Ca ₄ Al ₂ Fe ₄ O ₁₀	2.67 2.55 3.15	X
16-0410	Brownmillerite, syn, Calcium Aluminum I-	Ca ₂ (Al _{0.7} Fe _{0.3} -	2.62 2.76 2.65	O

ID	Chemical Name	Chemical Formula	3 Strongest Lines	Sys
70-1499	Calcium Iron Aluminum Oxide	Ca ₂ Fe _{1.28} Al _{0.72}	2.65 2.79 7.29	O
70-1498	Calcium Aluminum Iron Oxide	Ca ₂ Fe _{1.40} Al _{0.60}	2.66 2.69 1.94	O
52-1258	Calcium Iron Aluminum Oxide	Ca ₃ 18 Fe _{15.48} Al-	2.61 1.53 2.88	A
49-1598	Calcium Aluminum Iron Oxide	Ca ₄ Al ₄ Fe ₈ O ₁₉	2.68 2.52 1.70	H
49-0038	Calcium Aluminum Iron Oxide	Ca ₄ Fe ₄ Al ₄ O ₉	2.68 2.13 1.64	A
42-1489	Calcium Aluminum Iron Oxide	Ca ₂ Al _{1.38} Fe _{0.62}	2.63 2.65 1.91	O
38-0469	Hibonite-SH, ferroan, Calcium Aluminu-	Ca (Al , Fe) ₁₂	2.67 2.51 2.13	H
35-0040	Calcium Aluminum Iron Oxide	Ca ₃ (Al , Fe) ₂	2.65 2.89 2.54	R
30-0226	Brownmillerite, syn, Calcium Aluminum I-	Ca ₂ (Al , Fe +3-	2.64 7.25 1.82	O
25-0120	Calcium Aluminum Iron Oxide	Ca ₄ Al ₄ Fe ₄ O ₁₉	2.67 2.53 1.42	H
21-0830	Calcium Aluminum Iron Oxide	Ca ₄ Al ₂ Fe ₄ O ₁₀	2.67 2.55 3.15	X
16-0410	Brownmillerite, syn, Calcium Aluminum I-	Ca ₂ (Al _{0.7} Fe _{0.3} -	2.62 2.76 2.65	O
11-0190	Calcium Aluminum Iron Oxide	Ca ₆ Al ₄ Fe ₂ O ₁₅	2.62 2.76 2.65	X
11-0124	Brownmillerite, syn, Calcium Aluminum I-	Ca ₄ Al ₂ Fe ₂ +3 O ₁₀	2.63 2.77 1.92	O
10-0032	Brownmillerite, syn, Calcium Aluminum I-	Ca ₄ Al ₂ Fe ₂ +3 O ₁₀	2.64 7.25 2.78	X
02-9965	Calcium Aluminum Iron Oxide	4 Ca O - Al ₂ O ₃ -	2.63 1.92 2.77	X
01-1068	Calcium Aluminum Iron Oxide	Ca ₂ (Al Fe) O ₅	2.66 1.93 2.78	X

LIST OF ABBREVIATIONS

IP	Iron Powder
FA	Fine Aggregate
C	Cube
CM	Cylinder
P	Prism
CTM	Compression Testing Machine
MOC	Mix Cube
MOCM	Mix Cylinder
MOP	Mix Prism
DM0	Durability Mix with 0 percent iron powder
DM15	Durability Mix with 15 percent iron powder
DM30	Durability Mix with 30 percent iron powder
DM45	Durability Mix with 45 percent iron powder
XRD	X-Ray Diffraction
JCPDS	Joint Committee on Powder Diffraction Std.
C/S	Cross Section

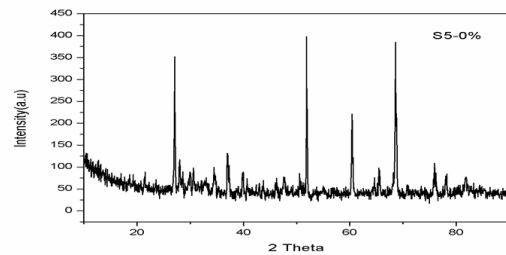


Fig.17. Graph plotted between I values and 2θ values of S5-0% IP-28 DAYS

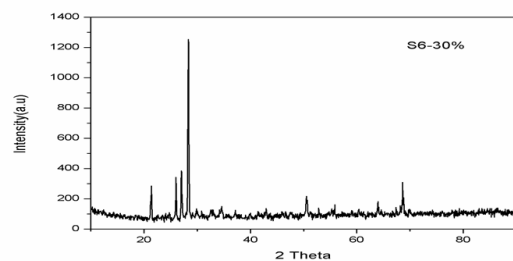


Fig.18 Graph plotted between I values and 2θ values of S6-30% IP-14 DAYS

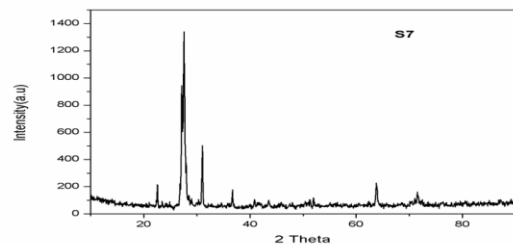


Fig.19 Graph plotted between I values and 2θ values of S7-45% IP-14 DAYS

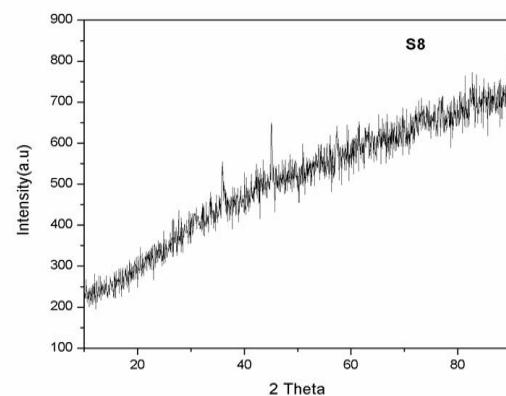


Fig.20 Graph plotted between I values and 2θ values of S8 IP

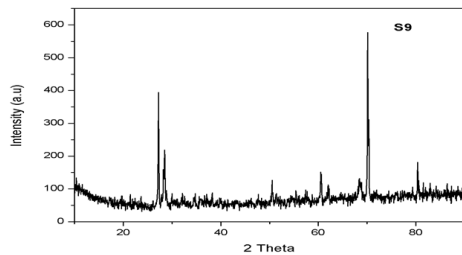


Fig.21. Graph plotted between I values and 2θ values of S9-15% IP-28 DAYS

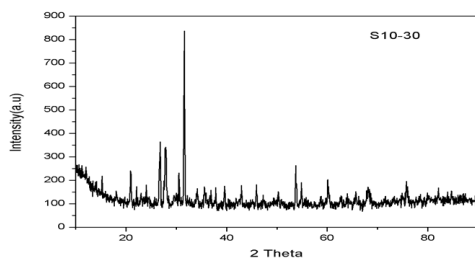


Fig.22. Graph plotted between I values and 2θ values of S10-30% IP-28 DAYS

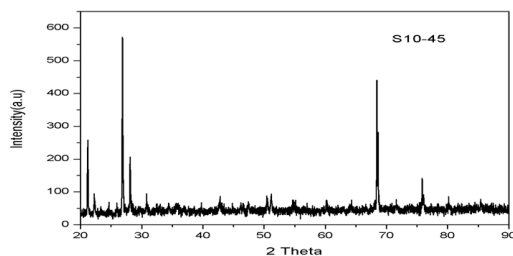


Fig.23. Graph plotted between I values and 2θ values of S11-45% IP-28 DAYS

For easier understanding, the results are displayed in the following table.

Table -:15 XRD Test Results

SAMPLE	JCPDS NUMBER	CHEMICAL NAME	CHEMICAL COMPOUND	SYSTEM
S1-15% IP-7 DAYS	52-1258	CALCIUM IRON ALUMINIUM OXIDE	$\text{CaAl}_4\text{Fe}_8\text{O}_{19}$ $\text{Ca}_3.18\text{Fe}_{15.48}\text{Al}_{11.34}\text{O}_{28}$	ANORTHIC (A)
S2-30% IP-7 DAYS	49-1586	CALCIUM ALUMINIUM IRON OXIDE	$\text{CaAl}_4\text{Fe}_8\text{O}_{19}$	HEXAGONAL (H)
S3-45% IP-7 DAYS	25-0120	CALCIUM ALUMINIUM IRON OXIDE	$\text{CaAl}_8\text{Fe}_4\text{O}_{19}$	HEXAGONAL (H)
S4-15% IP-14 DAYS	52-1258	CALCIUM ALUMINIUM IRON OXIDE	$\text{CaAl}_8\text{Fe}_8\text{O}_{19}$	HEXAGONAL (H)
S5-0% IP-28 DAYS	30-0040	CALCIUM ALUMINIUM IRON OXIDE	CaAlF_eO_2	HEXOGONAL
S6-30% IP-14 DAYS	52-1258	CALCIUM ALUMINIUM IRON OXIDE	$\text{CaAl}_4\text{Fe}_8\text{O}_{19}$	HEXAGONAL (H)
S7-45% IP-14 DAYS	70-1499	CALCIUM ALUMINIUM IRON OXIDE	$\text{CaAl}_2\text{Fe}_e\text{O}_2$	HEXOGONAL
S9-15% IP-28 DAYS	70-1498	CALCIUM ALUMINIUM IRON OXIDE	CaAlF_eO_2	HEXOGONAL
S10-30% IP-28 DAYS	49-1586	CALCIUM ALUMINIUM IRON OXIDE	$\text{CaAl}_4\text{Fe}_8\text{O}_{19}$	HEXOGONAL
S11-45% IP-28 DAYS	25-0120	CALCIUM ALUMINIUM IRON OXIDE	$\text{CaAl}_8\text{Fe}_4\text{O}_{19}$	HEXAGONAL (H)

The peak intensities at different angles are compared with a database of different minerals and compounds. Similarly, compounds with peak intensities matching those of the scans are identified and the compounds present in the samples are also determined. The peak indicates that the iron content is of crystalline nature and the broad parts indicate that the elements are amorphous in nature. The broadening portion of the curve represents the particles in diffraction pattern.

XRD Test gives the mineral composition of the sample under observation in the form of graphs shown above and JCPDS software gives us the Chemical name, formula and the structure of the lattice formed. After studying them, we can easily conclude our study by determining the reasons behind our strength and durability test results. Adding to that, it helps us to find out the optimum percentage of partial replacement.

IX. CONCLUSION

After conducting the aforementioned experiments, we came up with the following conclusions.

1. After conducting Slump Cone Test, we noticed a gradual decrease in the slump value upon the addition of iron powder in the mix (37 mm in 0% to 9 mm in 45% iron powder embedded concrete). This displays the reduction in the workability of the mixes. Iron powder makes fresh concrete dry, causing it to become hard and elastic which is the sole reason behind the decrease in workability. [1]
[2]

2. We noticed that the compressive strength (28 days) of concrete increases with the addition of iron powder from 34.2 N/mm² to 39.9 N/mm² i.e., from 0% to 30%. The compressive strength drops upon any further increase of iron powder which is showcased by the strength of 39.1 N/mm² of 45% Iron powder embedded concrete.

3. The split-tensile strength results lead to a little bit of confusion as 30% iron powder embedded concrete boasts better results at 7th day of testing while 45% iron powder embedded concrete gives better results at 28th day of testing.

4. The flexural strength of concrete continue to increase with the addition of iron powder in it. 45% iron powder gives the maximum strength of 6 N/mm² and 7.48 N/mm² at 7th and 28th day of testing.

5. The increase in flexural strength was found to be pronounced than compressive and split-tensile strength.

6. The reason behind the increase in strengths can be related to the particle size of iron powder. As it is smaller than sand, they were able to fill the voids between sand particles similar to the way sand particles fill the void between coarser aggregates thus resulting in less voids and higher density and strength. In the case of the iron powder, the increase in strength may be attributed to the modest increase in fineness of particles especially in the smaller diameter particles. In addition, because the particle size is smaller than sand, the surface area will be larger. Because of higher surface area of iron powder compared to sand, the concrete is expected to have higher strength due to more bonded areas with hydrating cement.

7. From the Water Absorption test and Dry & Wet strength test results, it is concluded that the mix with 30% iron powder gives the best results.

8. From the strength tests and durability tests results, we can conclude by saying that the optimum percentage of replacement is 30%.

9. Although the iron powder generally has less silicon oxide content compared to sand and that not all iron powder may react chemically with cement, the filler effect will bring improvements in the concrete. This is clearly visible with our XRD test results.

10. Finally, it can be concluded iron powder can be used as a partial substitute for natural sand to prepare concrete. It reduces the consumption of sand, solves the environmental pollution problem of iron powder, and encourages the development of eco-friendly projects. It is also important to note that full replacement of sand by IP isn't possible because it is beneficial only till the optimum percentage of 30%, after which it degrades and

deteriorates the mix. Also, the weight of the concrete increases with the increase in percentage of IP.

APPENDIX

SEARCH RESULT

Display Matched Item Number: 1 to 22

Print Search Result

OK Cancel

ID	Chemical Name	Chemical Formula	3 Strongest Lines	Sys
89-2827	Brownmillerte, Fe-rich, syn, Iron Alum-	Fe1.33 Al.67 Ca2-	2.80 7.30 2.69	O
77-0978	Calcium Iron Aluminum Oxide	Ca7.12 Fe0.88 Fe2-	10.7 2.61 2.60	A
74-1348	Brownmillerte, Iron Aluminum Calcium O-	Fe Al O3 (Ca O)2	2.84 2.67 1.93	O
74-0903	Iron Aluminum Calcium Oxide	Fe2 O3 Al2 O3 (-)	2.84 2.67 1.93	O
71-0987	Brownmillerte, Calcium Iron Aluminum O-	Ca2 Fe Al O5	2.68 2.69 1.94	O
70-1499	Calcium Iron Aluminum Oxide	Ca2 Fe1.28 Al0.72-	2.65 2.79 2.29	O
70-1498	Calcium Aluminum Iron Oxide	Ca2 Fe1.40 Al0.60-	2.66 2.69 1.94	O
52-1258	Calcium Iron Aluminum Oxide	Ca3.18 Fe1.48 Al-	2.61 1.53 2.88	A
49-1598	Calcium Aluminum Iron Oxide	Ca Al4 Fe8 O19	2.68 2.52 1.70	H
46-0038	Calcium Aluminum Iron Oxide	Ca Fe5 Al O9	2.58 2.13 1.64	A
42-1489	Calcium Aluminum Iron Oxide	Ca2 Al1.38 Fe0.62-	2.63 2.65 1.91	O
38-0489	Hibonite-5H, ferroan, Calcium Aluminu-	Ca (Al , Fe)12 -	2.67 2.51 2.13	H
35-0040	Calcium Aluminum Iron Oxide	Ca3 (Al , Fe)2 -	2.65 2.69 2.54	R
30-0228	Brownmillerte, syn, Calcium Aluminum I-	Ca2 (Al , Fe +3 -	2.64 2.75 1.82	O
25-0120	Calcium Aluminum Iron Oxide	Ca Al8 Fe4 O19	2.67 2.53 1.42	H
21-0830	Calcium Aluminum Iron Oxide	Ca Al2 Fe4 O10	2.57 2.55 3.15	X
18-0410	Brownmillerte, syn, Calcium Aluminum I-	Ca2 (Al0.7 Fe0.3-	2.62 2.78 2.65	O

SEARCH RESULT

Display Matched Item Number: 1 to 22

Print Search Result

OK Cancel

ID	Chemical Name	Chemical Formula	3 Strongest Lines	Sys
70-1499	Calcium Iron Aluminum Oxide	Ca2 Fe1.28 Al0.72-	2.65 2.79 2.29	O
70-1498	Calcium Aluminum Iron Oxide	Ca2 Fe1.40 Al0.60-	2.66 2.69 1.94	O
52-1258	Calcium Iron Aluminum Oxide	Ca3.18 Fe1.48 Al-	2.61 1.53 2.88	A
49-1598	Calcium Aluminum Iron Oxide	Ca Al4 Fe8 O19	2.68 2.52 1.70	H
46-0038	Calcium Aluminum Iron Oxide	Ca Fe5 Al O9	2.58 2.13 1.64	A
42-1489	Calcium Aluminum Iron Oxide	Ca2 Al1.38 Fe0.62-	2.63 2.65 1.91	O
38-0489	Hibonite-5H, ferroan, Calcium Aluminu-	Ca (Al , Fe)12 -	2.67 2.51 2.13	H
35-0040	Calcium Aluminum Iron Oxide	Ca3 (Al , Fe)2 -	2.65 2.69 2.54	R
30-0228	Brownmillerte, syn, Calcium Aluminum I-	Ca2 (Al , Fe +3 -	2.64 2.75 1.82	O
25-0120	Calcium Aluminum Iron Oxide	Ca Al8 Fe4 O19	2.67 2.53 1.42	H
21-0830	Calcium Aluminum Iron Oxide	Ca Al2 Fe4 O10	2.57 2.55 3.15	X
18-0410	Brownmillerte, syn, Calcium Aluminum I-	Ca2 (Al0.7 Fe0.3-	2.62 2.78 2.65	O
11-0190	Calcium Aluminum Iron Oxide	Ca8 Al4 Fe8 O15	2.62 2.78 2.65	X
11-0124	Brownmillerte, syn, Calcium Aluminum I-	Ca4 Al2 Fe2 +3 O10	2.63 2.77 1.92	O
10-0032	Brownmillerte, syn, Calcium Aluminum I-	Ca4 Al2 Fe2 +3 O10	2.64 2.75 2.78	X
02-0985	Calcium Aluminum Iron Oxide	4 Ca O Al2 O3 -	2.63 1.92 2.77	X
01-1088	Calcium Aluminum Iron Oxide	Ca2 (Al Fe) O5	2.66 1.93 2.78	X

LIST OF ABBREVIATIONS

IP	Iron Powder
FA	Fine Aggregate
C	Cube
CM	Cylinder
P	Prism
CTM	Compression Testing Machine
MOC	Mix Cube
MOCM	Mix Cylinder
MOP	Mix Prism
DM0	Durability Mix with 0 percent iron powder
DM15	Durability Mix with 15 percent iron powder
DM30	Durability Mix with 30 percent iron powder
DM45	Durability Mix with 45 percent iron powder
XRD	X-Ray Diffraction
JCPDS	Joint Committee on Powder Diffraction Std.
C/S	Cross Section

SYMBOLS AND NOTATIONS

& And

%	Percentage
°C	Degree centigrade
TiO ₂	Titanium Dioxide
SiO ₂	Silicon Dioxide
Al ₂ O ₃	Aluminium Oxide
Fe ₂ O ₃	Iron(III) Oxide or Ferric Oxide
CaO	Calcium Oxide
MnO	Manganese Oxide
MgO	Magnesium Oxide
Na ₂ O	Sodium Oxide
K ₂ O	Potassium Oxide
P ₂ O ₅	Phosphorous Pentoxide
Cu	Copper
Ni	Nickel
Mm	Millimetre
Kg	Kilogram
f _c	Target Mean Compressive Strength at 28 days in N/mm ²
f _{ck}	Characteristic Compressive Strength at 28 days in N/mm ²
mm ²	Square Millimetre
L	Litre
m ³	Cubic Metre

REFERENCE

- [1]. NBM&CW. <https://www.nbmcw.com/equipments/crushing-mining-equipments/40169-alternative-sand-an-inevitable-resource-to-river-sand.html>
- [2]. United States Environmental Protection Agency. <https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/ferrous-metals-material-specific-data>
- [3]. Alizadeh R., Shekarchi M., Chini M., Ghods P., Hoseini M., Montazer S., "Study on Electric Arc Furnace Slag Properties to be used as Aggregates in Concrete", CANMET/ACI International Conference on Recent Advances in Concrete Technology, 2003.
- [4]. M. Vijayalakshmi, A.S.S.Sekar, G.G.Prabhu, "Strength and Durability Properties of Concrete made with Granite Industry Waste", Construction and Building Materials, September 2013.
- [5]. Shehdeh Ghannam, Husam Najm, Rosa Vasconez, "Experimental Study of Concrete made with Granite and Iron Powders as Partial Replacement of Sand", Elsevier-Sustainable Materials and Technologies, June 2016.
- [6]. Moussa Anan Largeau, Raphael Mutuku, Joseph Thuo, "Effect of Iron Powder (Fe₂O₃) on Strength, Workability, and Porosity of the Binary Blended Concrete", Open Journal of Civil Engineering, November 2018.
- [7]. Ujjwal Uppal, Er. Preeti Kuhar, "Effect of Iron Slag Powder on Mechanical Properties of Concrete", International Journal of Latest Research In Engineering and Computing (IJLREC), June 2017.

- [8]. T.I.Ugama, S.P.Ejeh, D.Y.Amarthey, "Effect of Iron Ore Tailing on the Properties of Concrete", IISTE-Civil and Environmental Research, 2014.
- [9]. Ali N.Alzaed, "Effect of Iron Filings in Concrete Compression and Tensile Strength", International Journal of Recent Development in Engineering and Technology(IJRDET), October 2014.
- [10]. Gunalan Vasudevan, "Performance on Used Iron Sand as Concrete Admixture", International Conference on Civil, Biological and Environmental Engineering, February 2016
- [11]. Zhing-xi Tian, Zeng-hui Zhao, Chun-quan Dai, Shujie Liu, "Experimental Study on the Properties of Concrete Mixed with Iron Ore Tailings", Hindawi Publishing Corporation-Advances in Materials Science and Engineering, March 2016.
- [12]. Dr. J.D.Bapat, S.S.Sabnis, S.V.Joshi, C.V.Hazaree, "History of Cement and Concrete in India-A Paradigm Shift", ResearchGate Conference Paper, April 2007.
- [13]. Ayokunle O.Familusi, Damilola A.Ogundare, Babatunde E.Adewumi, Matthew O.Alao, "Use of Quarry Dust and Iron Filings in Concrete Production", 5th National Conference on Engineering Technology, February 2018.
- [14]. Element. <https://www.element.com/materials-testing-services/x-ray-diffraction>
- [15]. Sunil Raiyani, Urmi Morbia, Purvi Karanjiya, "XRD and SEM Analysis of Biofiber Reinforced Concrete", 7th National Conference on Emerging Vistas of Technology in 21st Century, April 2016.
- [16]. Geotechnical Instrumentation and Analysis.
- [17]. https://serc.carleton.edu/research_education/geochemicalsheets/techniques/XRD.html

AUTHOR PROFILE



Aman Raj pursued his bachelor's degree (B.Tech) in department of Civil Engineering from Vellore Institute of Technology, Vellore, Tamil Nadu. He has done notable projects and research works in the field of concrete.



Keshav Sharma pursued his bachelor's degree (B.Tech) in department of Civil Engineering from Vellore Institute of Technology, Vellore, Tamil Nadu. He is having a highly competent academic career and expertise in technicality.



Ankit pursued his bachelor's degree (B.Tech) in department of Civil Engineering from Vellore Institute of Technology, Vellore, Tamil Nadu. He is having a keen knowledge in civil engineering softwares.