IMPLEMENTATION OF INDUSTRIAL WASTE FERROCHROME SLAG IN CONVENTIONAL CEMENT CASTABLES

SUNIL KUMAR SHRIVASTAVA, MR. VIJAY KUMAR TEMBHRE, MR. LOKESH HARINKHEDE

1M. Tech Students of School of Engineering, 2Asst. Pro. Civil Department, 3Asst. Pro. Civil Department
Sardar Patel University Balaghat, India.

Abstract: In this present work use of Ferrochrome slag in conventional cement castables. Ferrochrome slag is a major solid waste generated from submerged electric arc furnaces during manufacturing of ferrochrome alloy. The waste slag has excellent mechanical and engineering properties for utilization as concrete aggregate material. But it contains about 6–12% of residual chromium which has the potentiality of releasing hazardous chromium compounds to the environment. Ferrochrome slag is a waste material obtained from the manufacturing of high carbon ferrochromium alloy. This slag is formed as a liquid at 1700 °C and its main components are SiO2, Al2O3 and MgO. Additionally, it consists of chrome, ferrous/ferric oxides and CaO. Effects of varying 10–30 % by weight, ferrochrome slag as fine aggregate used in these constables were investigated in this work. Compressive strength and flexure strength of high carbon ferrochrome slag mix concrete over standard concrete were studied for varying mix of 10-30 % for different curing periods. Slag containing constables portrays good thermal properties such as thermal shock resistance, permanent linear change and pyro metric cone equivalent. The most important of them is metallurgical coke. Quartzite, bauxite, dolomite, corundum, lime and olivine are used as fluxing materials to get the right composition of slag. A careful quality control of raw materials ensures maximum output and uniform quality in the smelting process. The main components of the slag are SiO2, MgO, and Al2O3. The slag also includes Cr and Fe oxides and calcium oxide. Common phases in the slag are glass, spinel’s (Al2O3–MgO) and forsterite (MgO–SiO2) and small amount of CaO.

Keywords- Ferrochrome slag, Fine Aggregate, Coarse Aggregate, Applications, Mechanical Properties, water storage, check dams

1. INTRODUCTION

High Carbon Ferrochrome (HCFC) is the common alloying material for the production of different grades of stainless steel. Chromium and iron in chromite ore can form a continuous series of solid solution under certain conditions of heat treatment containing 45–80% of chromium. It is manufactured through direct smelting in Submerged Arc Furnace (SAF) at a temperature more than 1500 °C. The furnace has the suitable system for tapping heavy metal and lighter slag and their handling. For the production of each Metric Ton (MT) of ferrochrome about 2.5–2.6 MT of chromite ore, 0.5–0.6 MT of coke and 0.3 MT of fluxing agents are required. There is a generation of 1–1.2 MT of solid waste slag (By product) for each MT of ferrochrome product. The waste slag material can be made available in different sizes under different cooling conditions and after material recovery. It contains about 6–12% deleterious substances like chromium as chromium oxide and has the potentiality of releasing hazardous chromium compounds to the environment restricting its use and disposal. Chromium is one of the most common toxic heavy metal found in the environment. It exists in the common oxidation states of hexavalent chromium Cr (VI) and trivalent chromium Cr (III). While chromium as Cr (III) is less mobile and less harmful, Cr (VI) is highly leachable and extremely toxic under all environmental conditions. As per OSHA, the major health effects associated with exposure to Cr (VI) include lung cancer, nasal septum ulcerations and perforations, skin ulcerations, and allergic and irritant contact dermatitis etc. Toxicity of chromium ranges from pulmonary to dermatological problems. As per US EPA, it is a suspected carcinogen.

In ferrochrome manufacturing process, the slag is a reactive medium, which most of the reduction reaction takes place. Ferrochrome (FeCr) slag is found to consist of mainly silica, alumina and magnesia with significant amounts of chromium and iron oxide in the form of Partially Altered Chromite (PAC) and entrained ferrochrome alloy. At smelting condition, chromium is reported to exist as divalent CrO above 1600 °C. It is converted into metallic and trivalent chromium on cooling under ambient condition.
The slag was found to be particularly suitable for high strength concrete (M-55 and higher). The mechanical and the physical properties of the FeCr slag satisfied the requirement of the aggregate for granular layers of flexible pavement. Blended with fly ash there is a decrease in chromium leaching from the slag matrix. Bauxite based castables with conventional and low cement castables have drawn great attention in non-recovery coke oven batteries, coal-fired power boilers, industry furnaces and iron industries for many years. Addition of micro silica in these castables, improves its properties, gives reduction in water demand, and increases packing density. It can be minimized by secondary resources, composite processing of raw material and development of low waste for such castables.

In the production of refractories, there is an option of metallurgical industry wastes to be utilized. Slags formed in production of high carbon ferrochrome are usually dumped as a waste material. Utilization of dumped ferrochrome slag in refractory castables reduces the cost of product and is eco-friendly. This material is being used for road construction, brick manufacturing and has recently been tried in cement industry and as a base layer material in road pavements due to its excellent engineering properties. Global ferrochrome production is totaled around 11.7 million tons in the year 2017. It is estimated that 90% of global ferrochrome produced is consumed by the stainless-steel industry (Basson and Daavittila, 2013). For this reason, ferrochrome production is closely linked with stainless steel production.

The slag production is 1.10–1.60/t of Ferrochromium alloy depending on feed materials.

Ferrochromium is a master alloy of iron and chromium. In high carbon ferrochromium, metallic Cr content is 60-65% with varying amounts of Fe and C. Ferrochromium is produced pyrometallurgically by carbothermic reduction of chromite ore (FeO.Cr 2O3).

The main raw material in the production of ferrochrome is chromite, which is basically chrome and iron oxides containing mineral.

### II. EXPERIMENT PROGRAM

**Preparation Of Concrete Specimens**

Different mix of FeCr & Ordinary concrete obtained to conduct compression test on standard BIS specimen of size 150×150×150 mm, flexural test on standard BIS specimen of size 500×100×100 mm. The curing period for the BIS specimen are 7, 28 & 56 days respectively.

#### Ingredients & Mixing Procedure

<table>
<thead>
<tr>
<th>Quantity of Ingredients:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement : OPC Abuja 400 Kgs,</td>
</tr>
<tr>
<td>Sand : River sand 850 Kgs</td>
</tr>
<tr>
<td>Coarse Aggregates : Mix of 10 &amp; 20 mm 1008 Kgs,</td>
</tr>
<tr>
<td>Water : Potable water 160 Kgs</td>
</tr>
<tr>
<td>Chemical Admixture: BASF RIOPLUS 7.5 Kgs</td>
</tr>
</tbody>
</table>

Uniform mixing of concrete be ensured to get correct test results of the specimen. For ordinary concrete, initially the coarse aggregate is weighed for required quantity per mix proportioning, the dry Sand & Cement is weighed and poured uniformly into concrete pan mixture, dry mixing is carried out, later water mixed with chemical admixture, mixing is ensured up to a minimum of 2 minutes until uniform mixer of concrete obtained.

#### Casting and Curing of Cube Specimens

The steel cube moulds were coated with oil on their inner surface and were placed on granite platform. The amount of cement, sand, coarse aggregates required for cubes, were weighed. The materials were first dry mixed then mixed with 1/3rd amount of total water. Slump test is conducted to measure the degree of workability of mix. Concrete was poured into the moulds in three layers: each layer was uniformly tamped by a tamping rod with 25 numbers of blows. The top surface was finished using a trowel, and cube specimen identification mark done. Moulds were safely demoulded after 24 hours, causing no damage to the specimen and concrete cube specimens were kept in curing tank, completely immersed in for curing at a temp between 24 degree and 30 degrees centigrade.

#### Casting and Curing of Prism Specimens

The steel prism moulds were coated with oil on their inner surfaces and were placed on a granite platform. The amount of cement, sand, coarse aggregates required for 32 prisms were weighed. The materials were first dry mixed then mixed with water. Slump test is conducted to measure the degree of workability of mix. Concrete was poured into the moulds in two equal layers: each layer was uniformly tamped by a tamping rod. The top surface was finished using a trowel. Moulds were safely demoulded after 24 hours, causing no damage to the specimen and concrete prism specimens were kept in curing tank, completely immersed in water for curing at a temp between 24 degree and 30 degrees centigrade.
III. METHODOLOGY

Flexural Strength of concrete

Modulus of rupture is defined as the normal tensile stress in concrete, when cracking occurs in flexure test (IS 516-1599). This tensile stress is the flexural strength of concrete and is calculated by the use of the formula, which assumes that the section is homogeneous.

\[ F_b = \frac{Pl}{bd^2} \]

Where, \( F_b \) = Modulus of rupture, N/mm²
\( b \) = Measured depth in mm
\( l \) = Span length in mm
\( P \) = Max, Load in KN applied to the specimen.

The symmetrical two points loading creates a pure bending zone with constant bending moment in the middle third of span and thus the modulus of rupture obtained is not affected by shear, as in the case of single concentrated load acting on the specimen. The concrete test specimen is a prism of cross section 100mm × 100mm and 500mm long. It is loaded on a span of 400 mm. Modulus of Rupture is useful as design criterion or concrete pavements and for evaluating the cracking moment (Mcr), which is the moment that causes the first crack in a pressurized concrete or partially prestressed concrete beam.

Testing of prism specimen

At each desired curing periods the Prism specimens were taken out of water and kept for surface drying. The prisms were tested in Flexure testing machine by arranging two-point loading system. Each Specimen is carefully placed in position. Load is applied without shock and rate of increase in loading is maintained. Maximum load applied on the specimen is recorded at the point of failure of the specimen and flexural strength is calculated.

<table>
<thead>
<tr>
<th>Days</th>
<th>Sample No.</th>
<th>Peak Load (KN)</th>
<th>Mean Peak Load (KN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>Prism 1</td>
<td>15</td>
<td>14.75</td>
</tr>
<tr>
<td></td>
<td>Prism 2</td>
<td>14.5</td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>Prism 1</td>
<td>17.5</td>
<td>18.5</td>
</tr>
<tr>
<td></td>
<td>Prism 2</td>
<td>19.5</td>
<td></td>
</tr>
<tr>
<td>56</td>
<td>Prism 1</td>
<td>19</td>
<td>19.25</td>
</tr>
<tr>
<td></td>
<td>Prism 2</td>
<td>19.5</td>
<td></td>
</tr>
</tbody>
</table>

Flexural Strength of standard concrete

IV. RESULT AND DISCUSSION

COMPRESSIVE STRENGTH

The compressive strength is the main criterion for the purpose of structural design. The strength development in High Carbon Ferrochrome Slag Mix Concrete (HCFC) studied at 7, 28 & 56 days. The variation of compressive strength on HCFC different percentage (10, 20, and 30) for different days of curing period are studied and given in Table 5.1, Table 5.2 & Table 5.3
The compressive strength development at various curing ages for all type of concrete are presented in tabular form. Result of all concrete specimens exhibited increase in compressive strength with increase of curing age.

### Table 5.1: Compressive Strength of HCFC Mix Concrete for 7 Days of Curing

<table>
<thead>
<tr>
<th>Mix (%)</th>
<th>Sample No.</th>
<th>Weight (Kg)</th>
<th>Peak load (KN)</th>
<th>Peak Stress (MPa)</th>
<th>Mean Peak Stress (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>CUBE 1</td>
<td>8.878</td>
<td>845.9</td>
<td>37.60</td>
<td>37.73</td>
</tr>
<tr>
<td></td>
<td>CUBE 2</td>
<td>8.610</td>
<td>825.6</td>
<td>36.69</td>
<td></td>
</tr>
<tr>
<td></td>
<td>CUBE 3</td>
<td>8.720</td>
<td>830.4</td>
<td>36.91</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>CUBE 1</td>
<td>8.634</td>
<td>842.9</td>
<td>37.46</td>
<td></td>
</tr>
<tr>
<td></td>
<td>CUBE 2</td>
<td>8.856</td>
<td>865.3</td>
<td>38.46</td>
<td>37.59</td>
</tr>
<tr>
<td></td>
<td>CUBE 3</td>
<td>8.569</td>
<td>829.3</td>
<td>36.86</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>CUBE 1</td>
<td>8.744</td>
<td>815.5</td>
<td>36.24</td>
<td></td>
</tr>
<tr>
<td></td>
<td>CUBE 2</td>
<td>8.798</td>
<td>826.2</td>
<td>36.72</td>
<td>36.26</td>
</tr>
<tr>
<td></td>
<td>CUBE 3</td>
<td>8.651</td>
<td>806.1</td>
<td>35.82</td>
<td></td>
</tr>
</tbody>
</table>

### Table 5.2: Compressive Strength of HCFC Mix Concrete for 28 Days of Curing

<table>
<thead>
<tr>
<th>Mix (%)</th>
<th>Sample No.</th>
<th>Weight (Kg)</th>
<th>Peak load (KN)</th>
<th>Peak Stress (MPa)</th>
<th>Mean Peak Stress (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>CUBE 1</td>
<td>8.720</td>
<td>947.01</td>
<td>42.09</td>
<td></td>
</tr>
<tr>
<td></td>
<td>CUBE 2</td>
<td>8.760</td>
<td>958.7</td>
<td>42.61</td>
<td></td>
</tr>
<tr>
<td></td>
<td>CUBE 3</td>
<td>8.820</td>
<td>972.76</td>
<td>43.23</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>CUBE 1</td>
<td>8.465</td>
<td>948.94</td>
<td>42.17</td>
<td></td>
</tr>
<tr>
<td></td>
<td>CUBE 2</td>
<td>9.020</td>
<td>1001.57</td>
<td>44.51</td>
<td>43.35</td>
</tr>
<tr>
<td></td>
<td>CUBE 3</td>
<td>8.915</td>
<td>975.89</td>
<td>43.37</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>CUBE 1</td>
<td>8.818</td>
<td>961.65</td>
<td>42.74</td>
<td></td>
</tr>
<tr>
<td></td>
<td>CUBE 2</td>
<td>8.654</td>
<td>929.29</td>
<td>41.30</td>
<td>41.48</td>
</tr>
<tr>
<td></td>
<td>CUBE 3</td>
<td>8.793</td>
<td>909.26</td>
<td>40.41</td>
<td></td>
</tr>
</tbody>
</table>
V. FLEXURAL STRENGTH

It is seen that strength of concrete in compression and tension in both direction (i.e. direct tension and flexural tension) are closely related, but the relationship is not of direct proportionality. The ratio of two strengths depends on general level of strength of concrete. In other words, for higher compressive strength of concrete shows higher tensile strength, but the rate of increase of tensile strength is increasing order. The use of ferrochrome Slag increases the tensile strength of concrete the variation of flexural strength on HCFC concrete with different percentage (10, 20, 30) for different curing periods are given in Table 5.4 Table 5.5 & Table 5.6

<table>
<thead>
<tr>
<th>Mix (%)</th>
<th>Sample No.</th>
<th>Peak Load (KN)</th>
<th>Mean Peak Load (KN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>Prism 1</td>
<td>13.50</td>
<td>13.75</td>
</tr>
<tr>
<td></td>
<td>Prism 2</td>
<td>14.0</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>Prism 1</td>
<td>13.50</td>
<td>14.25</td>
</tr>
<tr>
<td></td>
<td>Prism 2</td>
<td>15.0</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>Prism 1</td>
<td>15.5</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>Prism 2</td>
<td>12.5</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mix (%)</th>
<th>Sample No.</th>
<th>Peak Load (KN)</th>
<th>Mean Peak Load (KN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>Prism 1</td>
<td>17.50</td>
<td>17.0</td>
</tr>
<tr>
<td></td>
<td>Prism 2</td>
<td>16.5</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>Prism 1</td>
<td>17.5</td>
<td>18.50</td>
</tr>
<tr>
<td></td>
<td>Prism 2</td>
<td>19.7</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>Prism 1</td>
<td>17.5</td>
<td>17.25</td>
</tr>
<tr>
<td></td>
<td>Prism 2</td>
<td>17</td>
<td></td>
</tr>
</tbody>
</table>

Table 5.4: Flexural Strength of HCFC mix concrete for 7 Days of Curing

Table 5.5: Flexural Strength of HCFC mix concrete for 28 Days of Curing

<table>
<thead>
<tr>
<th>Mix (%)</th>
<th>Sample No.</th>
<th>Peak Load (KN)</th>
<th>Mean Peak Load (KN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>Prism 1</td>
<td>15.5</td>
<td>17.0</td>
</tr>
<tr>
<td></td>
<td>Prism 2</td>
<td>18.5</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>Prism 1</td>
<td>17.5</td>
<td>18.0</td>
</tr>
<tr>
<td></td>
<td>Prism 2</td>
<td>18.5</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>Prism 1</td>
<td>16.0</td>
<td>16.75</td>
</tr>
<tr>
<td></td>
<td>Prism 2</td>
<td>17.5</td>
<td></td>
</tr>
</tbody>
</table>

Table 5.6: Flexural Strength of HCFC mix concrete for 56 Days of Curing

<table>
<thead>
<tr>
<th>TYPES</th>
<th>MEAN PEAK LOAD (KN)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>7 DAYS</td>
</tr>
<tr>
<td>OC</td>
<td>14.75</td>
</tr>
<tr>
<td>HCFC 10 %</td>
<td>13.75</td>
</tr>
<tr>
<td>HCFC 20 %</td>
<td>17.0</td>
</tr>
<tr>
<td>HCFC 30%</td>
<td>17.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TYPES</th>
<th>COMRESSIVE STRENGTH (Mpa)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>7 DAYS</td>
</tr>
<tr>
<td>OC</td>
<td>38.18</td>
</tr>
<tr>
<td>HCFC 10 %</td>
<td>37.73</td>
</tr>
<tr>
<td>HCFC 20 %</td>
<td>42.64</td>
</tr>
<tr>
<td>HCFC 30%</td>
<td>45.75</td>
</tr>
</tbody>
</table>
VI. GRAPHICAL ANALYSIS

COMPRESSIVE STRENGTH TEST

Effect of Compressive Strength of Standard Concrete at different curing days

Effect of Compressive Strength of 10% HCFC Mix Concrete at different curing days

Effect of Compressive Strength of 20% HCFC Mix Concrete at different curing days

Effect of Compressive Strength of 30% HCFC Mix Concrete at different curing days

Variation of Compressive strength of HCFC Mix Concrete for Different Curing Days

Comparison of Compressive strength of HCFC Mix Concrete over Standard Concrete for Different Curing Day

Effect of Flexural Strength of Standard Concrete at different curing days

Effect of Flexural Strength of 10% HCFC Mix Concrete at different curing days
I. APPLICATIONS

5.1. Marine applications
A marine application includes boats, fishing vessels, docks, cargo tugs, floatation buoys, and water or fuel tanks.

5.2. Terrestrial applications
1. Agricultural applications: Grain storage bins, silos, lining for irrigation channels, pipes, shells for fish and chicken farms, pedestrian bridges and check dams.
2. Rural energy applications: Biogas holders, biogas digesters, incinerators and panels for solar energy collectors.
3. Housing applications: Houses, community centres, museums, mosque domes, precast housing elements, wall panels, corrugated roofing sheets, sunscreens, sandwich panels, permanent form work, water tanks and repair and rehabilitation of existing housing.

II. CONCLUSION

In this present study an effort has been taken to enlighten the use of different types of commercially available ferrochrome slag to obtain the High carbon Ferrochrome slag mix concrete and comparing their Compressive and Flexural Strength with ordinary concrete. Based on the experimental observation in current study following conclusions can be made.

1. Slag remains as a waste product in the production of high-carbon ferrochromium metal. By slow cooling in the air, the slag crystallizes in the form of a stable CaO–MgO–Al2O3–silicate product with mechanical properties like igneous origin rocks.
2. The reinforced slag concrete is suitable for wearing courses of concrete pavements for traffic load.
3. The use of ferrochromium slag as aggregate in concrete pavements offers a more economical solution than then standard ones, due to the very high price of stones of igneous origin, which have to be transported from distant locations.
4. Replacement of ferrochrome slag with standard concrete impart certain strength which can be used for either road construction or in brick manufacturing.
5. Concrete with slag is environmentally compatible with low chromium leaching.
VII. REFERENCES


2. Properties of concrete pavements prepared with ferrochromium slag as concrete aggregate by J. Zelic

3. The use of steel slag aggregate to enhance the mechanical properties of recycled aggregate concrete and retain the environment by Hisham Qasrawi


5. www.sciencedirect.com


7. Properties of bricks with waste ferrochromium slag and zeolite by Osman Gencel, Mucahit Sutcub, Ertugrul Erdogmus, Vahdettin Kocd, Vedat Veli Caye, Mustafa Sabri Gokf [2013]

8. Implementation of ferrochrome slag with combined effect of calcined alumina in conventional concrete by Pattem Hemanth Kumar, Abhinav Srivastava, Vijay Kumar, & Vinay Kumar Singh 2014
