Full Length Research Paper

Slag as coarse aggregate and its effect on mechanical properties of concrete

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Abundant availability of natural resources has become a dream for present day engineering society due to large scale consumptions. The engineering society is in a gremlin to fulfill human basic needs due to scarcity of natural resources. The unaccountable population growth rate makes problem of availability of coarse aggregate for construction more severe. On the other hand, slag is a waste product of the ferroalloys industry. This low carbon slag is considered as third class hazardous waste chemically composed of carcinogenic, such as hexavalent chromium and needs large space to be dumped. To overcome the problem of scarcity of natural aggregates and to save the environment from the pollution due to dumping of slag, civil engineers opined that there is significance potential for reuse of slag for use in value added application to maximize economic and environment benefit. Here an attempt has been made in this investigation to determine the strength characteristics of slag for application in normal strength structural concrete. Substitution of natural aggregates with slag significantly increases the strength characteristics. The experimental results revealed that increase in strength is not prominent up to 20% substitution of slag with natural aggregate. The experimental results of flexural strength and split tensile strength is compared with different codal values. The results revealed that ACI-1995 underestimates the split tensile strength while ACI-1992 over estimates these values. Flexural strength can be predicted from ACI-1985.

KEY WORDS: Natural coarse aggregate; slag; compressive strength; Split tensile strength; Flexural Strength

INTRODUCTION

The ferroalloys industries generate historically substantial solid waste. The accumulated waste needs a huge space to be dumped and causes serious problems to the environment. This low carbon slag, which is considered as third class hazardous waste chemically composed of carcinogenic, such as hexavalent chromium. By exposure to the environment creates health hazard to the human beings like problems in respiration and nervous system disorder. When the slag is dumped it pollutes the ground water. The slag can be easily eroded by the water and wind to contaminate the air and surface water. As per the survey conducted by EnSafe, Inc. (2002), a single ferroalloys industry produces 220,000 tons of low carbon slag per year. Due to the greater use of ferroalloys in the quantity will may increase to 12,000,000 tons per year. The slag may require a large place for dumping.

According to (Song and Kang,2011), excessive ferroalloy production has been a problem for many years in the international market particularly in China. Ferroalloys Works requires a vast area to dump the slag its bi product. The final objective of the plant is to release zero discharge of solid waste.

However, it is possible to transform the solid waste slag into an environment-friendly resource to serve the human being. Consequently, the construction of plants that are “environment-friendly” and that accommodate “recycling” has become a target of most ferroalloy producers in the world to ensure sustainable development. The present day researchers are in the opinion that preservation of environment and conservation of rapidly diminishing Natural resources should be the essence of sustainable development. Each and every human being in this
Table 1. Different casting

<table>
<thead>
<tr>
<th>Mix Designation</th>
<th>MIX-0</th>
<th>MIX-20</th>
<th>MIX-40</th>
<th>MIX-60</th>
<th>MIX-80</th>
<th>MIX-100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Aggregate (%)</td>
<td>100</td>
<td>80</td>
<td>60</td>
<td>40</td>
<td>20</td>
<td>0</td>
</tr>
<tr>
<td>Slag (%)</td>
<td>0</td>
<td>20</td>
<td>40</td>
<td>60</td>
<td>80</td>
<td>100</td>
</tr>
</tbody>
</table>

Table 2. Properties of Natural Aggregate and Slag.

<table>
<thead>
<tr>
<th>Properties</th>
<th>Natural Coarse Aggregate</th>
<th>Slag</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific Gravity</td>
<td>2.62</td>
<td>3.5</td>
</tr>
<tr>
<td>Impact Value</td>
<td>7.1 %</td>
<td>6.1 %</td>
</tr>
<tr>
<td>Crushing Strength</td>
<td>54.8 %</td>
<td>35.5 %</td>
</tr>
<tr>
<td>Water Absorption</td>
<td>0.5 %</td>
<td>0.4%</td>
</tr>
</tbody>
</table>

Universe requires a shelter. As far as shelter is concerned one thinks that his shelter should be unique and all are in race in construction. Now the nature is unable to provide the raw material to the human being to fulfill the desire of making a shelter due to the uncontrollable growth of population. So, the slag which is the waste product of the ferroalloys industry can be used as the coarse aggregate in the construction field.

So, now it is the right time for preserving the natural resources to avoid the natural calamities. To save the environment from the pollution caused due to the slag and to meet the scarcity of natural aggregate in the construction field, the possibility of use of the low carbon slag as coarse aggregate cannot be overlooked. Here an attempt is made to replace natural coarse aggregate with slag in production of concrete. The strength of the concrete depends on the properties of its constituent materials along with their volumetric fraction, water cement ratio, admixture added, curing methodology and degree of control. To find out the optimum volume fraction of slag as a coarse aggregate for making of concrete, the volume fraction of slag is varied in this research work keeping other parameters constant.

Objective

The main objective of this research work is

1. Variation in strength of concrete with percentage of slag.
2. Effect of slag on fresh properties of concrete.

In the second phase of the work, test results were analyzed and compared with the theoretical values obtained from different codes.

EXPERIMENTAL PROGRAMME:

To achieve the above mentioned objectives, M30 grade concrete with natural aggregates was designed and its strength is determined. To verify the effect of addition of slag on fresh properties and hardened properties of concrete, slag is added in place of natural coarse aggregate up to 100% with an increment of 20%. The ratio of water: Cement: Sand: Aggregate for 100% natural coarse aggregate is found to be 0.45: 1: 1.2: 2.8 respectively and same proportion is also maintained for all castings when natural coarse aggregate is replaced by slag. To achieve the above mentioned objectives, the total work is divided in to two phases. In the first phase of work, a mix design is prepared according to (Setty, 1982 and Gambhir, 2007) with slag in production of concrete. The strength of the concrete depends on the properties of its constituent materials along with their volumetric fraction, water cement ratio, admixture added, curing methodology and degree of control. To find out the optimum volume fraction of slag as a coarse aggregate for making of concrete, the volume fraction of slag is varied in this research work keeping other parameters constant.

MATERIAL

The mix proportion for M30 grade concrete was found to be 1:1.2:2.8 with w/c ratio 0.45. The cement was 53 grades with specific gravity 3.15 of cement confirming to IS: 12280 -1987. Initial and final setting time of cement was found be 65 minutes and 255 minutes. The fine aggregate conforms to zone III of IS: 383-1978. Crushed hard granite and slag conforming to IS: 383-1978 passing through 20mm sieve and retaining on 4.75mm sieve was used. The mechanical properties of slag and natural coarse aggregate are presented in table 2. The chemical analysis shows that the slag is composed of Calcium oxide 48%, silicon dioxide 25%, manganese oxide 11% and iron, sulfur, aluminum, chromium 16%. The target mean strength of concrete was found to be 39.9MPa with
natural coarse aggregate. Moulds are prepared with different percentage of natural aggregate and slag keeping fine aggregate, cement and water constant for all mix. Portable water is used throughout the investigation.

**PREPARATION OF CONCRETE MOULD**

Concrete moulds are cleaned properly and the screws are tightened properly to make sure that no slurry will escape through the joint. After tightening the moulds are oiled properly for easy stripping of the specimen. After proper mixing of concrete, tests for workability on fresh concrete such as Vee-Bee test, slump test and compaction factor test are conducted. The results of workability for various mix is reported on table 3. Moulds are filled with concrete with proper compaction for test of hardened concrete. After 24 hours of casting moulds are removed, samples are designated with a permanent marker and cured in a curing tank for 28 days. MIX-80 represents preparation of concrete with 80% slag and 20% natural aggregate. After 28 days of curing, concrete samples are white washed with lime for observation of crack pattern.

**Tests on Hardened Concrete:**

Tests for Compressive strength, spilt tensile strength and flexural strength are conducted on hardened concrete and results for different mixes are reported on table 4.

**INTERPRETATION OF TEST RESULTS**

The test results obtained are shown in the Table 4 and compared with values obtained from various codes. The test results such as weight, compressive strength, spilt tensile strength and flexural strength with different proportion of slag are presented below.

**WEIGHT**

The weight of the specimen depends on specific gravity of its constituents materials. The materials having high specific gravity sustains more compressive load. To verify the effect of weight of the specimen on strength parameters, individual weight of cubes were taken. The values are tabulated in Table 4. The average weight of specimen prepared with MIX-0, MIX-20, MIX-40, MIX-60, MIX-80, and MIX-100 was found to be 8.45 Kg, 8.51 Kg, 8.64 Kg, 8.76 Kg, 8.86 Kg and 8.96 Kg respectively. The values are plotted in figure 1. From the figure it is clear that the increase in weight is not marginal. So when the natural aggregate is to be replaced with slag having higher specific gravity cannot increase the dead load of the structure marginally. The weight of the cube with natural coarse aggregate and proportion mentioned in the experimental program mathematically found to be 8.02 Kg against the experimental value of 8.45 Kg. The weight of the cube with 100% slag is found to be 9.08 Kg against the experimental value of 8.96 Kg.

The percentage increase in weight of cube with respect to slag percentage is reported in figure 2. From the figure it is found that though the increase in weight varies linearly with replacement of slag but the increase is very nominal. When the natural aggregate is replaced by

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### Table 3. Fresh concrete properties of different Castings.

<table>
<thead>
<tr>
<th>MIX</th>
<th>Slump (mm)</th>
<th>Compaction Factor</th>
<th>Vee-Bee test (seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MIX-0</td>
<td>1</td>
<td>0.9</td>
<td>5</td>
</tr>
<tr>
<td>MIX-20</td>
<td>1</td>
<td>0.9</td>
<td>5</td>
</tr>
<tr>
<td>MIX-40</td>
<td>1</td>
<td>0.9</td>
<td>5</td>
</tr>
<tr>
<td>MIX-60</td>
<td>2</td>
<td>0.9</td>
<td>4</td>
</tr>
<tr>
<td>MIX-80</td>
<td>2</td>
<td>0.89</td>
<td>4</td>
</tr>
<tr>
<td>MIX-100</td>
<td>2</td>
<td>0.89</td>
<td>4</td>
</tr>
</tbody>
</table>

### Table 4. Test results of hardened concrete

<table>
<thead>
<tr>
<th>MIX</th>
<th>Avg. Weight of cubes (Kg)</th>
<th>Compressive Strength (N/mm²) 28 days</th>
<th>Spilt Tensile Strength (N/mm²)</th>
<th>Flexural Strength (N/mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MIX-0</td>
<td>8.45</td>
<td>40.89</td>
<td>3.40</td>
<td>4.24</td>
</tr>
<tr>
<td>MIX-20</td>
<td>8.51</td>
<td>42.22</td>
<td>3.54</td>
<td>4.51</td>
</tr>
<tr>
<td>MIX-40</td>
<td>8.64</td>
<td>45.33</td>
<td>3.61</td>
<td>4.92</td>
</tr>
<tr>
<td>MIX-60</td>
<td>8.76</td>
<td>48.00</td>
<td>3.68</td>
<td>5.19</td>
</tr>
<tr>
<td>MIX-80</td>
<td>8.86</td>
<td>51.56</td>
<td>3.75</td>
<td>5.60</td>
</tr>
<tr>
<td>MIX-100</td>
<td>8.96</td>
<td>54.22</td>
<td>3.82</td>
<td>5.88</td>
</tr>
</tbody>
</table>
20%, 40%, 60%, 80% and 100% with slag, the percentage increase is 0.71%, 2.25%, 3.67%, 4.85% and 6.04% respectively. So when the total natural aggregate is replaced by slag only dead load is found to be increased experimentally by 6.04% against the calculated value of 13.27%, which is very nominal. From this it can be inferred that slag can be used as replacement of natural coarse aggregate in the construction field.

**COMPRESSIVE STRENGTH**

Compressive strength is an important property of harden concrete which influences other mechanical properties of concrete. Compressive strength of concrete specimen prepared with MIX-0, MIX-20, MIX-40, MIX-60, MIX-80, and MIX-100 was found to be 40.89 MPa, 42.22 MPa, 45.33 MPa, 48.00 MPa, 51.56 MPa, and 54.22 MPa respectively. A graph is plotted between the compressive strength and percentage of slag is shown in figure 3. Observation shows the increase in compressive strength with increasing in the percentage of slag content. The crushed specimen of MIX-60 is shown in figure 4. It is clearly observed that the failure is due to the failure of mortar.

Percentage increase in compressive strengths of MIX-0

![Figure 1. Average weight Vs Percentage of Slag](image1)

![Figure 2. Percentage increase in weight w.r.t to MIX-0 Vs Percentage of Slag](image2)

![Figure 3. Compressive strength vs percentage of slag](image3)

![Figure 4. Crack pattern of a cube of MIX-60](image4)
The percentage increase in Compressive strength w.r.t to MIX-0 vs percentage of Slag is plotted in the figure 5. The percentage increase in Compressive strength was found to be very high and the variation was found to be linear from 20% onwards. In this investigation it is observed that the compressive strength increases with increase in the percentage of slag. Replacement of natural aggregate with slag up to 20% does not improve compressive strength so much. The same has been reported by earlier researchers when natural aggregate is replaced by recycled aggregates Behera and Behera, (2010). This may be possible due to low volume fraction of slag. But with increasing slag percentage the percentage of strength increases up to 34.78%. The use of slag with high specific gravity might be the cause of enhancement of compressive strength. So, concrete with slag can be used for design of compression members.

**SPLIT TENSILE STRENGTH**

The split tensile strength of concrete specimen with natural aggregate (MIX-0) and totally with slag (MIX-100) was found to be 3.40 MPa and 3.82 MPa respectively. The increase in the split tensile strength is nominal. The split tensile strength of specimen prepared with MIX-20, MIX-40, MIX-60 and MIX-80 was found to be 3.54 MPa, 3.61 MPa, 3.68 MPa and 3.75 MPa respectively. The theoretical values of split tensile strength were calculated according to ACI-1985, ACI-1992 and ACI-1995 with reference to (Rasid et al., 2002) and Mansur and Islam, (2002). Test Value along with different values according to codes is plotted against the percentage of slag in the figure 6. Here it is found that the test value lies between the ACI-1995 and ACI-1992. The percentage increase in split tensile strength with respect natural aggregate is calculated and compared with different codal values. Percentage increase in split tensile strength with percentage of slag is plotted in figure 7. Here it is found that for all values the variation is linear beyond 20%. So the split tensile strength increases accordingly with increase in compressive strength.

**FLEXURAL STRENGTH**

Flexural strength of concrete specimen prepared with MIX-0, MIX-20, MIX-40, MIX-60, MIX-80, and MIX-100 was found to be 4.24 MPa, 4.51 MPa, 4.92 MPa, 5.19 MPa, 5.60 MPa and 5.88 MPa respectively. The theoretical values of flexural strength are also calculated.
from IS 456:2000, ACI-1995, ACI-1992, ACI-1985 and plotted along with test results in figure 8. From the figure it is found that up to MIX-40 the flexural strength is nearly equal to IS 456:2000 and ACI-1985 and beyond MIX-40 it lies in between ACI-1985 and ACI-1992. The percentage increase in flexural strength is plotted in the figure 9. In this investigation the flexural strength is found to be increasing with increasing in the percentage of slag. The variation of the graph is found to be linear beyond 20%. So the flexural strength increases with increase in slag content.

THE PERCENTAGE INCREASE IN WEIGHT AND STRENGTH PARAMETER

In this investigation the percentage increase in weight for the specimen prepared with MIX-20, MIX-40, MIX-60, MIX-80, MIX-100 are found to be 0.71%, 2.25%, 3.67%, 4.85% and 6.04% respectively, for compressive strength the percentage increase is found to be 3.26%, 10.87%, 17.39%, 26.09% and 34.78% respectively, for spilt tensile strength the percentage increase is found to be 4.17%, 6.25%, 8.33%, 10.42% and 12.50% respectively and for flexural strength the percentage increase is found to be 6.49%, 17.17%, 22.65%, 32.33% and 38.72% respectively. A graph between weight, percentage increase in strength parameter and percentage increase in slag is plotted in the figure 10. From the graph it is clear that the percentage increase in strength parameters is marginal with a small increase in percentage of weight. The percentage increase in weight is found to be very low while percentage increase in flexural strength is highest for increase of slag from 0% to 100%. So the use of slag will increase the dead load of the structure very nominal but as far as the strength is concerned the increase in dead load can be overlooked.

CONCLUSION

From the experimental investigation, the following
investigation can be drawn, the workability increases with increase in the percentage of slag as coarse aggregate in place of normal coarse aggregate. The weight of the cube increases with increase in the percentage of slag as coarse aggregate. The increase is nominal, so the concrete with slag can be used in structural works. Compressive strength increases with increase in the percentage of slag, so it is better to design compression members with it. Split tensile strength increases with increase in the percentage of slag, which can be regarded as a good sign from the durability point of view. Flexural strength of concrete with use of slag increases with increase in percentage of slag. There is no such change in the mechanical properties of hardened concrete up to 20% replacement of natural aggregate with slag.

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