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PARAMETRIC STUDY OF FERROCHROME SLAG WITH REPLACEMENT TO COARSE AGGREGATE IN CONCRETE

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Abstract: Concrete is a combination of fine and coarse aggregates & cement with water. It is a material that is widely used for construction building and other civil engineering structures. The basic objective of this study was to identify alternative source of good quality coarse aggregate. Ferrochrome slag is by product from the production of ferrochrome, an essential component in stainless steel industry. An amount of 1.1 to 1.6 ton of slag is produced for each ton of ferrochrome. Ferro chrome slag is produced in process of calcinations at 1700 degree centigrade in liquid state, at certain temperature conditions and then hardened in solid form which is a waste material. The wastematerial can be used as partial replacement of coarse aggregates in concrete. In this present project work M20 grade of concrete is used and compressive strength test are carried out for 0%, 25%, 50%, 75%, 100% replacement of Ferro chrome slag as apartial replacement of coarse aggregate in concrete. For strength parameters the compressive test is carried out on cubes specimens at the age of 7 ,14& 28 days of standard curing and fresh concrete slump is carried to know the workability of concrete. From the results maximum compressive strength is obtained as 31.03 N/mm2 for 7 days of curing at the replacement of 25% of ferrochrome slag and 36.05 N/mm2 for 14 daysof curing for replacement of 50% ferrochrome slag. At 25% replacement for 7 days of curing compressive strength is increased by 19.08% and at 50% of replacement for 14 days of curing compressive strength is increased by 30.06% , at 25 % replacement for 28 days curing compressive strength is increased by 32% and 50% of replacement for 28 days of curing compressive strength is increased by 36% as compared to conventional concrete .

INTRODUCTION

Nowadays, concrete is widely used world-wide and will remain the most common construction material for still a long time ago. Concrete is a composite material composed of fine aggregate and coarse aggregate bonded together with cement paste that hardens overtime. It is second most used substance in the world after water and is most widely used in building material as it has excellent technical properties and competitive price on market.

Concrete is a versatile material widely used as principle element for structures and for other applications. The demand on concrete is increasing day by day due to the growingpopulation, housing, transportation and other amenities. As a result, the demand forconcrete making materials also increases leading to the scarcity of naturally available fine and coarse aggregate required for concrete making. Additionally, the speedy development of industrialization contributed to different types of waste products which is environmentally dangerous and creates problem in disposal. Solid waste management is one of the subject essentially inscribing the current interest today. Industrial waste materialsin concrete reimburses lack of natural resources and solving the disposal problem of waste.There are some industrial waste which can be used as an ingredient in concrete. Utilization of suitable waste products in construction industries has become an inevitable option in recent days by fulfilling the demands of concrete as well as reduction in impact on environment. The use of industrial waste as aggregates in concrete provides good platformto utilize the waste as alternatives to naturally available aggregates in concrete as aggregates are the main constituents of concrete making about 75% of its total volume. Useof natural resources is the rapid developing sector of the construction industry. This raises a very important concerns on the depleting of these resources at an alarming rate which causes serious threats to the environmental balance. Due to the increase in the world populations, the rapid growing of the industrial, domestic, commercial and technological activities, the associated generation of the solid wastes is increasing substantially creatingan additional burden on the environment. The solid waste materials generating from industries are not only occupying valuable land mass but also polluting the environment and creating real challenges to the safe disposal. The best strategy for solid waste management is to work towards achieving the 5Rs of reduction, recovery, recycling, reuse,and research.

The present project work introduces a new material known as **FERROCHROME SLAG** which is a solid waste residue that is obtained by the smelting process during the production of stainless steel in ferroalloy Industries. It is one of the alternative materials which can be used as both coarse and fine aggregate for replacement of river sand and crushed rock ballast in concrete by altering the physical form. Ferrochrome slag a waste bi-product generated during the manufacturing of ferrochrome alloy. Ferrochrome alloy is manufactured in a submerged electric arc furnace by physiochemical process at the temperature of 1700oC. Individually the molten liquids of the ferrochromium and slag flowout into dippers. Due to the different specific gravities of metal and slag, separation of the two liquids takes place. The liquefied ferrochrome slag gradually cools down in air forminga stable, dense, crystalline product.

Fig 1.1 Ferrochrome Slag

(Source: https://ru.all.biz/en/slag-ferrochrome-g1133086)

Ferrochrome Slag is a waste material obtained from the manufacturing units of ferrochromium which is used to increase the properties of steel such as resistance to corrosion, oxidation and to improve hardness, tensile strength at high temperatures, wear and abrasion resistance etc. Various efforts are being made to use the industrial wastes as an alternate construction material to conserve the natural resources and effective utilizationof the industrial waste to sustain the industrialization. But limited attempts have been made to characterize Indian ferrochrome slag as a construction material. In the work an effort hasbeen made to characterize the ferrochrome slag as an embankment and pavement material. Different laboratory tests pertaining to Geotechnical and highway material characterizationhas been made and the results have been compared with other industrial wastes like fly ash,red mud and natural soil. An effort also has been made to use stabilize the low strength, residual soil in terms of increasing its strength. The results show it exhibits higher strengthas compared to other coarse aggregates.

2. FERROCHROME SLAG AS COARSE AGGREGATE

In this study report the theoretical aspect of the Ferrochrome slag using a conventional material are done. Chapter number 3 covers General information about the Ferrochrome slag, Application of ferrochrome slag, process of manufacturing of Ferrochrome slag, different proportions to be used for different constructions, test methodsare discussed in this chapter. We will study the advantages, disadvantages of ferrochrome slag.

WHAT IS FERROCHROME SLAG?

Ferrochrome (FeCr) slag is by product from the production of Ferrochrome, an essential component in stainless steel industry. An amount of 1.1 to 1.6 ton of slag is produced for each ton of FeCr. FeCr metal is produced in electric-arc furnaces by a physical

–chemical process from the oxide of chromium ore with coke as a reducing agent at temperatures between 1500ºC to 1700ºC. Both the molten FeCr and the slag flow out into ladles. After gravity separation from the metal, the molten slag, slowly cools in the air, forming a stable and dense crystalline product having an excellent mechanical properties similar to basalt.

Figure 2.1 Ferrochrome Slag

(Source: https://www.tomra.com/en/sorting/mining/segments/slag-metal-sorting/ferro-chrome-slag)

These waste materials can be divided into following category based on the type of coolingconditions. :-

i. Air cooled ferrochrome slag

ii. Water cooled ferrochrome slag

Air cooled ferrochrome slag:

Air-cooled slag is a lump manufactured from molten slag by air-cooling. As per specified application, the slag is then crushed and screened. Air-cooled slag after alloy recovery is available in 10-20mm size, which had been used as coarse aggregate by many researchers. The air-cooled ferrochrome slag has gained popularity as a coarse aggregate in concrete.

Water cooled ferrochrome:

Water-cooled ferrochrome slag is obtained by quenching the molten ferrochrome slag from a blast furnace in water or steam. In this study, water-cooled slag in granulated form having more or less similar grain size like natural sand has been utilized as fine aggregate for the production of concrete. These materials contain residual chromium for which disposal as landfill may pollute the groundwater due to leaching of chromium. But reuse of water-cooled ferrochrome slag is lagging behind. A little is reported (Panda et al.,2013) till date on limited properties of concrete with Water-cooled ferrochrome slag.

MANUFACTURING PROCESS OF FERROCHROME SLAG

Charging: The reactants consist of metallic (chrome) ore and a carbon-source reducing agent, usually in the form of coke, low-volatility coal or wood chips. Limestone may also be added as a flux material. Raw materials are crushed, sized, and some cases, dried, and then conveyed to a mix house for weighing and blending. Conveyors, buckets, skip hoists,or cars transport the processed material to hoppers above the furnace. The mix is then gravity-fed through a feed chute either continuously or intermittently, as needed.

Smelting: Three-phase electric current arcs are formed from electrode to electrode throughthe charge material. Power is applied continuously. The carbonaceous material in the furnace charge reacts with oxygen in the metal oxides of the charge and reduces them to base metals. The reactions produce large quantities of carbon monoxide (CO), which passesupward through the furnace charge. In the further reaction, this carbon monoxide gets converted into carbon dioxide (CO_2). Feed materials may be charged continuously or intermittently.

Tapping / Pouring: The molten metal and slag are released through a tapping process. Oneor more tap holes extending through the furnace shell at the hearth level. Tap holes are opened with pellet shot from a gun, by drilling or by oxygen lancing. The molten metal andslag flow from the tap hole into a carbon-lined trough, then into a carbon-lined runner which directs the metal and slag into a ladle, ingot moulds, or chills (chills are low, flat, iron or steel pans that provide rapid cooling of the molten metal).

Tapping is generally an intermittent process based on production rate of the furnaceand may vary between 1-5 hour intervals. Tapping typically lasts 10 to 15 minutes. In somecases, tapping is done continuously. After tapping is completed the furnace is resealed by inserting a carbon paste plug into tap hole. Chemistry adjustments may be necessary after furnace smelting to achieve a specified product.

During tapping, slag is skimmed from the surface of the molten metal and the metalis transferred to the ladles for pouring into moulds. The slag can be disposed of in landfills,or used as a raw material in a furnace to produce a chemically related some ferroalloy product.

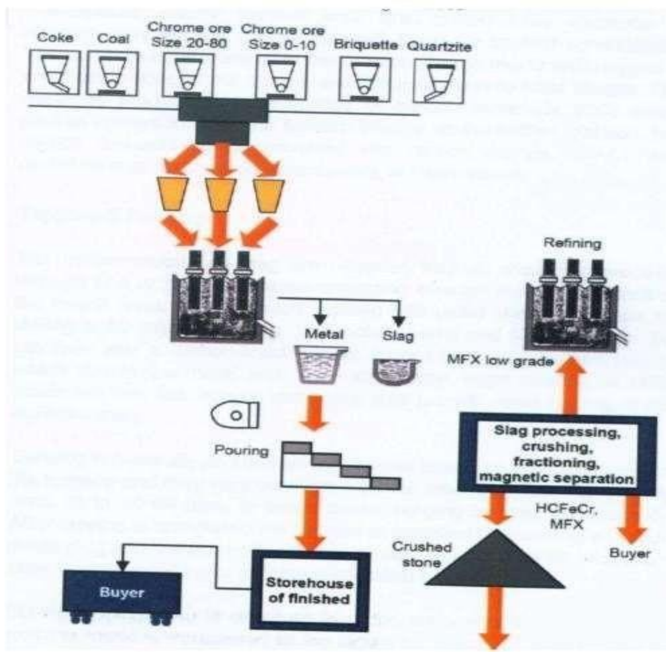


Figure 2.2 Manufacturing of Ferrochrome Slag

(Source: https://docplayer.net/75638110-Utilization-of-ferrochrome-slag.html)

PROPERTIES OF FERROCHROME SLAG

i. Physical properties of Ferrochrome slag
ii. Chemical properties of Ferrochrome slag
iii. Mechanical properties of Ferrochrome slag

Physical properties of Ferrochrome slag

a) Shape and Appearance

Water cooled ferrochrome slag is appeared to be dark in colour and is said to have granulated and crystalline texture. Whereas air cooled slag is grey in colour and is said to have a lumpy texture.

b) Particle Gradation

From the tests conducted governing to IS 2386(I), 1997, it can be incurred that watercooled ferrochrome are of size less than 4.75 mm and they belong to zone I. Air cooled ferrochrome slag are of size 8-20mm.

Table 2.1 Physical Properties of Ferrochrome Slag

Sr.no	Property	FeCr Slag	Coarse Aggregate	Fine Aggregate
1	Abrasion Resistance (%)	14.00-18.00	18.60	-
2	Crushing Value (%)	17.50-19.60	20.10	-
3	Impact value (%)	11.00-15.50	15.30	-
4	Elongation Index (%)	10.30-13.80	13.5	-
5	Flakiness Index (%)	9.83-19.0	18.50	-
6	Water Absorption (%)	0.25-2.3	0.20	0.73
7	Specific Gravity g/cm^3	2.70 -3.15	2.83	2.7
8	CBR Value	107-140	21-103	-

Chemical properties of Ferrochrome slag

The chemical composition of FeCr slag includes three major elements: Silicon (Si),Aluminium (Al), and Manganese (Mg). Together with their oxides, these components makeup 83% of the slag. The slag also includes oxides such as Cr, Ni, Fe and Ca.

Table 2.2 Chemical Properties of Ferrochrome Slag

Sr.no	Chemical components	Percentage (%)
1	Silicon dioxide (SiO_2)	34-35
2	Aluminium oxide (AL_2O_3)	23-24
3	Magnesium oxide (MgO)	22-23
4	Chromium oxide (Cr_2O_3)	5-6
5	Nickel oxide (NiO)	4-5
6	Calcium oxide (CaO)	1-4

The free and combined limes contribute to nearly 3% of the chemical composition of FeCr slag and the summation of silicon, aluminium and iron oxides is about 60% whichless than 70% which is required in order to classify this material as a pozzolanic material.

Mechanical properties of Ferrochrome slag

There are various mechanical test performed on ferrochrome slag concrete which are as follows:

Compressive strength test

Strength in compression is one of the important properties of concrete. It has a certain relationship with other properties of concrete. The properties are improved by improvement in compressive strength. The size of the specimen tested is 150x150x150 mm.Concrete cubes are tested for 7 and14 days strength as per IS: 516-1959 (Part 5). Compressive load is applied at 1.40 KN/cm2/min and it is tested in a compression testing machine.

ADVANTAGES OF FERROCHROME SLAG

Utilization of ferrochrome slag has several following advantages:

i) Ferrochrome slag for construction purpose eliminates the cost of dumping.
ii) Ferrochrome slag particles have more strength, toughness and are less abrasive.
iii) As it is used in construction, the cost of the concrete gets reduced.
iv) Disposal issues of ferrochrome slag can be overcome by utilizing it in concrete.
v) Lessens the demand for primary natural resources.
vi) Decreases the environmental impact due to quarrying and aggregate mining.
vii) Minimizes the cost of dumping.
viii) It gives effective compressive strength.

LIMITATIONS OF FERROCHROME SLAG

Utilization of ferrochrome slag has several following disadvantages:

i) It is harmful for environment.
ii) It leads to the problem of dumping as there is scarcity of dumping area.
iii) As it is a ferroalloy material it may leads to corrosion.
iv) It may lead to less workable concrete.

APPLICATION OF FERROCHROME SLAG

i) The potential application of FeCr as an alternative aggregate in pavements and roadconstruction has been investigated.
ii) Ferrochrome slag is safe to use as a material in road construction.

3. EXPERIMENTAL WORK

3.1 GENERAL

In this chapter the calculation of mixed design is carried out. According to this mixdesign calculations concrete cubes are casted, for casting of cube workability of concrete using slump cone test is checked.

3. 2 MIX DESIGN FOR M-20 GRADE CONCRETE

We are determining the properties for concrete mix design M-20. For this we areusing following data.

a) Stipulation for proportion

i) Grade designation M-20
ii) Type of cement (OPC 53 grade)
iii) Minimum cement content = 280 Kg/m^3 (from table 5 IS 456-2000)
iv) Maximum water cement ratio = 0.55
v) Workability = (50 mm to 100 mm) slump
vi) Exposure condition = severe (from table 5 IS 456-2000)
vii) Method of concrete placing =Manually
viii) Type of aggregate = Crushed angular aggregate

b) Test data

i) Specific gravity of cement =3.12

ii) Specific gravity of coarse aggregate = 2.82

iii) Specific gravity of fine aggregate = 2.59

iv) Water absorption of coarse aggregate= 1.03%

v) Water absorption of fine aggregate= 1.49%

Sieve analysis of coarse and fine aggregate attached separately coarse aggregate and fineaggregate use in surface saturated dry condition i.e. S.S.D

c) Target strength for mix proportioningFck'= fck + 1.65(S)

Where,

Fck' = Target average compressive strength at 28 days Fck = Characteristic compressive strength at 28 days S= Standard deviation

From table 1 of I.S -10262, standard deviation S = 4 N/mm^2 and characteristic compressiveStrength required is 20 N/mm^2

Therefore, target average compressive strength = 20+1.65*4 = 26.60 N/mm^2.

d) Selection of water cement ratio

From table 5 of IS 456, maximum water-cement ratio = 0.55

e) Selection of water cement ratio

From table 2, maximum water content

For 20mm aggregate =186 lit (for 25mm to 60 mm slump range) Estimated water content for 60 mm slump = 186+3/100*186 = 192 litTherefore, adopted water content =192 lit.

f) Calculation of cement content

Water cement ratio = 0.55 Water required = 192 lit

Therefore, water content = 192/0.55=349.09 kg/m^3

Minimum cement content for severe condition =300 kg/m^3 (from IS 456-2000)

349.09 kg/m^3> 300 kg/m^3, hence ok.

g) Proportion of cement content

from table 3, volume of coarse aggregate corresponding to 20 mm size aggregate and fineaggregate (zone 2) for water cement ratio of 0.50 = 0.60

In our case water cement ratio 0.55. Therefore, volume of coarse aggregate is required to be increased to decrease the fine aggregate content. As a water cement ratio is lower by 0.10, the proportion of volume coarse aggregate is increased by 0.02 (at the rate of-/+ 0.01for every +/- 0.05 change in water cement ratio)

Therefore, corrected proportion of volume of coarse aggregate for the water cement ratio of

0.55 = 0.62 + 0.01 =0.63.

Volume of fine aggregate content = 1 – 0.6. = 0.37

h) Mix calculation

The mix calculation per unit volume of concrete shall be as follow

1. Volume of concrete = 1m^3
2. Volume of cement = mass of cement/specific gravity of cement *1/1000

   =300/3.15*1/1000

   =0.10 m^3

3. Volume of water=mass of water/specific gravity of water *1/1000

   = 192/1*1/1000

   = 0.0192 m^3

4. Volume of all in aggregate = (a-(b+c))

   = (1-(0.10+0.192))

   =0.71 m^3

5. Mass of fine aggregate = f*volume of fine aggregate*specific gravity of fineaggregate*1000

   = 0.71* 0.37*2.59*1000

   = 680.39 kg

6. Mass of coarse aggregate = f*volume of coarse aggregate*specific gravity of coarseaggregate *1000

   = 0.656*0.63*2.82*1000

   =1165.45 kg
7. 20mm coarse aggregate is used 35%= 407.91 kg
8. 12mm coarse aggregate is used 65%= 442.25 kg Therefore,

proportion of M20 grade concrete is 1:1.95:3.

Table 3.1 Mix Proportion for Trial Mix M20

i) Cement = 349.09 kg/m^3
ii) Coarse aggregate =1165.45 kg/m^3
iii) Fine aggregate = 680.39 kg/m^3
iv) Water = 192 lit/m^3
v) Water cement ratio = 0.55

EXPERIMENTAL WORK

General

For carrying out study of partial replacement of coarse aggregate using Ferrochromeslag systematic experimental study has been carried out. For this different lab test on material and concrete block has been undertaken. The result of experimental study is enumerated in this chapter. For quality of concrete the material used should be of good quality. Initially the constituent material was weighed and dry mixed homogeneously and then water is added to the mix then filled in the respective moulds of cubes. For each variation respective 3 cubes were casted.

Workability

The concrete slump test measures the consistency of fresh concrete before it sets. Itis performed to check the workability of freshly made concrete, and therefore the ease withwhich concrete flows. It can also be used as an indicator of an improperly mixed batch**.**

Compressive strength

Compressive strength is the ability of material or structure to carry the loads on its surface without any crack or deflection. A material under compression tends to reduce the size, while in tension, size elongates. Compressive strength formula for any material is theload applied at the point of failure to the cross-section area of the face on which load was applied.

Compressive Strength = Load / Cross-sectional Area

Procedure of Test

For this test mainly 150mm * 150 mm * 150 mm cubes are used.

i) Clean the mounds properly and apply oil inside the cube frame.

ii) Fill the concrete in the moulds in layers approximately 50mm thick/

iii) Compact each layer with not less than 35 strokes per layer using a tamping rod (steel bar 16mm diameter and 600 mm long,)

iv) Level the top surface and smoothen it with a trowel.

v) The concrete cubes are removed from the moulds between 16 to 72 hours, usuallythis done after 24 hours. Remove the specimen from water after specified curing time and wipe out excess water from the surface. Take the dimension of the specimen to the nearest 0.2mm and then place the specimen in the machine in sucha manner that the load shall be applied to the opposite sides of the cube cast. Alignthe specimen centrally on the base plate of the machine. Rotate the movable portiongently by hand so that it touches the top surface of the specimen.

vi) Apply the load gradually without shock and continuously at the rate of 140 kg/cm^2/min, till the specimen fails. Record the maximum load and note it.

4. RESULT AND CONCLUSIONS

GENERAL DISCUSSION

In this chapter the study report is prepared on the basis of the results come out afterthe test conducted on concrete. The test results given in this chapter gives us idea about theperformance of the concrete in Compressive strength. The test result gives idea about the suitability of concrete as replacement of coarse aggregate with Ferrochrome slag in the construction project. For this work total 30 no. of cubes of size (150x150x150) mm were casted for M20 grade of concrete for various percentages of FCS such as 0%, 25%, 50%, 75%, and 100% respectively. The results were obtained by compression test on cubes at 7 days and 14 days of curing.

RESULTS

In this project study Compressive strength test is conducted on concrete cube usingproportions of Cement, Sand, Coarse aggregate and Ferrochrome slag. The graph is plottedusing the test result given in previous chapters.

Table 4.1 Compressive Strength at 7 Days of

Sr. No.	% Replacement	Load (KN)	Compressive Strength (N/mm^2)	Average Compressive Strength (N/mm^2)
1	0%	541	24.04	24.88
		496	22.04	
		643	28.57	
2	25%	627	27.86	31.03
		713	31.68	
		755	33.55	
3	50%	554	24.62	28.69
		684	30.04	
		707	31.42	
4	75%	543	24.13	26.97
		593	26.35	
		658	30.44	
5	100%	527	23.42	25.94
		648	28.80	
		576	25.60	

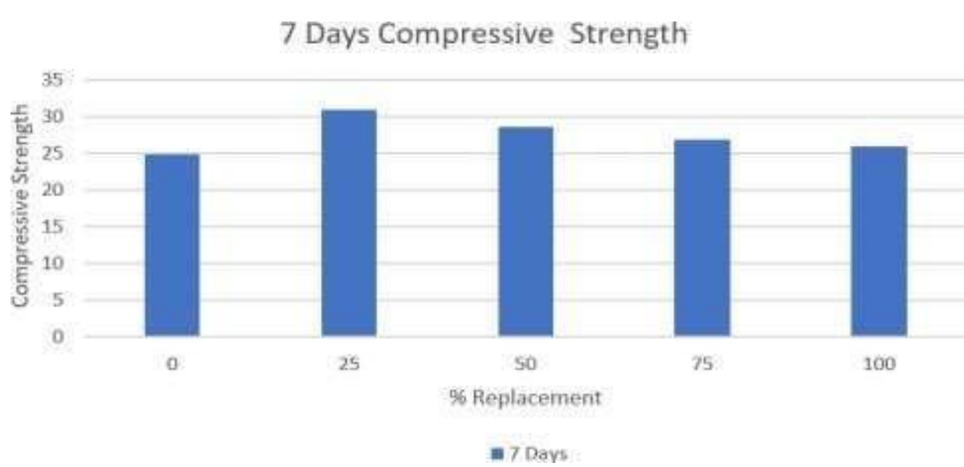
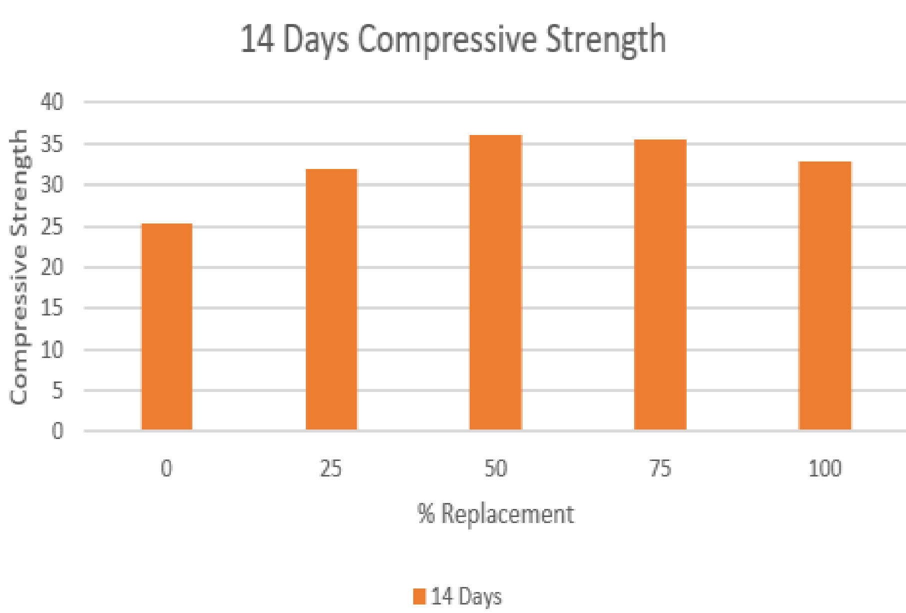


Table 4.2 Compressive Strength at 14 Days of Curing

Sr. No.	% Replacement	Load (KN)	Compressive Strength (N/mm^2)	Average Compressive Strength (N/mm^2)
1	0%	561	24.93	25.21
		511	22.71	
		630	28.00	
2	25%	757	33.64	32.01
		603	28.60	
		801	35.60	
3	50%	780	34.66	36.05
		799	35.51	
		855	38.00	
4	75%	784	34.84	35.49
		760	33.77	
		852	37.86	
5	100%	744	33.07	32.82
		707	31.42	
		764	33.96	

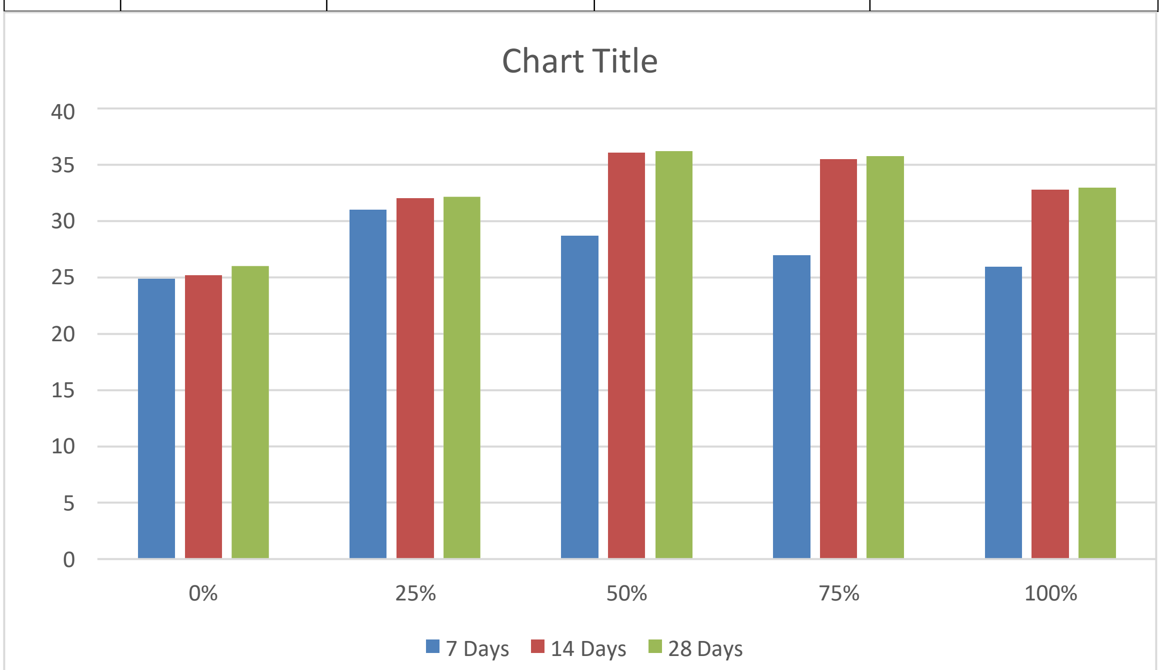


DISCUSSION ON RESULT

From the results maximum compressive strength is obtained as 31.03 N/mm^2 for 7 days of curing at the replacement of 25% of ferrochrome slag and 36.05 N/mm^2 for 14 days of curing for replacement of 50% ferrochrome slag. At 25% replacement for 7 days of curing compressive strength is increased by 19.08% and at 50% of replacement for 14 days of curing compressive strength is increased by 30.06% as compared to conventional concrete.

Table 4.3 Comparative Analysis of Compressive Strengthfor 7 Days ,14 Days and 28 days of Curing

Sr. No.	**%Replacement**	**Strength 7 Days**	**Strength 14 Days**	**Strength 28 Days**
1	0%	24.88	25.21	26.02
2	25%	31.03	32.01	32.16
3	50%	28.69	36.05	36.19
4	75%	26.97	35.49	35.78
5	100%	25.94	32.82	32.96



CONCLUSIONS

Based on the experimental investigation conducted on conventional concrete and ferrochrome slag aggregate replaced concrete for M20 Grade, the following conclusions are drawn:

i) Ferrochrome slag can be considered as alternative to conventional concrete in M20grade concrete mix due to its higher strengths achieved.

ii) The usage of ferrochrome slag as coarse aggregate in concrete reduces the usage ofconventional coarse aggregate resulting in reduction of Environmental pollution.

iii) Scarcity of aggregate can be overcome by replacing ferrochrome slag in concrete.

iv) Maximum compressive strength is obtained as 31.03 N/mm2 for 7 days of curing at the replacement of 25% of ferrochrome slag.

v) For 14 days of curing maximum compressive strength is obtained as 36.05 N/mm2 atthe replacement of 50% of ferrochrome slag.

vi) At 25% replacement for 7 days of curing compressive strength is increased by 19.08%and at 50% of replacement for 14 days of curing compressive strength is increased by30.06% as compared to conventional concrete

vii) For 28 days of curing maximum compressive strength is obtained as 36.19N/mm^2 at replacement of 50% of ferrochrome slag.

viii) For 28 days of curing maximum compressive strength is obtained as 32.96 N/mm^2 atreplacement of 100% of ferrochrome slag.

FUTURE SCOPE

i) Ferrochrome slag can also be replaced to fine aggregate.

ii) For more accuracy % replacement can be taken at every 10% variation interval.

iii) Higher grade of concrete can also be taken into consideration.

iv) It can be also used for design of road construction.

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