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Evaluation of ferrock: A greener substitute to cement

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ABSTRACT

Concrete, the second most used entity after water around the globe which accounts for 8 to 10% of total CO_2 emissions is mainly due to cement. This proposes to evaluate the ability of Ferrock to be used as one of the best possible substitute for cement in concrete. It is an iron based binding compound which utilises variety of waste materials to form a carbon negative building material. Iron dust (a waste from iron industries) which would otherwise end up in landfills is used along with small proportions of limestone, fly ash and *meta*-kaolin to make this novel substance.

Our study compares the environmental impacts of ordinary Portland cement and Ferrock (iron dust 60%, fly ash 20%, Metakoalin 12% and limestone 8%) focussing specially on their contribution to carbon pollution, water use and energy consumption. By substituting cement with Ferrock in varying proportions as 4%, 8%, and 12% in concrete we are trying to find the optimum ratio of replacement which would give desired results in both strength (compressive, split tensile & flexural tested) along with sustainability. In all the test result which is comperes 8% which shows the good result in strength.

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1. Introduction

Methods to reduce greenhouse gases like CO_2 in the atmosphere are an active research area today. Climate change has prompted scientists to search for newer alternatives in this regard in all kinds of fields. Cement in concrete, the second most used entity after water in the world today, is the fourth largest source of anthropogenic carbon emissions It's been called the foundation of modern civilization [1]. The world's infatuation with this high carbon intensive material has grown to be real pandemic as the accumulation of these emissions contributes to the growing threat of Global climatic catastrophe. For each one ton of cement created more or less eight ton of CO_2 is released. It's alarmingly polluting the environment. So this Project checks how far ferrock can be used as a substitute to cement [2]. The key ingredient is iron dust, a waste from iron mill which goes straight to the landfill as it's not recycled conventionally and the process of recovering iron from this powder is uneconomical. The iron dust reacts with carbon-di-oxide and rust, which creates an iron carbonate matrix to form Ferrock while it dries.

The accepted reaction steps for this process are:

$$Fe + 2CO^2 + H^2O \rightarrow Fe^{2+} + 2HCO^-{}_3 + H^2 \uparrow$$

$$Fe^{2+} + 2HCO^-{}_3 \rightarrow FeCO_3 + CO_2 + H_2O$$

The net reaction then is:

$$Fe + CO_2 + H_2O \rightarrow FeCO_3 + H_2 \uparrow$$

Here we use materials such as Metakoalin, limestone, fly-ash along with iron dust for proper binding and performance requirements [3]. As per the available literature we know that the best possible proportion of ingredients are iron dust (60%), fly-ash (20%), Metakoalin (12%) and limestone (8%). Analysis (atomic absorption spectroscopy) shows that fully cured samples contain between 8 and 11% captured CO_2 by weight. Ferrock is therefore "carbon negative" unlike Portland cement, which during manufacture is a major source of CO_2 and other air pollutants.

1.1. History of Ferrock

It was, whereas, David Stone was doing his Ph.D. in environmental chemistry at the University of Arizona in Tucson once an unsuccessful experiment uncovered a novel material. Stone ini-

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tially discarded this implausibly exhausted material, then suddenly realized it would have a helpful purpose as a lot of environmentally friendly, yet robust, alternative to cement. His aim was to search out a material that might be mixed and poured rather like cement and with a similar strength and flexibility that concrete offers. The iron among the steel mud reacts with $C0_2$ and rusts to create iron carbonate. It's this that's consolidated into the matrix of Ferrock and, like concrete, when it's dried; it can't be melted back to a liquid type, however retains It's exhausting, rock-like qualities [6–8].

1.2. Application of ferrock

Ferrock in original form has 5 times more compressive strength and flexures much more before failure when compared to control mix [4]. For carrying out the total replacement of cement the main requirement is a 100% CO_2 atmosphere for curing which couldn't be satisfied for our project. As according to the scope of this paper, we have substituted cement by percentage weights of ferrock. Thus in our results we find that the strength of control mix can be achieved in substitutions itself. It has various applications similar to normal concrete in buildings, bridges and other conventional uses of concrete. Also, as our specimen gains strength in CO_2 environments it will be very useful in polluted sites of industrial zones [5]. Further, ferrock concrete can also be used for structures in contact with sea water as this fastens the process of rusting and gives strength to ferrock.

2. Material testing

2.1. Properties of cement

It is forever desirable to use the most effective cement in constructions [2]. Therefore, the properties of a cement should be investigated in Figs. 1 and 2. Though fascinating cement properties could vary depending on the kind of construction, usually a decent cement possesses following properties shown in Table 1.

2.2. Properties of fine aggregate

Aggregate is the granular material accustomed manufacture concrete or mortar and when the particles of the granular material square measure therefore, fine that they meet up with a 4. 75 mm sieve [15], it's known as fine aggregate shown in Fig. 3. It's widely utilized in the construction industry to increase the quantity of concrete, therefore it's a price saving material, and you must understand everything regarding the fine aggregate size, its density and grading zone to search out the simplest material in Table 2.

Fig. 1. Specific Gravity of Cement.

Fig. 2. Initial Setting & Final Setting Time.

Table 1
Properties of cement.

S.NO	Properties	Values
1	Specific gravity	3.16
2	Consistency	32%
3	Initial setting time	45 min
4	Final setting time	480 min

2.3. Properties of coarse aggregate

Aggregates are crystalline, or granular rocks that are extracted to be used within the construction industry. These will be either primary aggregates or secondary aggregates. Aggregates are an important material in building and repairing things like roads, railways, and houses Fig. 4. Aggregates are utilized in concrete to produce economy within the cost of concrete [10]. These don't react with cement and water. But there are properties or characteristics of aggregate that influence the properties of ensuing concrete mix on Table 3.

3. Experimental procedure

In the basic mix, cement: fine aggregate: coarse aggregate was in a ratio of 1:2.2:3.1 for M20 grade concrete (16) taking the experimental values of material testing. In the first mix, 0% of ferrock is added by weight of cement [8,9]. For the second mix, 4% of ferrock by weight of cement is used as a substitute. Similarly, 8% and 12% of ferrock powder is substituted by weight of cement. The ingredients and their exact proportions are listed in below Tables 4–6.

Initially various research papers and other information should be studied carefully. All the materials like cement, sand, coarse aggregate and ferrock powder which were used in preparation of concrete had be tested and their characteristic behaviour has be noted in the table form. Using the stipulated values mix proportion of M20 grade has be designed for the concrete mix design. With the help of mix ratio the weight of all materials are calculated for mix-

Fig. 3. Specific Gravity & Sieve Analysis of Fine Aggregate.

Table 2
Properties of fine aggregate.

S.NO	Properties	Values
1	Source	Crusher
2	Specific gravity	2.6
3	Fineness Modulus	3.20
4	Sieve analysis (zone)	Zone II

ing concrete in required volumes for all the specimen [11]. Then the specimens of cube size 150 mm × 150 mm × 150 mm size, split tensile cylinder size 300 mm X 150 mm and flexural beam of 100 mm × 150 mm × 150 mm has been casted as per decided percentage substitutions. The casted specimens have been kept for 24 h in a dry place for making harden concrete and then removed from mould. After remolding the specimens it has to keep for curing in water tank for 7, 14 and 28 days. After curing the specimen is taken out from curing tank and dried for few hours to remove the water content. The dried specimen is to be tested for compressive strength, split tensile and flexural strength. The results of substituted specimens have been compared to conventional concrete without substitution [16]. It has given a value at which percentage of ferrock in concrete reaches its maximum strength. The optimum dosage has been noted from the experimental result. The result and discussion have shown the properties and strength of ferrock concrete.

3.1. Compressive strength of cube

The specimens are of size 150 mm × 150 mm × 150 mm for various proportions of 0%, 4%, 8% and 12% has casted. The casted cubes are kept for curing of 7 days 14 days and 28 days. Then it was tested in compression testing machine of 2000kN which is shown in Fig. 5.

3.2. Splitting tensile test

The tensile strength of concrete is one of the fundamental and necessary properties that greatly have an effect on the extent and size of cracking in structures Fig. 6. Moreover, the concrete is incredibly weak in tension because of its brittle nature [13]. Hence. It's not expected to resist the direct tension. So, concrete develops cracks once tensile forces exceed its strength. Therefore, it's necessary to work out the strength of concrete to work out the load at

Fig. 4. Specific Gravity & Sieve Analysis of Coarse Aggregate.

Table 3
Properties of Fine Aggregate.

S.NO	Properties	Values
1	Specific gravity	2.86
2	Fineness Modulus	3.62
3	Water Absorption	1.0%

Table 4
Proportion of Mix Ingredients of cubes.

Grade	No of cubes	Ferrock (%)	Cement (kg)	FA (kg)	CA (kg)	Ferrock (kg)
M20	9	0	13.89	30.55	43.05	0
	9	4	13.32	30.55	43.05	0.57
	9	8	12.512	30.55	43.05	1.11
	9	12	12.213	30.55	43.05	1.677

Table 5
Proportion of Mix Ingredients of cylinder.

Grade	No of cylinder	Ferrock (%)	Cement (kg)	FA (kg)	CA (kg)	Ferrock (kg)
M20	9	0	18.56	40.84	57.54	0
	9	4	17.817	40.84	57.54	0.742
	9	8	17.075	40.84	57.54	1.484
	9	12	16.332	40.84	57.54	2.227

Table 6
Proportion of Mix Ingredients of Beams.

Grade	No of Beams	Ferrock (%)	Cement (kg)	FA (kg)	CA (kg)	Ferrock (kg)
M20	9	0	21.76	47.87	71.808	0
	9	4	20.889	47.87	71.808	0.87
	9	8	20.019	47.87	71.808	1.74
	9	12	19.148	47.87	71.808	2.611

Fig. 5. Testing of Cubes.

that the concrete members might crack. Furthermore, rending strength take a look at on concrete cylinder may be a technique to work out the strength of concrete in expression 5. The procedure supported the ASTM C496 (Standard take a look at the technique of Cylindrical Concrete Specimen) that almost like alternative codes like IS 5816 1999 [12].

Fig. 6. Splitting Tensile test on cylinder.

Fig. 7. Testing of Beam.

3.3. Flexural strength test

The flexural strength of concrete beam was determined based on IS 516-1959. Place the specimen within the machine in such a way that the load is applied to the higher most surface as cast within the mould [15]. Apply load continuously without shock and increasing at a rate of 180 kg/min and is multiplied till the specimen fails. Measure the space between the line of fracture and nearest support [14]. The check is distributed with beam specimen to search out of the flexural strength of typical concrete and therefore, the results are as shown Fig. 7.

Table 7
Compressive Strength of Cube M20 Grade.

Grade	Ferrock (%)	Compressive Strength (N/mm^2)		
		7 days	14 days	28 days
M20	0	14.93	20.69	26.80
	4	22.29	28.73	35.13
	8	21.20	29.36	37.87
	12	20.60	26.59	30.15

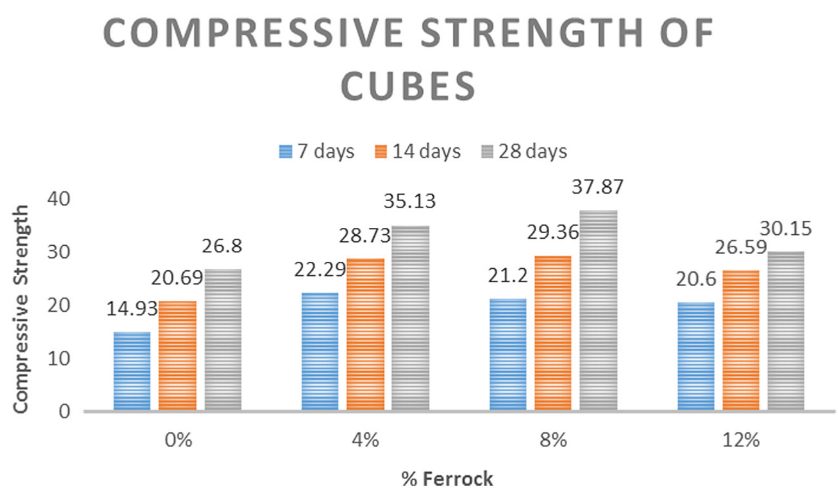

Fig. 8. Compressive Strength of M20 for 7, 14 & 28 days.

Table 8
Splitting tensile test on cylinder M20 Grade.

Grade	Ferrock (%)	Splitting Tensile test on cylinder (N/mm^2)		
		7 days	14 days	28 days
M20	0	2.34	2.71	3.05
	4	2.45	2.78	3.35
	8	2.63	2.97	3.65
	12	2.32	2.47	2.87

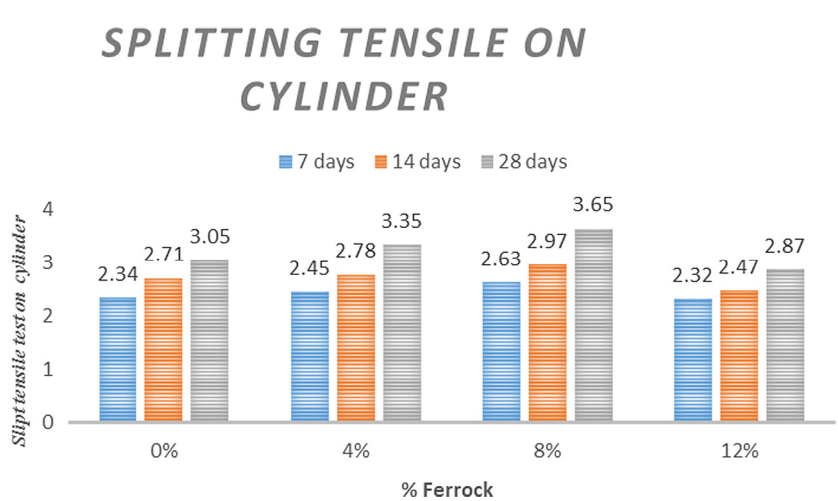

Fig. 9. Splitting tensile test of M20 for 7, 14 & 28 days.

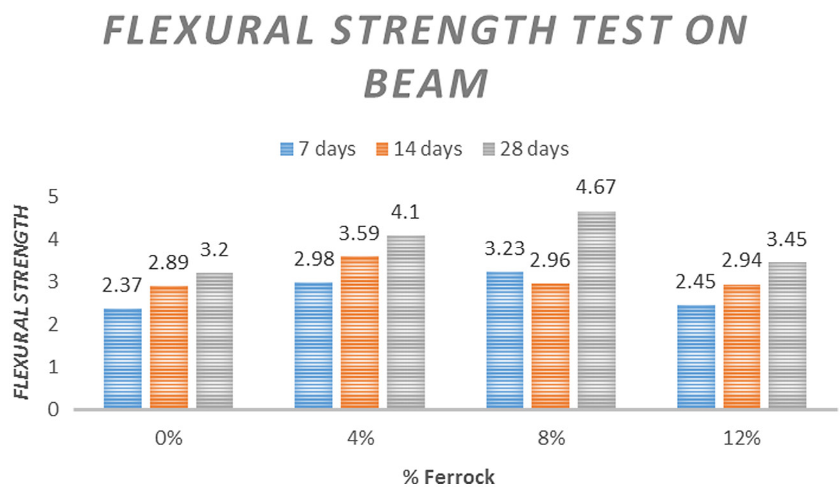

Fig. 10. Flexural strength of concrete beam M20 for 7, 14 & 28 days.

Table 9
Flexural strength of concrete beam M20 Grade.

Grade	Ferrock (%)	Flexural strength of concrete beam (N/mm^2)		
		7 days	14 days	28 days
M20	0	2.37	2.89	3.2
	4	2.98	3.59	4.1
	8	3.23	2.96	4.67
	12	2.45	2.94	3.45

4. Results and discussion

The compressive strength for cube of controlled mix for 7, 14 and 28 days are 14.93 N/mm^2, 20.69 N/mm^2 and 26.80 N/mm^2 respectively Table 7. The compressive strengths for 4%, 8% and 12% ferrock concrete for 28 days are all higher than normal concrete. They are 35.13 N/mm^2, 37.87 N/mm^2 and 30.15 N/mm^2 respectively Fig. 8.

The splitting tensile test on cylinder for controlled mix for 7, 14 and 28 days are 2.34 N/mm^2, 2.71 N/mm^2 and 3.05 N/mm^2 respectively Table 8.The splitting tensile test for 4%, 8% and 12% ferrock concrete for 28 days are all higher than normal concrete. They are 3.35 N/mm^2, 3.65 N/mm^2 and 2.87 N/mm^2 respectively Fig. 9.

The flexural strength of control mix concrete is 7, 14 and 28 days are 2.37 N/mm^2, 2.89 N/mm^2 and 3.2 N/mm^2 respectively Fig. 10.The flexural strengths for 4%, 8% and 12% ferrock concrete for 28 days are all higher than normal concrete. They are 4.1 N/mm^2, 4.67 N/mm^2 and 3.45 N/mm^2 respectively Table 9.

5. Conclusion

Investigation on the Ferrock as an alternative for the cement concrete was carried out in the present work to improve the strength of the materials when used as Solid block. Destructive test was carried out for compressive strength, Splitting tensile test and flexural strength for 7, 14 and 28 days. Compressive strength of the ferrock concrete was improved to 35.13 N/mm^2, 37.87 N/mm^2 and 30.15 N/mm^2 respectively with the 4%, 8% and 12% respectively. From the results it is evident that the 8% ratio has improved strength when compared to the other ratios of the concrete. Splitting tensile test of the ferrock concrete was improved 3.35 N/mm^2, 3.65 N/mm^2 and 2.87 N/mm^2 respectively with the 4%, 8% and 12% respectively. From the results it is evident that the 8% ratio has improved strength when compared to the other ratios of the concrete. Flexural strength of the ferrock concrete was improved 4.1 N/mm^2, 4.67 N/mm^2 and 3.45 N/mm^2 respectively with the 4%, 8% and 12% respectively. From the results it is evident that the 8% ratio has improved strength when compared to the other ratios of the concrete. Test results on the compressive strength, splitting tensile test and flexural strength has revealed that the 8% ratio of the ferrock cement has better results when compared to the other ratios. Hence the test results reveal that the 8% ratio will be optimum to be used in the construction industry.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] Deborah N. Huntzinger, Thomas D. Eatmon, A life-cycle assessment of Portland cement manufacturing: comparing the traditional process with alternative technologies, J. Clean. Product. 17 (7) (2009) 668–675, https://doi.org/10.1016/j.jclepro.2008.04.007.

[2] Jones, R. et al. Fly Ash Route to Low Embodied CO2 and Implications for Concrete Construction , World of Coal Ash (WOCA) Conference -May 9-12, 2011

[3] Revathy Jayaseelan, Gajalakshmi Pandulu, G. Ashwini, Neural networks for the prediction of fresh properties and compressive strength of flowable concrete, J. Urban Environ. Eng. 13 (1) (2019) 183–197.

[4] H.S. Mehta, Vishal Porwal Green Building Construction for Sustainable Future, Civil and Environmental Research www.iiste.org ISSN 2224-5790 (Paper) ISSN 2225-0514 (Online) Vol.3, No.6, 2013.

[5] Bhooma Nepal, Vanita Aggarwal, Papercrete a study on green structural material–international, J. Appl. Eng. Res. (2014) 253–260.

[6] J. Revathy, P. Gajalakshmi, Sanju, Investigation on the Performance Characteristics of Concrete Incorporating Nanoparticle, Jordan, J. Civil Eng. 3 (2019) 351–360.

[7] M. Arabani, S.M. Mirabdolazimi, Experimental investigation of the fatigue behaviour of asphalt concrete mixtures containing waste iron powder, Mater. Sci. Eng. A 528 (10–11) (2011) 3866–3870.

[8] A.K. Mohanty, M. Misra, L.T. Drzal, Sustainable Bio-Composites from renewable resources: Opportunities and challenges in the green materials world, J. Polym. Environ. 10 (1–2) (2002) 19–26.

[9] J.B. Sun, G.A. Zhang, W. Liu, M.X. Lu, The formation mechanism of corrosion scale and electrochemical characteristic of low alloy steel in carbon dioxide-saturated solution, Corros. Sci. 57 (2012) 131–138.

[10] M. I. Abdul Aleem P. D. Arumairaj GEOPOLYMER CONCRETE- A REVIEW IJESET 1 2 118 122 10.7323/ijeset 10.7323/ijeset/v1_i2 10.7323/ijeset/v1_i2_14 http://www.ijeset.com/about-international-journal-of-engg.sciences-emerging-technologies/index.html http://www.ijeset.com/volume-1-issue-2.

html http://www.ijeset.com/media/14N2-GEOPOLYMER-CONCRETE-A-REVIEW.pdf
[11] P. Prathebha, Aswini, S. Revathy, Effect of nano particles on strength and durability properties of cement mortar, Appl. Mechan. Mater. 857 (2016) 65–70.
[12] Santhosh kumar karri, G.V. Rama Rao, P. Markandeya Raju, Strength and durability studies on GGBS concrete SSRG Int. J. Civil Eng. (SSRGIJCE) ISSN 2 10 2015 2348 8352.
[13] N.A. Lloyd, B.V. Rangan, Geopolymer Concrete with Fly Ash, Second International Conference on Sustainable Construction Materials and Technologies, ISBN 978-1-4507-1490-7, 2012.
[14] D.J. wantoro Hardjito, Steenie E. Wallah, Dody M. J. Sumajouw B. Vijaya Rangan, On the development of fly ash-based geopolymer concrete, ACI Materials Journal, Technical Paper, Title no. 101-M52, 2012.
[15] IS 383: 1970- Specification of Coarse Aggregate and Fine Aggregate Bureau of Indian standards, New Delhi.
[16] IS 10262 – Concrete Mix Design Bureau of Indian Standards 2009 New Delhi.