Optimization of solids composition in ferrock mortar

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Abstract. Ferrock is the commercial name given by the Dr Stone working with university of Arizona which holds the patent on this novel material. This is an alternative material developed for structural applications in place of concrete. In this paper, ferrock mortar is prepared with various solids such as iron powder, iron dust, cement and fly ash to establish the optimum combinations of solids for preparing the high strength ferrock systems. Iron dust in the form of powder (size less than 90 microns) and fine aggregate (size between 150 microns to 2.36mm) is used in the study to develop the iron carbonate matrix which is major binding material in ferrock. For the process of iron carbonation, carbon dioxide is prepared from the chemical reaction of sodium bicarbonate and acetic acid. Iron dust cubes are carbonated to form iron carbonation matrix upon fusion. This material has very high strength than the references cement mortar samples.

Keywords. Iron carbonation, ferrock, carbonation, structural binder, durable

1 Introduction

Ferrock is the structural binder developed as an alterative to cement in the concrete [1]. This material can be used for structural applications based on the preliminary investigations made by Dr. Stone at the university of Arizona. University of Arizona has developed and patented this material which is having improved behaviour in terms of mechanical and durability point of view[2]. Iron dust used for the study is the waste produced from the iron ore-based industries [3]. This iron waste is usually used for landfills for its disposal and has been very environmentally dangerous as the heavy metals from this iron ore waste gets into the earth and subsequently into the underground water polluting it [4-5]. So, researchers found the novel use of this waste as a replacing material for the concrete. It is known fact that the cement production emits carbon dioxide into the atmosphere leaving a substantial carbon footprint on the environment where as this material ferrock is a carbon negative material

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which means that carbon dioxide is removed from the atmosphere by the ferrock material [6].

2 Principle

The mechanism of preparing ferrock depends on the process of formation of iron carbonate matrix by consuming the carbon dioxide. Iron dust reacts with the carbon dioxide and form a very hard material called iron carbonate which acts like a binder. Carbon dioxide available in the air will be enough to propel the process of carbonation in ferrock systems [7].

3 Materials

1. Iron powder (Fe powder)

Iron dust passing through 90 microns is considered as Iron powder (Fe powder).

2. Iron dust (Fe dust)

Iron dust of size less than 2.36mm can be used as fine aggregate in the ferrock systems

4 Particle size distribution

1. Fineness modulus of Fe dust

To measure iron dust's particle size distribution, fineness modulus, effective size, and uniformity coefficient, tests for grain size analysis or sieve analyses are performed. The fineness modulus is merely a numerical measure of fineness that provides some insight into the average size of the aggregate's particle population. It serves as a technique of standardising aggregate grading to some extent. It is calculated by multiplying the weight of material retained in each of the standard sieves by the percentage, then dividing the result by 100. Finding the fineness modulus is intended to grade a given aggregate for the most cost-effective mix [8].

Table 1. Sieve analysis of Iron dust

The dry weight of aggregate = 1000gms

S. No	Sieve size	Weight retained (gm)	Cumulative weight retained	Percentage of weight retained
1	4.75mm	0	0	0
2	2.36mm	0	0	0
3	1.18mm	523	523	52.56
4	600µ	281	804	80.80
5	300µ	137	941	94.57
6	150µ	54	995	100
7	90 µ	5	1000	
Total percentage weight retained= 327.9				

Fineness Modulus of Iron dust = Percentage of weight retained/100=3.28
The fineness modulus 3.28 indicates that the size of the iron dust used for ferrock is between 600 microns and 1.18mm.

2. Effective size of Fe dust

The particle size when 10% of the sample's Fe dust particles (by weight) are smaller and 90% are larger is known as the effective size. This is commonly referred to as the D10. Effective particle size (D10), which indicates that 10% of the particles are smaller than this size (diameter), is the average particle diameter of the sample at the 10 percentile. The effective size (D10) can be determined from the graph where the percent passing is plotted against the sieve size [9].

Table 2. Percentage of weight passed through sieve

S. No	Sieve size	Weight retained (gm)	Percentage of weight retained	Percentage of weight passed
1	4.75mm	0	0	100
2	2.36mm	0	0	100
3	1.18mm	523	52.56	47.44
4	600µ	281	80.80	19.20
5	300µ	137	94.57	5.43
6	150µ	54	100	0
7	90 µ	5	Not applicable	Not applicable

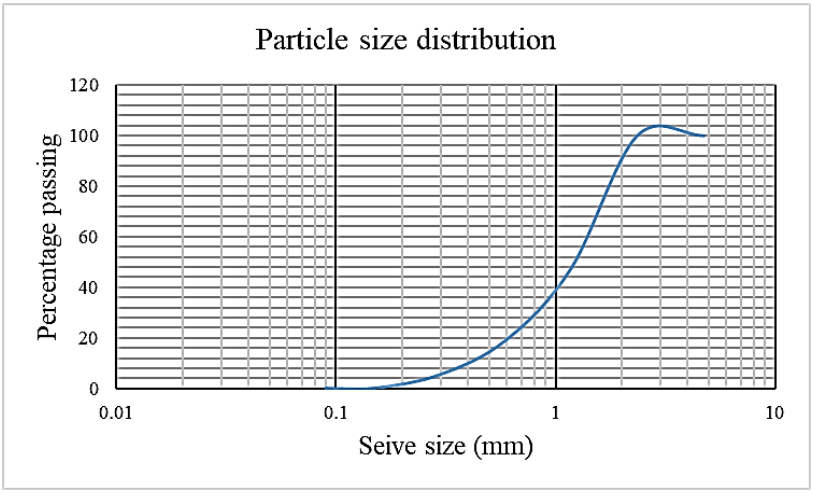

Figure 1. Particle size distribution

From the graph,
D_{10}=0.399mm where only 10% of the sample has a smaller size
D_{30}=0.822mm where only 30% of the sample has a smaller size
D_{60}=1.462mm where 60% of the sample has a smaller size

3. Uniformity Coefficient

The metrics of gradation are uniformity coefficient (Cu) and coefficient of gradation (Cc). These coefficients aid in categorising the material as either well- or poorly-graded. Particles in uniformly graded material are similar and have a Cu value of roughly 1. When the

uniformity coefficient is 2 or 3, the material is poorly graded. Sand from beaches falls into this category [10].
The Uniformity Coefficient is D60/D10=1.462/0.399=3.664
A higher Cu value suggests that the Fe dust mass contains particles of various sizes.

4. Coefficient of Curvature (Cc)

Coefficient of curvature is given by the formula:
$Cc= (D_{30}^2)/D_{60}*D_{10} = (0.822^2)/1.462*0.399=1.16$
Fe dust must have a Cc value between 1 and 3 to be properly graded.
The value of Cu and Cc for any Fe dust cluster of a single size is 1.

5 Specific gravity of iron powder

1. Empty pycnometer's weight = W_1= 448 g
2. Pycnometer weight + 500 g sample = W_2= 948 g
3. Pycnometer weight + 500 g sample + water = W_3 = 1690.30
4. Pycnometer weight + water = W_4= 1253 g

The specific gravity (sp. Gr) of iron powder = $G = W_2-W_1 / (W_2-W_1) – (W_3-W_4)$ =7.84

6 Preparation of CO_2

Baking soda and vinegar are combined, and a chemical reaction results in the production of carbon dioxide gas. Except for the gas bubbles you may have seen when the vinegar and baking soda combination started to fizz, carbon dioxide is invisible. Carbon dioxide, water, sodium ions, and acetate ions are produced when baking soda (sodium bicarbonate) and vinegar (acetic acid) are combined. Sodium acetate and carbonic acid are created when the vinegar's acetic acid combines with sodium bicarbonate. Since carbonic acid is unstable, the gaseous carbon dioxide is created during a breakdown reaction [11].

$$NaHCO_3 + HC_2H_3O_2 \rightarrow NaC_2H_3O_2 + H_2O + CO_2$$

7 Compressive strength

The Fe cube samples of size 100 mm are made with minimum water required to mould them into cubes. In case of pure Fe samples, sand is not used as fine aggregate instead Fe dust is used as fine aggregate. For cement and fly ash samples, sand is used as fine aggregate along with Fe dust. For cement based Fe samples, the solids used are 1 part and sand used in 3 parts.
The compressive strength of the ferrock mortar samples made with 1) pure iron dust 2) cement and iron dust and 3) cement, fly ash and iron dust are tested for various percentages of combinations as shown in the table 3. Iron (Fe) samples are exposed to atmospheric air (partial carbonation and carbon dioxide (continuous carbonation). For partial carbonation. Fe samples are placed in the atmosphere for 28 days to facilitate the carbonation process through the carbon dioxide available in the atmosphere. For continuous carbonation, based on the literature, the exposure period is prefixed as 7 days and Fe samples are kept in air tight container along with the sodium bicarbonate and acetic acid.

Table 3. Compressive strengths of Fe based samples

Type	Solids (100%)				Indian standard sand	Water/ solids ratio	Exposed to	Compressive strength (MPa)	
	Fe Dust		Cement	Fly ash				7 days	28 days
	Fe powder	Fe fine aggregate							
Fe1	40%	60%	-	-	-	0.30	Partial carbonation	-	14.13
Fe2	40%	60%	-	-	-	0.30	Continuous carbonation	82.12	65.39
Fe3	-	100%	-	-	-	0.30	Partial carbonation	-	14.69
Fe4	-	100%	-	-	-	0.30	Continuous carbonation	79.99	69.23
C5	-	-	100%	-	100%	0.42	Full hydration	NDA	53.29
Fe-C6	-	40%	60%	-	100%	0.42	Partial Carbonation and hydration	NDA	33.13
Fe-C7	-	50%	50%	-	100%	0.42	Partial Carbonation and hydration	NDA	37.23
Fe-C8	-	60%	40%	-	100%	0.42	Partial Carbonation and hydration	NDA	41.09
Fe-FA9	-	60%	-	40%	100%	0.42	Partial Carbonation	-	8.56
Fe-FA10	-	50%	-	50%	100%	0.42	Partial Carbonation	-	7.21
Fe-C - FA11	-	40%	30%	30%	100%	0.42	Partial Carbonation and hydration	NDA	37.33
Fe-C-FA11	-	50%	25%	25%	100%	0.42	Partial Carbonation and hydration	NDA	29.19
Fe-C-FA12	-	60%	20%	20%	100%	0.42	Partial Carbonation and hydration	NDA	29.37

*NDA = No Data Available

8 Conclusions

From the studied conducted, the following observations are made:

1. Iron powder of size less than 90 microns and Iron dust of size less than 2.36mm are used in the combination ratios of 40 and 60 are used for the study with the average particle size of Fe dust is 0.399mm.

2. Two types of carbonation methods tested are: 1) air carbonation which is not so effective and 2) continuous carbonation.
3. Pure Fe samples yield compressive strength of 82.12 after 7 days when exposed to full and continuous carbonation when compared to the cement samples which attained strength of 53.29 at 28 days.
4. Cement mortar samples takes 28 days for complete hydration where as iron dust samples need only 7 days for complete carbonation.

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