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Sweet Corrosion Behaviour of Concrete by Utilizing Iron Dust as a Binding Material in Concrete

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ABSTRACT

Concrete is a boon to the construction industry. As the largest synthetic production in the world, concrete's annual demand is about 6 times the global human population (approximately 40BMT). Cement is the main binding material in the concrete. The demand for concrete increases with the demand for cement globally (approximately 4.1BMT). During the manufacturing of cement equal amount of CO_2 is emitted into the atmosphere. It results in Green House Effect which in turn leads to the Global warming. So, the world needs a carbon negative concrete i.e., which absorbs the amount of carbon dioxide, quite more than it emits. To develop such a concrete, a newer approach of utilizing iron waste as a binding material has been attempted. Here, corrosion of iron in carbon dioxide environment is called as a sweet corrosion behavior (binding mechanism). The suggested mechanism is implemented in concrete and compared with the conventional concrete.

Keywords: Iron based binder, Sweet corrosion, Carbon negative concrete.

INTRODUCTION

Cement is one of the major carbon footprint materials in the world. CO_2 emission from the cement plants accounts for approximately 40% from the combustion related fuel use and 60% from the calcination process (due to the use of raw materials such as limestone and clay) It is estimated that, globally 5-6% of carbon dioxide greenhouse gas emissions are generated from cement production The continuous emission of gases like, nitrogen oxides, carbon dioxide, water, oxygen, dust, chlorides, fluorides, sulfur dioxide, carbon monoxide, organic compounds and heavy metals from the industries and factories pollutes the local and global environment resulting in ozone depletion, acid rain, biodiversity loss, reduced crop productivity, global warming etc.Global warming is primarily a problem of too much emission of carbon dioxide in the atmosphere which lead to the increase in the average temperature of the Earth's atmosphere and oceans because of the built up of greenhouse gases in our atmosphere

Global concrete production is approximately 5.3 billion cubic meters per year The sustainable use of resources is especially important in the concrete production industry, since concrete is the most widely used construction material and is the second most consumed substance on earth after water . India is the second largest cement producing country in the world, next to china Therefore, the cement industry must adopt more energy-efficient technologies to reduce its environmental impact. To reduce the greenhouse gas emissions and to save the environment alternate and industrial waste materials like fly ash, rice husk ash, slag, micro silica etc. are being used as a cement replacement material, which will help in making the concrete ecofriendly, energy efficient and more durable

In the present investigation, an attempt was made to develop a carbon negative concrete by replacing the conventional cement fully and partially by an iron based binder. Fly ash, metakaolin, lime powder, glass powder are the other ingredients used and oxalic acid is used as an accelerator in the formation of iron carbonate. Different combination of the above ingredients was tried on trial and error basis and the compressive and split tensile tests were carried out to find out the best mix proportion. The studies were carried out by considering the curing condition and the fineness of the binder. The results obtained were compared with the conventional concrete and presented.

EXPERIMENTAL PROCEDURE

MATERIAL USED

Portland Pozzolana (fly ash based) Cement having a specific gravity of 3.18 and conforming to IS: 8112-1989 was used. Foundry Sand is the waste material obtained from foundries which is used as a replacement for sand. It is a high-quality silica sand with uniform particle size. It contains: O (62.73 **%**), Si (16.53%), C (8.56%), Fe (5.55%)**,** Al **(**3.12%), Ti (3.09%), Ca **(**0.42%)**.** The specific gravity and fineness modulus of foundry sand was 2.1 and 1.91 respectively. Locally available crushed coarse aggregate (maximum size 10 mm), conforming to Indian Standard was used. The specific gravity and fineness modulus of coarse aggregate used was 2.72 of 7.43 respectively.

Table 1: Chemical composition of Metakaolin, Fly ash and Glass powder used for the study

Components (%)	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O
Metakaolin(MK)	54.26	35.34	0.42	0.091	3.33	0.000	6.54	
Fly ash(FA)	56.723	18.53	3.445	0.727	2.779	0.281	16.459	1.050
Glass powder(GP)	82.394			13.04	2.398		1.370	0.268

Iron dust (ID) is a waste material obtained from the shot blasting unit. The chemical composition of iron dust (ID) used was: Fe (88**%**), Cu (0.2%), Mn (0.8%), Cr (0.3%)**,** Ca **(**0.1%), K (0.04%), O **(**10%**).** The composition of metakaolin, fly ash and glass powder used for the investigation are given in Table 1. The XRD analysis for FA, GP, MK and ID are shown in Fig. 1. In addition, lime powder (LP) and oxalic acid (OA) was used. Here LP acts as a nucleation site for the formation of iron carbonate. OA acts as an accelerator of iron carbonate formation.

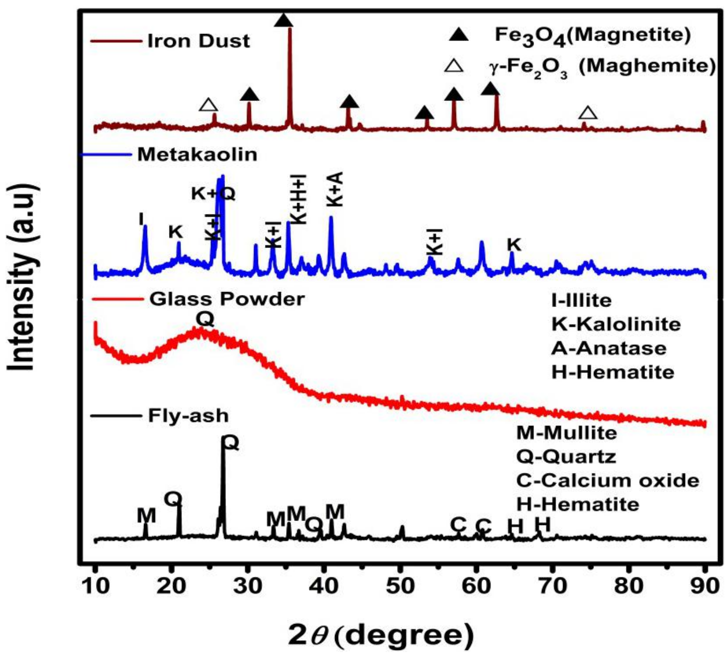

Figure 1: XRD characteristics of FA, GP, MK and ID

METHODOLOGY

All the iron based binder materials such as FA, GP, MK, ID, LP and OA are mixed together in the required proportion and it is kept in the ball for finer grounding of particles. The whole mixer obtained after grounding is called the iron based binder. Fig.2 shows the pictorial representation of manufacture of iron based binder and iron based binder concrete.

Iron based binder is an alternative binder which uses the concept of carbon dioxide corrosion (sweet corrosion) as a binding mechanism of concrete.

Combination of Iron based binder and the conventional cement:

The experimental analysis is carried out in two ways:

a. **Full replacement of cement with iron based binder** (IBB): The specimens were cast with IBB in various combinations (Table 2) and water. After casting the specimens were subjected to CO_2 curing in CO_2 chamber for 4 days and kept in open atmosphere for 3 days. The best mix at which the maximum compressive strength obtained was taken for partial replacement studies.

b. **Partial replacement of cement with iron based binder**(IBB): The specimens were cast with various replacement levels of cement with best IBB mix along with foundry sand, jelly and water. After casting the specimens were subjected to water curing for 4 days and kept in CO_2 chamber for 3 days.

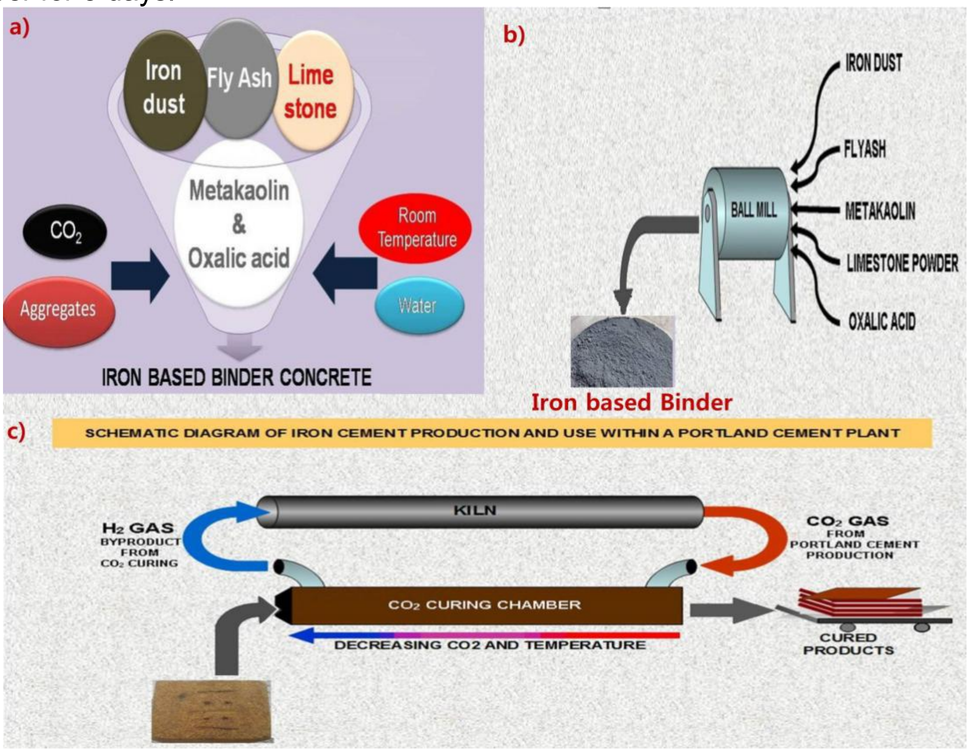

Figure 2: Manufacture of Iron based binder concrete (a) Materials (b) mix material (c) casting specimen and CO_2 curing

TEST PROGRAM

Compressive and split tensile test

Cube and cylindrical specimens of size 50 x 50 x 50 mm and 50 mm dia. with 100 mm height were cast for compressive and split tensile strength measurements with five different (FRC1 to FRC 5) combinations of IBB ingredients as shown in Table 2 by fully eliminating cement. In partial replacement of cement, the best (FRC) mix at which maximum compressive strength obtained from was chosen for partial replacement studies. From Table 3 it is found that FRC2 gives the maximum strength among the five combinations tried. This mix was chosen for partial replacement studies. Here, the best mix (FRC2) was replaced with cement under different combinations (PRC1 to PRC 5) as shown in Table 2. In PRC, concrete specimens were cast with various proportions of cement, IBB along with foundry sand, jelly and water (M1 to M5) as shown in Table 3. From Table 3 it is found that M1 mix gives the improved compressive strength when compared to the other mix proportions. M1 mix was taken for further evaluation studies. By taking the M1 mix, the particle size effect and temperature effect was considered and the compressive and split tensile tests were carried out.

Curing conditions: Full / partial replacement of cement:

For full replacement of cement, the specimens were placed immediately (after casting) in the CO_2 chamber for 48 hrs. and kept in the open atmosphere for 3 days. In partial cement replacement, the cement was partially replaced with IBB under various combinations. As the hydration of cement requires water, the specimens were kept immersed in water for 4 days and in CO2 chamber for 3 days and the compressive, split tensile tests were carried out in the UTM of 40T capacity.

Table 2: Combination of binders tried for full and partial replacement of cement

Ingredients (%)	Full replacement of cement					Partial replacement of cement				
	FRC1	FRC2	FRC3	FRC4	FRC5	PRC1	PRC2	PRC3	PRC4	PRC5
Cement	0	0	0	0	0	70	60	50	40	30
Iron dust	60	60	60	60	60	30	40	50	60	70
Fly ash	24	20	15	10	18					
Metakaolin	5	10	10	10	10					
LP	9	8	8	8	8					
OA	2	2	2	2	4					
GP			5	10						

RESULTS AND DISCUSSION

FULL REPLACEMENT OF CEMENT WITH IRON BASED BINDER (IBB)

Compressive strength measurements

Table 3 shows the compressive strength of different IBB mixes. From the table, it is found that FRC2 gives the positive feedback in terms of compressive strength when compared to all other compositions. So, the binder mix FRC2 is taken for further evaluation studies in concrete. M_1 to M_5 shows the different combination of concrete mixes tried with iron based binder by eliminating cement.

Table 3: Compressive strength of iron based binder (100% replacement of cement)

Iron based binder (IBB) compressive strength (N/mm^2)					Concrete Mix ratio with IBB (100% cement replacement) compressive strength (N/mm^2)				
Mix	S-1	S-2	S-3	Average Strength	Mix using FRC2	S-1	S- 2	S- 3	Average Strength
FRC1	3.17	2.76	3.43	3.12	M_1(1:1:1)	4.87	4.76	4.34	4.66
FRC2	4.26	4.67	3.98	4.31	M_2(1:1:2)	3.19	3.72	3.98	3.63
FRC3	2.71	1.96	2.53	2.41	M_3(1:1.25:2.5)	1.46	0.97	1.08	1.17
FRC4	1.12	1.25	1.48	1.28	M_4(1:1.5:3)	0.73	0.49	0.58	0.6
FRC5	0.75	0.82	0.29	0.62	M_5(1:2:4)	0.53	0.46	0.09	0.36

From the table it is observed that, M_1 and M_2 mix shows the positive feedback than the other mixes. M_1 and M_2 mix was taken for further evaluation studies.

EFFECT OF TEMBERATURE AND PARTICLE SIZE ON STRENGTH FORMATION

Temperature effect of the IBB was studied by keeping the concrete specimens in CO_2 chamber under 20±5 °C and 28±5 °C. From the studies, it is found that 28±5 °C gives the improved results. Further, the effect of fineness of the IBB was studied by grinding the particles to 34 μm and 150 μm size and the specimens were cast and cured at 28±5 °C in the CO_2 curing chamber (Table 4) and split tensile (Table 5) strength were evaluated. From the results, it is observed that 34 μm size IBB particles improved the compressive and split tensile strength in M1 and M2 concrete mixes. Reduction in particle size leads to the increase in specific surface area of the iron particles which caused more absorption of CO_2 leading to increased formation of iron carbonate. But M1 has higher strength than M2. So M1 mix with 34 μm size particles were taken for further evaluation studies of partial replacement with cement in M25 concrete.

Table 4: Compressive strength of concrete by varying the fineness of the binder

Samples	Compressive Strength (N/mm^2)							
	Temperature effect				Reduction in particle size effect			
	M_1(1:1:1)		M_2 (1:1:2)		M_1(1:1:1)		M_2(1:1:2)	
	20±5 °C	28±5 °C	20±5 °C	28±5 °C	150 μm	34 μm	150 μm	34 μm
S-1	8.09	8.39	6.03	6.76	8.54	10.89	6.82	9.54
S-2	8.11	8.84	6.92	7.39	8.96	11.43	7.45	9.47
S-3	7.99	8.73	7.13	7.63	8.65	11.79	7.69	9.89
Average	8.06	8.65	6.69	7.26	8.72	11.37	7.32	9.63

Table 5: Split tensile strength of the concrete by varying the fineness of the binder

Samples	Split tensile strength (N/mm^2)							
	Temperature effect				Reduction in particle size effect			
	M_1(1:1:1)		M_2 (1:1:2)		M_1(1:1:1)		M_2(1:1:2)	
	20±5 °C	28±5 °C	20±5 °C	28±5 °C	150 µm	34 µm	150 µm	34 µm
S- 1	0.811	0.859	0.698	0.787	0.981	1.157	0.754	1.068
S-2	0.797	0.848	0.63	0.698	0.924	1.236	0.712	1.131
S-3	0.801	0.813	0.643	0.785	0.936	1.245	0.787	0.965
Average	0.803	0.842	0.657	0.756	0.947	1.213	0.757	1.055

SWEET CORROSION MECHANISM

Binding mechanism of IBB with CO_2 is shown by the following reactions. This sweet corrosion is an electro-chemical reaction which consists of anodic dissolution of iron (corrosion) by carbonic acid (carbon dioxide and water) and cathodic reduction of iron carbonate by the chelating agent oxalic acid [14]. The schematic representation of iron based binder mechanism is shown in Fig. 3.

$$Fe + 2CO_2 + 2H_2O \rightarrow Fe^{2+} + 2HCO_3 + H_2\uparrow \quad \text{----- (1)}$$

$$Fe^{2+} + 2HCO_3^- + \rightarrow FeCO_3 + CO_2 + H_2O \quad \text{----- (2)}$$

The net reaction is

$$Fe + CO_2 + H_2O \rightarrow FeCO_3 + H_2\uparrow \quad \text{----- (3)}$$

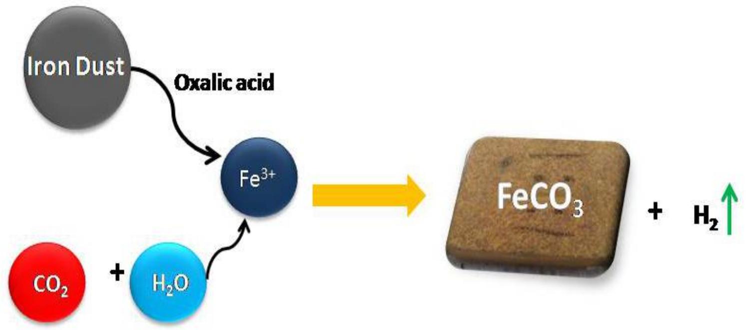

Figure 3: Schematic representation of iron based binder mechanism

PARTIAL REPLACEMENT OF CEMENT WITH IRON BASED BINDER

Compressive strength and Split tensile strength

The finer particle size of 34µm IBB was selected for further investigation in M25 concrete (cement: IBB: 70:30) along with cement under various combinations are shown in Table 2 (PRC1 to PRC5) were tried. The compressive and split tensile strength of the M25 concrete after 4 days of immersion in water and 3 days kept in CO_2 chamber is shown in Fig: 4. From the table, it is found that PRC1 and PRC2 mix has shown increase in compressive and split tensile strength when kept under combined water and CO_2 curing. The curing was carried out partially in water for hydration of cement. The combined curing accelerated the compressive and split strength of the concrete within 7 days. If the samples are exposed to atmosphere for 28 days, it is expected that the presence of IBB absorb more CO_2 from the atmosphere and it will lead to further increase in compressive and tensile strength of the concrete.

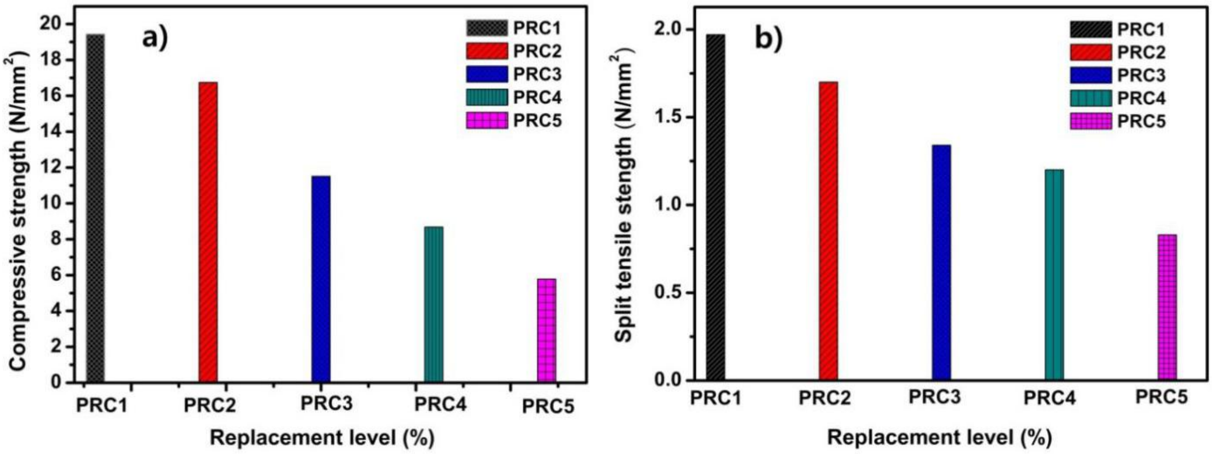

Figure 4: Compressive and split tensile strength of M25 concrete after 4 days curing

CONCLUSIONS

- No improvement in strength was found with 100% IBB (full replacement of cement).
- The particle size plays a major role in contributing the strength of the concrete. The finer the particle size of the IBB; exposing more surface area for the CO_2 absorption, leading to more iron carbonate formation which enhanced the strength of the concrete.
- In partial replacement of cement with IBB, combined water curing and CO_2 chamber curing enhanced the compressive and split tensile strength of the concrete.

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