UTILIZATION OF CUPOLA SLAG IN CONCRETE AS FINE AND COARSE AGGREGATE

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ABSTRACT

Nowadays waste materials are utilized in the preparation of conventional concrete. In the present work the waste material considered is cupola slag which is by-product of cast iron manufacturing. The design mix for M20 and M25 grade concretes were arrived and the target strength was found to be 26.960 N/mm² and 30.51 N/mm² respectively. Cupola slag was used in concrete as partial replacements for fine and coarse aggregates (5%, 10%, 15%, 20%, 25%, 50% and 100%) to ascertain applicability in concrete. Since the disposal of cupola slag in open area causes environment pollution, it can be recycled for use in construction industry without producing any harm to human and environment. The maximum compressive strength attained was 33.778 N/mm² and 38.222 N/mm² at 15% for both M20 and M25 grades of concrete respectively at 28 days. Similarly the maximum split tensile strength attained was 3.206 N/mm² and 3.819 N/mm² for M20 and M25 grades at 15% and 5% respectively. The concrete with cupola slag as partial replacement for coarse aggregates gives less strength when compared to fine aggregates.

Keywords: Cupola slag, compressive strength, split tensile strength

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1. INTRODUCTION

Construction activity requires several materials such as concrete, steel, brick, stone, glass, clay, mud, wood, and so on. However, the cement concrete remains the main construction material in construction industries. For its suitability and adaptability with respect to the changing environment, the concrete must be such that it can conserve resources, protect the environment, economize and lead to proper utilization of energy. To achieve this, major emphasis must be laid on the use of wastes in
concrete for new constructions. The utilization of recycled aggregate is particularly very promising as 75 per cent of concrete is made of aggregates.

The waste materials considered as aggregates are slag, power plant wastes, recycled concrete, mining and quarrying wastes, waste glass, incinerator residue, red mud, burnt clay, sawdust, foundry sand etc. The above waste materials causes serious disposal problem in urban areas.

One of the major challenges of our present society is the protection of environment. Some of the important elements in this respect are the reduction of the consumption of energy and natural raw materials and consumption of waste materials. It conserves natural resources and reduces the space required for the landfill disposal. Reuse of post-consumer wastes and industrial byproducts in concrete is necessary to produce even “greener” concrete. Greener concrete also improves air quality, minimizes solid wastes, and leads to sustainable cement and concrete industry. Research & Development activities have been taken up all over the world for proving its feasibility, economic viability and cost effectiveness.

In recent research, waste products like rick husk, saw dust, paper waste etc. has been used in concrete as partial replacements for fine and coarse aggregates. Olutoge et al. (1995) concluded that Palm kernel shell is light and therefore ideal for substitution as aggregate in the production of light weight concrete. Olanipekun et al. (2006) investigated the properties of coconut shells (CCS) and palm kernel shells (PKS) as coarse aggregates in concrete. Baricova et al. (2010) concluded that blast furnace and cupola furnace slag can be utilized in the concrete production. Ivanka Netinger et al. (2010) studied the basic characteristics of slag and analyzed the possibilities of the application of slag in road as sub surface materials. Ahmed Ebrahim et al. (2012) revealed that the mechanical characteristics, and the resistance factors were improved by adding steel slag. Lewis (2012) discussed briefly the composition, properties, and uses of iron blast furnace slag and of steel slag and concluded that it can be used for structural fills, where very high stabilities are obtained.

Based on the above literature review, in the present work cupola slag is used as partial replacements for fine and coarse aggregates in concrete in steps of 5% up to 25%. Also study was extended for 50% and 100% replacements.

2. MATERIALS USED

Cupola slag, a by-product of cast iron manufacturing is produced during the separation of the molten steel from impurities in cupola furnaces. The slag occurs as a molten liquid melt and is a complex solution of silicates and oxides that solidifies upon cooling. Virtually all iron and steel is now made in integrated iron plants using an electric arc furnace process. The open hearth furnace process is no longer used. The chemical composition of cupola furnace slag is shown in Table 1.

<table>
<thead>
<tr>
<th>Chemical composition</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>CaO</td>
<td>20-50</td>
</tr>
<tr>
<td>SiO₂</td>
<td>25-55</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>5-20</td>
</tr>
<tr>
<td>MgO</td>
<td>5-30</td>
</tr>
<tr>
<td>MnO</td>
<td>1-4</td>
</tr>
<tr>
<td>FeO</td>
<td>1-15</td>
</tr>
</tbody>
</table>
In the basic oxygen process, hot liquid blast furnace metal, scrap, and fluxes, which consist of lime (CaO) and dolomitic lime (CaMg(CO\(_3\))\(_2\)), are charged to a furnace. The cupola slag in the form of fine and coarse aggregates is shown in Fig.1. The mix proportions for M20 and M25 grades are shown in Table 2.

![Figure 1(a) Fine aggregate](image1.png) ![Figure 1(b) Coarse aggregate](image2.png)

**Table 2 Mix Proportion for M20 and M25**

<table>
<thead>
<tr>
<th>Grade of concrete</th>
<th>Cement</th>
<th>Fine aggregate</th>
<th>Coarse aggregate</th>
</tr>
</thead>
<tbody>
<tr>
<td>M20</td>
<td>1</td>
<td>1.205</td>
<td>3.245</td>
</tr>
<tr>
<td>M25</td>
<td>1</td>
<td>1.01</td>
<td>2.732</td>
</tr>
</tbody>
</table>

### 3. EXPERIMENTAL INVESTIGATION

The cube and cylinder specimens are casted and cured for 7 days and 28 days. The total number of cubes and cylinders casted are 96 each for both M20 and M25 grades. The compression and split tensile tests are carried out as detailed below.

#### 3.1. Compressive Strength

The compressive test on both conventional concrete and cupola slag concrete is carried out in accordance with IS 516-1999 standards. The test is conducted on concrete specimens of size 150mm x 150mm x 150mm. The specimen is placed at the centre of the compressive testing machine as shown in Fig 2 and the load is applied gradually till the specimen fails. The compressive strength of the specimen is calculated as follows:

\[ \text{Compressive strength} = \frac{P}{A} \ (\text{N/ mm}^2) \]

where, \( P \) – Load applied in N

\( A \) – Surface area of cube under loading in mm\(^2\)
3.2. Split Tensile Test
The test is conducted on concrete specimens of size 150 x 300mm. The cylindrical specimen is placed at the centre of the testing machine as shown in Fig.3 and the load is applied gradually till the specimen fails. The split tensile strength is found out using the following formula:

\[
\text{Split tensile strength} = \frac{2P}{\pi DL} \text{ (N/ mm}^2\text{)}
\]

where, \( P \) – Applied load in N, \( D \) – Diameter of cylinder in mm, \( L \) – Length of cylinder in mm

4. RESULTS AND DISCUSSION
The results of compressive strength and split tensile strength obtained for control and cupola slag concrete for M20 and M25 grades of concrete at 7 days and 28 days curing period are discussed in this section.
4.1. Compressive Strength

4.1.1. For Fine Aggregate Replacement

The comparison of compressive strength for M20 and M25 grade of concrete at 7 days and 28 days for fine aggregate replacements are shown in Figs. 4 and 5 respectively.

From Fig. 4, it is observed that the compressive strength for control specimen is 17.180 N/mm$^2$ and 20.430 N/mm$^2$ for M20 and M25 grades of concrete respectively. The compressive strength of concrete increases up to 25% and beyond that it decreases for both M20 and M25 grades of concrete. Fig. 5 shows that the compressive strength for control specimen is 26.960 N/mm$^2$ and 30.510 N/mm$^2$ for M20 and M25 grades of concrete respectively. The maximum value of compressive strength attained is 33.778 N/mm$^2$ and 38.222 N/mm$^2$ respectively for M20 and M25 grades at 15% replacement.
4.1.2. For Coarse Aggregate Replacement
The comparison of compressive strength for M20 and M25 grade of concrete at 7 days and 28 days for coarse aggregate replacements are shown in Figs. 6 and 7 respectively.

![Figure 6](image1)

**Figure 6** Comparison of compressive strength for M20 and M25 grades of concrete at 7 days

![Figure 7](image2)

**Figure 7** Comparison of compressive strength for M20 and M25 grades of concrete at 28 days

Fig. 6 shows that the compressive strength for control specimen is 17.180 N/mm$^2$ and 20.430 N/mm$^2$ for M20 and M25 grades of concrete respectively. The compressive strength of cupola added concrete decreases for M20 and M25 grade of concrete. From Fig. 7 it is observed that the compressive strength of control specimens is 26.960 N/mm$^2$ and 30.510 N/mm$^2$ for M20 and M25 grades of concrete respectively. The maximum value of compressive strength is 31.56 N/mm$^2$ and 25.78 N/mm$^2$ at 5% for M20 and M25 grades respectively.

4.2. Split Tensile Strength

4.2.1. For Fine Aggregate Replacement
The comparison of split tensile strength for M20 and M25 grade of concrete at 7 days and 28 days for fine aggregate replacements are shown in Figs. 8 and 9 respectively.
From Fig. 8, the split tensile strength for control specimen is 2.450 N/mm$^2$ and 2.830 N/mm$^2$ for M20 and M25 grades of concrete respectively. The split tensile strength of concrete increases when cupola slag is added up to 50% and 25% for M20 and M25 grades respectively. From Fig. 9, the split tensile strength for control specimen is 2.880 N/mm$^2$ and 3.680 N/mm$^2$ at 28 days for M20 and M25 grade of concrete respectively. The maximum value of split tensile strength attained is 3.206 N/mm$^2$ and 3.81 N/mm$^2$ at 15% and 5% for M20 and M25 grades respectively.

4.2.2. For Coarse Aggregate Replacement

The comparison of split tensile strength for M20 and M25 grade of concrete at 7 days and 28 days for coarse aggregate replacements are shown in Figs. 10 and 11 respectively.
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Figure 10 Comparison of split tensile strength for M20 and M25 grades of concrete at 7 days

From Fig. 10, the split tensile strength for control specimen is 2.450 N/mm$^2$ and 3.066 N/mm$^2$ for M20 and M25 grades of concrete respectively. The split tensile strength decreases gradually when compared to control specimens for both M20 grade and M25 grade.

Figure 11 Comparison of split tensile strength for M20 and M25 grades of concrete at 28 days

From Fig. 11, the split tensile for control specimen is 2.880 N/mm$^2$ and 3.680 N/mm$^2$ for M20 and M25 grade of concrete respectively and it decreases when cupola slag is added.

5. CONCLUSIONS
An experimental study was conducted to study the effect of cupola slag in concrete when used as partial replacement for fine and coarse aggregates. The following conclusions were drawn from the experimental studies for M20 and M25 grades of concrete.

- The maximum value of compressive strength obtained is 33.778 N/mm$^2$ and 38.222 N/mm$^2$ for M20 and M25 grades of concrete respectively when the fine aggregate is replaced by 15% cupola slag.
- The required strength of M20 concrete is achieved for 100% replacement in the case of M20 grade concrete and for 25% in the case of M25 grade concrete.
- The maximum value of compressive strength is 31.555 N/mm$^2$ for M20 grade when coarse aggregates is replaced by 5% of cupola slag, but the required strength is achieved up to 20% replacement.
The maximum value of compressive strength is 25.778 N/mm² for 5% replacement in the case of M25 grade concrete.

The maximum split tensile strength was achieved for 15% and 5% replacement of fine aggregates in the cases of M20 and M25 grades respectively. The split tensile strength gradually decreases when coarse aggregate is replaced by cupola slag in both the grades of concrete.

From the present study it is found that cupola slag when used as fine aggregate perform better than its use as coarse aggregate. The reason may be due to its mineralogical composition and size of crystals.

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