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USE OF FERROCHROME SLAG AS AGGREGATE IN CONCRETE- A REVIEW

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Abstract - *Solid waste management is one of the subjects essentially inscribing the current interest today. Utilization of industrial waste materials in concrete reimburses the lack of natural resources, solving the disposal problem of waste. There are a number of industrial wastes used as fully or partial replacement of coarse aggregate or fine aggregate. Ferrochrome slag (FS) is a solid waste residue that is obtained by the smelting process during the production of stainless steel in Ferroalloy industries. Review paper is focussed on the use of ferrochrome slag as an aggregate in concrete. The effect of FS on the properties of concrete such as workability, compressive strength etc are studied. The concrete product with ferrochrome slag as coarse and fine aggregate showed excellent results with respect to various fresh and hardened concrete properties and were found to be suitable for general purpose concrete work.*

KeyWords: Industrial solid waste, Ferrochrome slag, Concrete, compressive strength.

1. INTRODUCTION

Concrete is the most commonly used structural material for majority of construction because of its high resistance to fire, wind, water and earthquakes. Aggregate makes up to 70% of its volume and is the principal component material in concrete production. The demand for concrete is increasing day by day because of the growing population, housing, transportation and other amenities. As a result there is scarcity of conventional fine and coarse aggregates required for making concrete. Thus for reducing the cost of concrete and to reduce demand of conventional materials used in concrete, locally available waste materials such as fly ash, rice husk and various industrial and solid wastes are employed in concrete without affecting the design strength.(K. Rajashekar, C.N.V Sathyanarayana Reddy, 2015)

The use of industrial solid wastes as a partial replacement of raw materials in construction activities is a favourable method for reducing the environmental impact from the industry, compensating the lack of natural resources and thereby reducing the demand for extraction of natural raw materials. Several industrial by-products such as steel slag, copper slag, blast furnace slag and recently ferrochrome slag(FeCr-slag) are utilized successfully as sand or aggregate replacement in cement mortar and concrete. (C.R. Panda, K.K.Mishra, K.C.Panda, B.D. Nayak , B.B. Nayak, 2013)

Ferrochrome slag is a by-product produced during the production of ferrochrome alloy steel in submerged electrical arc furnace. Around 1.1–1.6 ton slag is generated per ton of ferrochrome produced depending on feed materials. (S.K. Nath, 2018). Ferrochrome slag is mainly found to consist of silica, alumina and magnesia with notable amounts of chromium and iron oxides in the form of Partially Altered Chromite (PAC) and entrained ferrochrome alloy. (C.R. Panda, K.K.Mishra, K.C.Panda, B.D. Nayak , B.B. Nayak, 2013). Ferrochrome slag is found to be suitable as construction material due to its excellent technical and material properties but its use is limited due to the environmental concern of release of chromium from slag. Air cooled slag is used as a partial substitution of coarse aggregate in concrete and water cooled granulated slag is used as a partial substitution for sand in concrete. Reports show that air cooled ferrochrome slag has gained popularity as a coarse aggregate in concrete. But the use of water cooled ferrochrome slag is lagging behind. (M.K. Dash, S.K. Patro, 2018). The annual generation of ferrochrome slag is calculated around 12.5 million tons which is also increasing by 2.8–3.0 wt% every year. Out of this a small percentage is used for road construction and the rest is simply discarded. Thus the dumping of these wastes along with other solid wastes can cause serious harm to the environment. Therefore it is necessary to examine these waste products so that it can be utilized effectively. Thus research significance for the bulk utilization of these wastes are increasing. Limited studies are available on the use of ferrochrome slag in road construction, cement additive and aggregate form in construction work. (S.K. Nath, 2018)

2. PHYSICAL PROPERTIES

2.1 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. (C.R. Panda, K.K.Mishra, B. Nayak, 2014)

Fig - 1: Water cooled ferrochrome slag

Fig - 2: Air cooled ferrochrome slag

2.2 Particle Gradation

From the tests conducted governing to IS 2386(I), 1997, it can be incurred that water cooled ferrochrome are of size less than 4.75 mm and they belong to zone I. Air cooled ferrochrome slag are of size 8-20mm. (C.R. Panda, K.K.Mishra, B. Nayak, 2014)

2.3 Specific Gravity

As per IS 2386(III), 1997, the specific gravity of water cooled ferrochrome slag is found to be 2.72 and that of air cooled slag is 2.84. (C.R. Panda, K.K.Mishra, B. Nayak, 2014)

2.4 Water Absorption

Water absorption of ferrochrome slag aggregates as per IS 2386(III), 1997 is found to be 1.15% and 0.42% for water cooled ferrochrome slag and air cooled slag respectively. (C.R. Panda, K.K.Mishra, B. Nayak, 2014)

3. CHEMICAL PROPERTIES

The chemical composition of ferrochrome slag aggregate is shown in Table 1. (C.R. Panda, K.K.Mishra, K.C.Panda, B.D. Nayak , B.B. Nayak, 2013)

Table -1: Chemical composition of FeCr Slag

Major chemical constituent	Water cooled FeCr slag (%)	Air cooled FeCr slag (%)
Cr2O3	10.37	8.32
Al2O3	19.75	22.84
SiO2	27.33	28.87
MgO	32.28	30.32
CaO	2.49	2.96
Fe2O3	4.12	2.85

4. WATER COOLED FERROCHROME SLAG AS FINE AGGREGATE

4.1 Experimental Program

The effect of water cooled ferrochrome slag(WCFS) as fine aggregate in concrete was studied on the basis of experiment conducted in [5]. In there Portland slag cement (PSC) conforming to Indian standard, IS 455:1989 is employed. The physical and chemical examination ascertained that the WCFS is profoundly suitable as a substitution substance of natural sand in concrete making. The SEM analysis of the WCFS (Fig 3) shows that the WCFS has spherical and porous texture. X-ray diffraction (XRD) of the WCFS (Fig 4) shows that chromite, forsterite, olivine, calcite, maghemite and chromferide are the main states present in WCFS. (M.K. Dash, S.K. Patro, 2018)

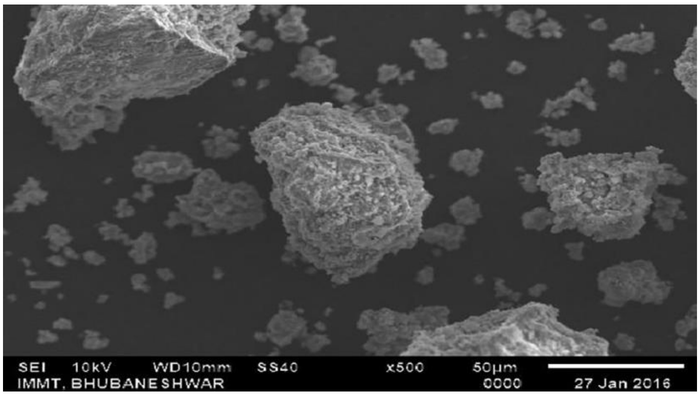
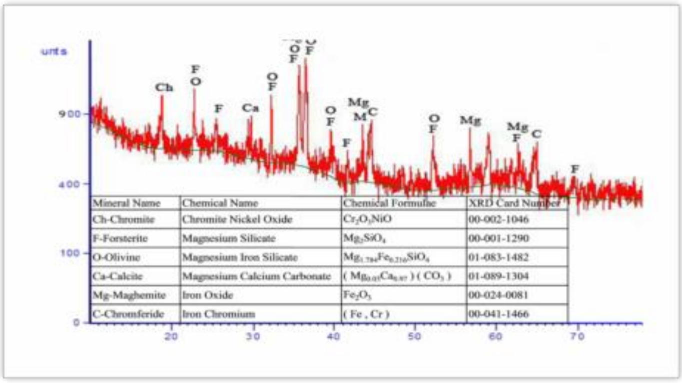


Fig - 3: SEM image of WCFS



Mineral Name	Chemical Name	Chemical Formulae	XRD Card Number
Ch-Chromite	Chromite Nickel Oxide	Cr_2O_3NiO	00-002-1046
F-Forsterite	Magnesium Silicate	Mg_2SiO_4	00-001-1290
O-Olivine	Magnesium Iron Silicate	$Mg_{1.784}Fe_{0.216}SiO_4$	01-083-1482
Ca-Calcite	Magnesium Calcium Carbonate	$(Mg_{0.03}Ca_{0.97})(CO_3)$	01-089-1304
Mg-Maghemite	Iron Oxide	Fe_2O_3	00-024-0081
C-Chromferide	Iron Chromium	(Fe , Cr)	00-041-1466

Fig - 4: XRD of WCFS

The design mix of M-30 grade concrete is prepared and the workability test of fresh concrete is performed as per IS10262:1999 and IS 1199:1959. The compressive strength, flexural strength and modulus of elasticity (MOE) tests are conducted as per IS 516:1959. The splitting tensile strength and ultrasonic pulse velocity tests are carried out as per IS 5816:1999 and IS 1311:1992 respectively. In this experiment a design mix of M-30 grade concrete with water to cement ratio 0.42 is adopted. Superplasticizer is added at the rate of 0.25% by weight of cement to all mixes with and without WCFS. A total of six mixtures are prepared containing 0–50% of WCFS at an increment of 10%. The mixtures are named 0WS, 10WS, 20WS, 30WS, 40WS and 50WS respectively. Cubes of size 150mm are prepared for compressive strength, ultrasonic pulse velocity. Beams of size 100 x 100 x 500 mm are prepared for flexural strength test. Cylinders of 150 mm diameter x 300 mm long are cast for the tests of splitting tensile strength and modulus of elasticity. (M.K. Dash, S.K. Patro, 2018)

4.2 Results and Discussions

4.2.1 Workability

Slump value for reference mix 0WS is found to be 120 mm and for 50WS concrete mix, it is found to be 30 mm. The results are presented in Table 2. It is understood that inclusion of the WCFS in concrete reduces the workability. The reason for reduction in workability may ascribe to the fact that the water absorption capacity of WCFS is more than that of natural sand. (M.K. Dash, S.K. Patro, 2018)

Table -2: Fresh concrete properties of mixes

	0WS	10WS	20WS	30WS	40WS	50WS
Fresh density(kg/m^3)	2512	2493	2477	2462	2449	2435
Slump(mm)	120	100	80	70	50	30

4.2.2 Compressive Strength

Due to the inclusion of water cooled ferrochrome slag compressive strength decreased. For 10-50% of WCFS, the compressive strength decreased by 2-14% in 28 days, 1-16% at 91 days and 2-16% in 180 days. There is an increment in compressive strength with curing period. The increase in compressive strength between 28 and 180 days for 0WS is recorded 13% and for 10WS, 20WS, 30WS, 40WS and 50WS varies from 11 to 14%. The compromise in strength up to 10% is very marginal, looking at huge replacement of natural fine aggregate with waste material. Thus it is concluded that replacement up to 30% may not affect much, rather it will strengthen the ecology and economy. The compressive strength of all concrete mixes after 14, 28, 91 and 180 days of curing are presented in Table 4.

By using the equation prescribed by ACI 209, the compressive strength of concrete with time is computed. The recorded values are shown in Table 3. The variation in results between achieved and computed strength are very marginal. The correlation among the measured and computed compressive strength are shown in Chart 1. The linear regression establishes that the measured strength matches with the computed strength. (M.K. Dash, S.K. Patro, 2018)

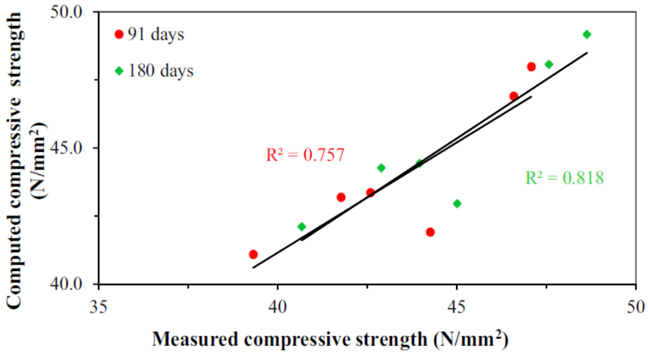


Chart -1: Correlation between computed and measured compressive strengths.

Table -3: Measured and computed compressive strength

Mixtures designation	Measured strength (N/mm^2)				Computed strength (N/mm^2)	
	14 Days	28 Days	91 Days	180 Days	91 Days	180 Days
0WS	35.99	42.89	47.08	48.63	47.98	49.17
10WS	37.70	41.93	46.59	47.57	46.90	48.07
20WS	33.63	37.47	44.26	45.01	41.91	42.96
30WS	33.70	38.76	42.59	43.96	43.36	44.44
40WS	33.73	38.61	41.77	42.89	43.19	44.27
50WS	33.66	36.73	39.32	40.67	41.09	42.11

4.2.3 Ultra sonic pulse velocity

The Ulta sonic pulse velocity (UPV) of various mixtures at 28, 91 and 180 days are presented in Table 4. The results proved that addition of the WCFS up to 30% there inegative variation in the UPV from 1–3%. The results of UPV are found consistent with that of compressive strength.

Table -4: UPV value

Mixture designation	28 Days	91 Days	180 Days
0WS	5020.33	5228.33	5363.67
10WS	4949.00	5172.33	5271.67
20WS	4707.33	5058.00	5088.67
30WS	4861.33	5050.67	5047.00
40WS	4746.67	4976.67	4974.33
50WS	4665.33	4825.67	4850.33

4.2.4 Split tensile strength

Splitting tensile strength test of the all concrete mixes are conducted at the age of 28, 91 and 180 days and the values are recorded in Table 5. It can be inferred that the splitting tensile strength values decreases with an increase in value of WCFS at the rate of 1-12%. It is found that with age the split tensile strength of all concrete specimens are found to increase. As age increases from 28 days to 91 and 91 to 180 days, split tensile strength increases by 1–6% and 2–6% respectively. The results are found consistent to that of the compressive strength. Results further showed that at 10% WCFS content the split tensile strength is almost equal to normal.

For design purpose the tensile strength may be calculated by

$$f_{st} = 0.45\sqrt{f_{ck}}$$

Where, f_{st} is the split tensile strength and f_{ck} is the compressive strength.

The tensile strength values computed based on this equation are recorded in Table 5. Regression analysis can be observed from Chart 2 and it shows that the relation between computed and measured split tensile strength at 91 and 180 days is strong. (M.K. Dash, S.K. Patro, 2018)

Table -5: Measured and Computed split tensile strength

Mixture design ation	Measured strength (N/mm²)			Computed strength (N/mm²)		
	28 Days	91 Days	180 Days	28 Days	91 Days	180Days
0 WS	3.60	3.74	3.14	2.95	3.09	3.14
10WS	3.53	3.70	3.10	2.91	3.07	3.10
20WS	3.39	3.57	3.02	2.75	2.99	3.02
30WS	3.58	3.60	2.98	2.80	2.94	2.98
40WS	3.41	3.46	2.95	2.80	8.91	2.95
40WS	3.15	3.32	2.87	2.73	2.82	2.87

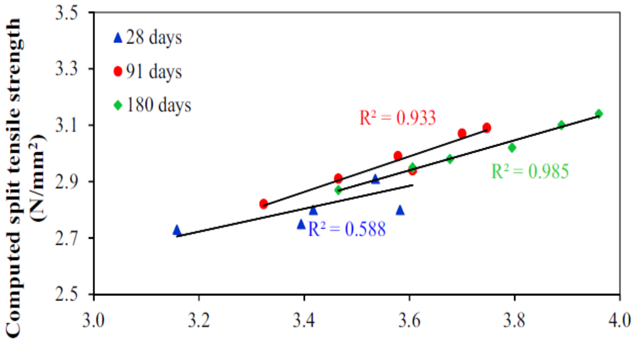


Chart -2: Correlation between measured and computed split tensile strengths

4.2.5 Flexural strength

Flexural strength of all concrete mixes at age of 28, 91 and 180 days are shown in Table 6. There is marginal reduction in flexural strength due to inclusion of the WCFS like that of compressive strength and splitting tensile strength. Flexural strength of concrete mixture 10WS is found to be nearly equal to strength of reference mix at all ages. The flexural strength increases with the age. At 180-day test the reference mixture attained a gain in flexural strength of 11.61%, whereas in comparison to strength of 28 days, mixtures 10WS, 20WS, 30WS, 40WS and 50WS achieved gain of 11.60%, 12.18%, 16.50%, 11.01% and 7.14% respectively. IS 456:2000 recommends equation to calculate the flexural strength of concrete from compressive strength given by,

$$f_{ft} = 0.70\sqrt{f_{ck}}$$

Where f_{ft} is the flexural strength and f_{ck} is the compressive strength. The computed strength as calculated using the above equation is presented in Table 6. The relation between computed and measured flexural strength is presented in Chart 3. It may be comprehended from Chart 3 that the relation between the computed and measured flexural strength is found to be fairly strong. (M.K. Dash, S.K. Patro, 2018)

Table -6: Measured and computed flexural strength

Mixture design ation	Measured strength (N/mm²)			Computed strength (N/mm²)		
	28 Days	91 Days	180 Days	28 Days	91 Days	180 Days
0 WS	4.65	4.99	5.19	4.58	4.80	4.88
10WS	4.57	4.80	5.10	4.53	4.77	4.82
20WS	4.35	4.59	4.88	4.28	4.65	4.69
30WS	4.12	4.57	4.80	4.35	4.56	4.64
40WS	4.27	4.50	4.74	4.35	4.52	4.58
40WS	4.20	4.35	4.50	4.24	4.38	4.46

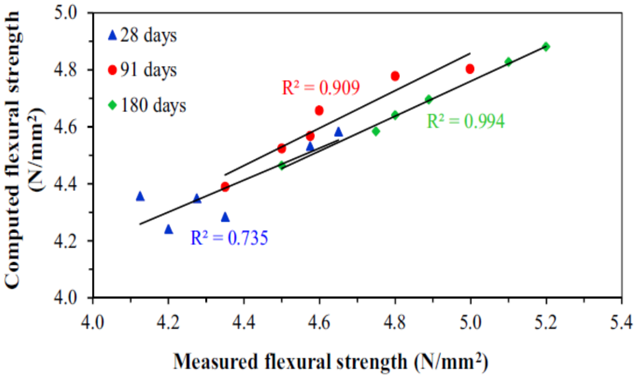


Chart -3: Correlation between measured and computed flexural strengths

4.2.6 Modulas of Elasticity

The Modulus of Elasticity (MOE) at the age of 28, 91 and 180 days is examined and test results are placed in Table 7. It is apparent that, with the addition of the WCFS in concrete mixtures there is a reduction in MOE at all curing periods. Modulus of elasticity at 28 days of reference mixture is 33.97 KN/mm². Decrease in MOE by 1.50%, 7.24%, 6.12%, 6.95% and 9.95% are observed for 10WS, 20WS, 30WS, 40WS and 50WS mixtures respectively in comparison to reference concrete. At 91 days, for concrete mixtures 10WS, 20WS, 30WS, 40WS and 50WS there is a decrease in MOE by 1.95%, 5.54%, 6.48%, 7.66% and 11.00% respectively with respect to reference mix. At 180 days the decrease in MOE is found to be 2.38%, 5.92%, 6.96%, 8.12% and 11.41% for 10WS, 20WS, 30WS, 40WS and 50WS respectively in comparison to normal mix. The increase in modulus of elasticity is also recorded with age. It increased by 7.27%, 6.78%, 9.24%, 6.87%, 6.45%, 6.02% between 28 and 91 days and 4.83%, 4.37%, 4.42%, 4.28%, 4.31%, 4.35% between 91 and 180 days for concrete mixtures 0WS, 10WS, 20WS, 30WS, 40WS and 50WS respectively. The elastic modulus of the concrete is assessed at 28, 91 and 180 days of curing, from the observed values of compressive strength based on the equation as recommended by IS 456:2000, and is presented in Table 7.

$$E = 5000 \times \sqrt{f_{ck}}$$

Where E is MOE in MPa, f_{ck} is the compressive strength in MPa. The correlation between the calculated elastic modulus and measured elastic modulus is shown in Chart 4. It is observed to display a strong relationship.(M.K. Dash, S.K. Patro, 2018)

Table -7: Measured and computed MOE

Mixture designation	Measured MOE (KN/mm²)			Computed MOE (KN/mm²)		
	28 Days	91 Days	180 Days	28 Days	91 Days	180 Days
0 WS	33.97	36.44	38.20	32.75	34.31	34.87
10WS	33.46	35.73	37.29	32.38	34.13	34.49
20WS	31.51	34.42	35.94	30.61	33.26	33.54
30WS	31.89	34.08	35.54	31.13	32.63	33.15
40WS	31.61	33.65	35.10	31.07	32.31	32.75
50WS	30.59	32.43	33.84	30.30	31.35	31.89

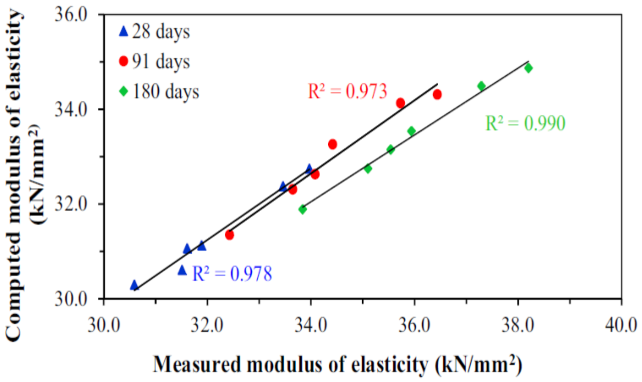


Chart -4: Correlation between measured and computed MOE

5. FERROCHROME SLAG AS COARSE AGGREGATE

5.1 Experimental Program

The experiment consists of testing the essential materials within the laboratory. The basic material tests are performed and results are compared by using Indian Standard Technique. The developed quantitative relation is taken as a combination quantitative relation. For this coarse aggregate is replaced by ferrochrome scum aggregate at an increasing rate of 25%. For each contemporary and hardened property, all the mixes developed are studied and tested. Total of ninety specimens are casted. Compressive and split strength tests are conducted within the laboratory. (Susheel S M , Sathwik S R, Vinayak T3,Darshan S, Sanjith J and Ranjith A, 2016)

5.2 Materials used

In this experimental work, standard Portland Cement (OPC), forty three grade confirming to IS: 8112 – 1989 is employed. Locally available river sand belonging to zone II of IS 383-1970 and quarried and crushed granite stones are used as fine and coarse aggregates respectively. Water fit for drinking is generally used for making concrete. Water shouldn't contain acids, oils, alkalies, vegetables or other organic impurities. Ferrochrome slag aggregate is also employed as coarse aggregate. The properties of conventional coarse aggregate and ferrochrome slag aggregate is shown in Table 8. (Susheel S M , Sathwik S R, Vinayak T3,Darshan S, Sanjith J and Ranjith A, 2016)

Table -8: Properties of conventional coarse and ferrochrome slag aggregate

Property	Conventional aggregate	Ferrochrome slag aggregate
Maximum nominal size	20	20
Specific gravity	2.75	3
Bulk density (kg/m³)	1470	1480
Water absorption(%)	0.5	0.5
Fineness modulus	3.71	5
Impact value(%)	13.5	13

5.3 Results and Discussions

5.3.1 Tests on fresh concrete

The different ingredients needed for the mix M25 are mixed by adding Ferrochrome slag aggregate by weight of conventional coarse aggregate with different percentages (25%,50%,75%,100%). Slump cone test, compaction factor test and Vee-bee consistometer test are performed to measure the workability of fresh concrete mix. The tests are carried out as per IS: 1199-1959, the results are shown in

Table 9. (Susheel S M , Sathwik S R, Vinayak T3,Darshan S, Sanjith J and Ranjith A, 2016)

Table -9: Results of tests on fresh concrete

Sl.No.	Grades of concrete	Ferrochrome slag replacement	Slump (mm)	Compaction Factor	Vee-Bee degree in s
1	M25	0	25	0.82	16
2		25	29	0.80	15
3		50	30	0.78	14
4		75	32	0.74	11
5		100	35	0.72	8

From the table it can be observed that both slump and Vee-bee time values decreases and Compaction factor value increases with the increase in percentage of Ferrochrome slag aggregate. (Susheel S M , Sathwik S R, Vinayak T3,Darshan S, Sanjith J and Ranjith A, 2016)

5.3.2 Cube 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, 14 and 28 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. The compressive strength of concrete mix is shown in Table 10.

Table -10: Results of cube compressive strength

Sl.No	Grade	Replacement of Ferrochrome slag aggregate (%)	Compressive strength(N/mm^2)		
			7 Days	14 Days	28 Days
1	M25	0	20.58	25.07	34.08
2		25	28.18	33.09	42.89
3		50	28.18	33.09	42.89
4		75	40.12	42.71	47.88
5		100	32.28	35.11	40.79

It can be observed that there is an increase in compressive strength with increase in percentage of ferrochrome slag aggregate upto 75%. There is also considerable increase in strength with time. (Susheel S M , Sathwik S R, Vinayak T3,Darshan S, Sanjith J and Ranjith A, 2016)

5.3.3 Splitting tensile strength

Splitting tensile strength is administered by inserting a cylinder specimen horizontally between the loading surfaces of a compression testing machine. The load is applied till the cylinder fails, along the vertical diameter. The loading condition produces a high compressive stress directly below the two generators, to that the load is applied. However the larger portion remaining depth is subjected to a homogeneous tensile stress acting horizontally. It is observed that the compressive stress is acting for 1/6 depth and remaining 5/6 depth is subjected to tension. The cacophonous check is easy to perform and offers additional uniform results than different tension tests. Strength determined within the cacophonous check is believed to be near to the true strength of concrete, than the modulus of rupture. Cacophonus strength provides 5 to 100% higher price than the direct strength. (Susheel S M , Sathwik S R, Vinayak T3,Darshan S, Sanjith J and Ranjith A, 2016)

Table -11: Results of split tensile strength

Sl.No	Grade	Replacement of Ferrochrome slag aggregate (%)	Split tensile strength(N/mm^2)		
			7 Days	14 Days	28 Days
1	M25	0	2.92	3.05	3.33
2		25	3.08	3.40	4.03
3		50	3.19	3.56	4.36
4		75	4.28	4.49	4.92
5		100	3.29	3.57	4.12

It is observed that similar to compressive strength, split tensile strength of the specimen increases upto 75% of ferrochrome slag aggregate. It also increases from 7-28 days of casting. (Susheel S M , Sathwik S R, Vinayak T3,Darshan S, Sanjith J and Ranjith A, 2016)

6. CONCLUSIONS

Workability of concrete reduces with the increase in percentage of WCFS. There is decrease in fresh density up to 3% on inclusion of the WCFS up to 50%. All the UPV values are good, however there is decrease in UPV value with the increase in the WCFS substitution in concrete. Mechanical properties such as compressive strength, splitting tensile strength, flexural strength and MOE decreases up to 10% when the WCFS upto 30% are added. By replacing equal mass of virgin sand, concrete containing 30% WCFS can be prepared. Thus the utilization of fine aggregate from natural source can be reduced. (M.K. Dash, S.K. Patro, 2018)

The following conclusions are drawn from the experiments conducted on conventional coarse aggregate concrete and ferrochrome aggregate replaced concrete of M25 grade. The basic properties of ferrochrome slag mixture like Relative density, Bulk density and impact worth area unit is higher than that of the standard coarse mixture. This indicates that the standard of fabric is nice and therefore the concrete prepared using the ferrochrome slag can have high density. The fineness modulus for all the aggregates are nearly same and thus there might not be much variation in physical behaviour. Compressive strength of concrete increases with increase of ferrochrome slag up to seventy fifth replacements and decreases slightly at 100 percent replacement. Similarly split tensile strength also increases with increase of ferrochrome slag upto seventy fifth replacement and decreases slightly at 100 percent replacement. Thus we can conclude that ferrochrome slag aggregate can be used as a replacement for conventional coarse aggregate. (Susheel S M , Sathwik S R, Vinayak T3,Darshan S, Sanjith J and Ranjith A, 2016)

Thus we can conclude that for better performance of concrete and for the efficient use of industrial waste the aggregates may be replaced by ferrochrome slag of desired amounts. In case of fine aggregates, the virgin sand may be replaced upto 30% by mass with water cooled ferrochrome slag aggregate. Moreover coarse aggregate may be replaced upto 75% by ferrochrome slag.

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