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Incorporation of Industrial Iron Wastes As Ingredients in Making Energy Efficient Concrete

Engineering

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ABSTRACT

Utilization of industrial soil waste has been encouraged in construction field for the production of concrete because it contributes in reducing the consumption of natural resources. The metal-casting industries called foundry generates enormous amount of by- products such as used foundry sand and iron dust. In the meantime the global demand for concrete increases annually. This demand leads to the over consumption of natural resources for manufacturing both cement and aggregates. So it not only results in exploitation of nature but also in polluting the environment by emitting carbon dioxide. To overcome these problems, using foundry sand as partial fine aggregate and iron dust in form of iron based cementitious material as the replacement in various proportions for conventional cement are suggested. These suggestions are examined and compared with properties of conventional concrete. The investigations were carried out in the form of Compressive strength, Split Tensile strength, Ultrasonic Pulse Velocity test, Rapid Chloride Permeability Test, Sorptivity test and Water Absorption test were conducted in concrete. The results show that the partial replacement gives appropriate strength as the conventional mix. It also identified that 10% replacement of cement by iron based cementitious material and 20% replacement of river sand by foundry sand as the optimum percentage of replacement in reinforced concrete to increase the strength and corrosion resistance.

1. INTRODUCTION

Concrete is the one of the most widely used construction material in the world. The major ingredients of concrete are Cement, water, fine aggregate and coarse aggregate. Due to increase in infrastructure development, the demand of concrete has been increasing rapidly. The demand of concrete is directly proportional to the demand of ingredients used in it. The river sand is one of the main ingredients in concrete. The worldwide consumption of sand as fine aggregate in concrete production is very high and several developing countries have encountered some strain in the supply of natural sand in order to meet the increasing needs of infrastructural development in recent years. The heavy demand for concrete has resulted in the over-exploitation of river sand in the river bed, and this has led to a range of harmful consequences, including increased river bed depth, water table lowering and the intrusion of salinity into rivers. The restriction in the extraction of sand from the river increases the price of sand and has severely affected the stability of the construction industry. To overcome the stress and demand of river sand, researchers and practitioners in the construction industries have identified some alternatives. [3]

In addition to that it is impossible to envisage a modern life without cement. Cement is an extremely important construction material used for housing and infrastructure development and a key to economic growth**.** Cement is one of the major carbon footprint materials in the world. It is the main binding material in concrete which consumes 10% to 15% of concrete's volume. Despite its popularity and profitability, the cement industry faces many challenges due to environmental concerns and sustainability issues. The cement industry is an energy intensive and significant contributor to climate change. The major environment health and safety issues associated with cement production are emissions to air and energy use. [1]

Cement manufacturing requires huge amount of non-renewable resources like raw material and fossil fuels. It is estimated that 5-6% of all carbon dioxide greenhouse gases generated by human activities originates from cement production. Emissions have local and global environment impact resulting in global warming, ozone depletion, acid rain, biodiversity loss, reduced crop productivity etc. [8]

In the meantime, Industries faces the problem of disposing their wastes. The above mentioned problems can be solved in a single way by using the industrial wastes such as foundry sand and Iron dust as partial fine aggregate and an ingredient for making Iron based cementitious material respectively. The Iron based cementitious material is added as partial substitution of conventional cement.

2. EXPERIMENTAL PROGRAM

2.1 Materials

2.1.1 Cement

Portland Pozzolana (fly ash based) Cement having a specific gravity of 3.18 and conforming to IS: 8112-1989[5] was used.

2.1.2 Iron Dust

Iron dust is a waste material obtained from foundries whiles the polishing the steel parts and utilities of various sizes and shape. The polishing is done by means of both conventional machine polishing and also by shot blasting. Here the iron dust obtained in a foundry near Dindigul, Tamilnadu is used. The table shows the chemical composition of Iron Dust.

Table 1 Chemical composition of Iron dust

Components of Iron dust	(%)
Fe	88
Cu	0.2
Mn	0.8
Cr	0.3
Ca	0.1
K	0.04
O	10

2.1.3 Metakaolin
Metakaolin is a fine, natural white clay which is manufactured from high purity kaolin clay by calcination at temperature range of 650 to 800°. The material, ground to an average particle size of 1.5 to 2.5µm, is white in colour. Commercially available metakaolin was tested for chemical Composition. The table shows the chemical composition of Metakaolin.

Table 2 Chemical composition of Metakaolin

Components of Metakaolin	(%)
SiO_2	54.216
Al_2O_3	35.343
Fe_2O_3	0.421
CaO	0.091
MgO	3.328
SO_3	0.000
Na_2O	6.544
K_2O	0.057

2.1.4 Fly Ash
Fly ash is a by-product of coal-fired electric generating plants. Here the Fly ash obtained in Thermal Powe Plant near Thoothukudi, Tamilnadu is used. The table shows the chemical composition of Fly ash.

Table 3 Chemical composition of Fly ash

Components of Fly ash	(%)
SiO_2	56.723
Al_2O_3	18.534
Fe_2O_3	3.445
CaO	0.727
MgO	2.779
SO_3	0.281
Na_2O	16.459
K_2O	1.050

2.1.5 Iron based Binder
Iron based binder incorporates Metakaolin and industrial wastes such as iron dust and fly ash. Manufacture of iron based binder starts from the collection of materials and mixing of those ingredients. The table shows the composition of iron based binder.

Table 4 Composition of Iron based Binder

Elements	(%)
Iron Dust	60
Fly Ash	30
Metakaolin	10

2.1.6 Foundry Sand
Foundry Sand is waste material obtained from foundries. It is high quality silica sand with uniform physical characteristics. It is a by-product of ferrous and non-ferrous metal casting industries. Here the Foundry Sand obtained in a foundry near Dindigul, Tamilnadu is used. The table shows the chemical composition of Foundry Sand.

Table 5 Composition of Foundry Sand

Components of Foundry Sand	(%)
O	62.73
Si	16.53
C	8.56
Fe	5.55
Al	3.12
Ti	3.09
Ca	0.42

2.1.7 River Sand
Natural coarse river sand of maximum particle size 4.75 mm was used. It has specific gravity of 2.66 and fineness modulus 3.2. The testing of sand was done as per Indian Standard Specifications IS: 383 -1970[6].

2.1.8 Coarse Aggregate
Locally available crushed coarse aggregate (maximum size 12.5 mm), conforming to Indian Standard was used. It has specific gravity of 2.72 and Fineness modulus 7.43.

2.1.9 Water
The water available in the concrete laboratory conforming to the requirements of water for concreting and curing as per IS: 456- 2000[7] was used.

2.2 Concrete mix proportions
The control concrete mixture is designed as per Indian Standard (BIS: 10262-1982). It was designated as M25. And then for this concrete (M25), Cement (PPC) was partially (0%, 5%, 10%, 15%, 20% and 30%) replaced with Iron Based Cement (IBC), fine aggregates (sand) was partially (0% and 20%) replaced with spent foundry sand.. Different Concrete mixture proportions are given in Table 6.

Table 6 Different Concrete mixtures

Mixtures	Cement (%)		Fine Aggregate (%)		Coarse Aggregate (%)	W/C Ratio
	PPC	IBC	River Sand (%)	Foundry Sand		
M1	100	0	100	0	100	0.45
M2	95	5	100	0	100	0.45
M3	90	10	100	0	100	0.45
M4	85	15	100	0	100	0.45
M5	80	20	100	0	100	0.45
M6	70	30	100	0	100	0.45
M7	100	0	80	20	100	0.45
M8	95	5	80	20	100	0.45
M9	90	10	80	20	100	0.45
M10	85	15	80	20	100	0.45
M11	80	20	80	20	100	0.45
M12	70	30	80	20	100	0.45

2.3 Testing of Specimens
Compressive strength was conducted on 100 mm cubes as per (BIS: 516-1959). Split tensile strength test was conducted on 60 x 100 mm cylinders as per (BIS: 5816-1999). Rapid chloride permeability test was performed on 100 x 50 mm discs as per ASTM 1202 C. Ultrasonic Pulse Velocity test was conducted on 100mm cube specimens as per BIS 13311

(part 1). Water absorption test was conducted on 100 mm cubes as per ASTM C642 – 97. Sorptivity test was conducted on 100 mm cubes as per ASTM C1585 – 13.

3. RESULT AND DISCUSSIONS

3.1. Compressive strength

Compressive strength test was conducted on cube specimens for each concrete mixture at 28 days for M25 grade of concrete. For, Concrete Grade M25, 28-day compressive strength of control concrete (0% IBC & 0% FS) was 34.28 MPa. It was observed the concrete replaced with 15% Iron based cement and 20% Foundry sand gives comparatively equal compressive strength as conventional M25 concrete beyond that there was sudden decline in compressive strength of concrete.

Table 7 Compressive Strength of Concrete

Mixtures	Compressive Strength (MPa)		
	7 days	21 days	28 days
M1	20.67	30.96	34.28
M2	19.99	27.97	33.14
M3	20.21	30.26	33.50
M4	20.19	30.08	33.30
M5	14.71	22.10	24.34
M6	12.74	19.06	21.06
M7	20.71	31.01	34.34
M8	20.39	30.53	33.80
M9	20.65	30.96	34.28
M10	20.25	30.32	33.57
M11	15.35	22.97	25.40
M12	14.36	21.48	23.75

3.2. Split tensile strength

Split tensile strength test was conducted on cylinder specimens for each concrete mixture at 28 days for M25 grade of concrete. For, Concrete Grade M25, 28-day Split tensile strength of control concrete (0% IBC & 0% FS) was 3.98 MPa. It was observed that Split tensile strength of the concrete replaced with 15 % Iron based cement and 20 % Foundry sand gives comparatively equal Split tensile strength as conventional M25 concrete beyond that there was sudden decline in Split tensile strength of concrete.

Table 8 Split tensile Strength of Concrete

Mixtures	Compressive Strength (MPa)		
	7 days	21 days	28 days
M1	2.29	3.46	3.98
M2	2.54	3.82	4.34
M3	2.34	3.57	4.08
M4	2.27	3.46	3.96
M5	2.21	3.08	3.52
M6	1.87	2.83	3.27
M7	2.47	3.76	4.30
M8	2.64	3.95	4.39
M9	2.41	3.49	4.10
M10	2.24	3.24	4.20
M11	1.78	2.78	3.73
M12	1.64	2.57	2.91

3.3 Rapid Chloride Permeability Test

Rapid Chloride Permeability test was conducted on disc specimens for each concrete mixture at 28 days for M25 grade of concrete. The RCPT ratings (per ASTM C1202) and the results of chloride permeability in coulombs for different mixes and are given in Table 9 and Table 10. It may be concluded that the specimens with Iron based cement and Foundry sand behave in a similar way in the chloride penetration .therefore, the inclusion Iron based cement and Foundry sand does not negatively affect the corrosive behavior of the concrete.

Table 9 RCPT ratings (per ASTM C1202).

Charge Passed (coulombs)	Chloride Ion permeability
>4000	High
2000-4000	Moderate
1000-2000	Low
100-1000	Very low
<100	Negligible

Table 10 Chloride Ion permeability

Mixtures	Charges Passed (coulombs)	Chloride Ion permeability
M1	101.06	Very low
M2	106.61	Very low
M3	121.51	Very low
M4	197.91	Very low
M5	318.60	Very low
M6	458.10	Very low
M7	104.94	Very low
M8	209.16	Very low
M9	318.60	Very low
M10	571.50	Very low
M11	602.20	Very low
M12	728.24	Very low

4.4 Ultrasonic Pulse Velocity Test

Ultrasonic Pulse Velocity test was conducted on cube specimens for each concrete mixture at 28 days for M25 grade of concrete. The USPV ranges (per BIS 13311 (part 1)) and the results of Concrete Quality in Grading for different mixes and are given in Table 11 and Table 12. Ultrasonic Pulse Velocity values increased with the increase in Iron based cement and foundry sand in concrete mixtures. USPV value for control concrete M-1 (0% IBC & 0% FS) at the age of 28 days was 4.03 Km/s. Further velocity increased to 4.44 K m/s for mix M-12 (30% IBC & 20% FS), an increase was observed after inclusion of Iron based cement and Foundry Sand in concrete.

Table 11 USPV ranges (per BIS 13311 (part 1))

Pulse Velocity (km/s)	Concrete Quality (Grading)
Above 4.5	Excellent
3.5 to 4.5	Good

Pulse Velocity (km/s)	Concrete Quality (Grading)
3 to 3.5	Medium
Below 3	Doubtful

Table 12 Concrete Quality

Mixtures	Pulse Velocity (km/s)	Concrete Quality (Grading)
M1	4.03	Good
M2	4.05	Good
M3	4.08	Good
M4	4.12	Good
M5	4.17	Good
M6	4.20	Good
M7	4.18	Good
M8	4.22	Good
M9	4.24	Good
M10	4.40	Good
M11	4.42	Good
M12	4.44	Good

3.5 Water Absorption Test

Water Absorption test was conducted on cube specimens for each concrete mixture at 28 days for M25 grade of concrete. From the table 13 it is found that the water absorption percentages of the concrete mixes from M2 to M12 are more or less equal to the water absorption of the control mix (M1). So the inclusion of iron based cement and foundry sand does not negatively affect the water absorption of the concrete.

Table 13 Water absorption

Mixtures	Water Absorption (%)
M1	5.57
M2	6.42
M3	6.23
M4	5.59
M5	6.01
M6	5.99
M7	6.25
M8	5.53
M9	5.55
M10	6.13
M11	5.06
M12	5.71

3.6 Sorptivity Test

Sorptivity test was conducted on cube specimens for each concrete mixture at 28 days for M25 grade of concrete. From the table 14 it is found that, the specimens containing Iron based cement and Foundry sand composites have lesser sorptivity values indicating the lesser porosity in concrete specimens when compared to control specimen. So the inclusion of iron based cement and foundry sand gives positive feedback by reducing the sorptivity of the concrete.

Table 14 Sorptivity values

Mixtures	Sorptivity value in 10-3 m/s
M1	3.83
M2	3.50
M3	3.33
M4	3.16
M5	2.67
M6	3.33
M7	3.00
M8	3.16
M9	3.00
M10	3.33
M11	3.33
M12	3.33

4. CONCLUSION

The partial replacement of Cement by Iron based cement and fine aggregates (sand) by Foundry sand improved the strength properties of concrete.

The specimens with Iron based cement and Foundry sand behave in a similar way in the chloride penetration therefore, the inclusion Iron based cement and Foundry sand does not negatively affect the corrosive behavior of the concrete.

Ultrasonic Pulse Velocity values increased with the increase in Iron based cement and foundry sand in concrete mixtures.

The partial replacement of Cement and Foundry sand by 15% Iron based cement and 20% Foundry Sand was found to be the optimum percentage of addition in reinforced concrete for increasing the durability in terms of corrosion resistance.

The specimens containing Iron based cement and Foundry sand composites have lesser sorptivity values indicating the lesser porosity in the concrete specimens.

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