EFFECT OF CURING METHODS ON THE PROPERTY OF RED MUD BASED GEOPOLYMER MORTAR

Smita Singh
Assistant Professor, Dept. of Civil Engineering, Amrita University, Bengaluru, India

Dr. M. U. Aswath
Professor & Head, Dept. of Civil Engineering, Bangalore Institute of Technology, Bangalore, India.

Dr. R.V. Ranganath
Professor, BMS College of Engineering, Bangalore, India

ABSTRACT

The aim of this investigation is to carry out the synthesis and performance studies on both heat cured and ambient cured mortar. Compressive strength is an important aspect of hardened mortar. Along with the compressive strength, tensile strength and modulus of elasticity of mortar have been discussed. Strength of thermally cured mortar improved with molarity whereas ambient cured mortar possessed better strength at lower molarity. All mortars with 30% red mud exhibited maximum strength. Highest strength obtained was 11.8 MPa for ambient cured mortar with 30% red mud and 6M molarity. Tensile strength followed similar pattern as the compressive strength. Ambient cured mortars were found to be stiffer than the thermally cured ones.

Key words: Red Mud, Ambient Cured, Thermally Cured, Geopolymer, Tensile Strength, Compressive Strength.

1. INTRODUCTION

Geopolymerisation has opened up new avenues for the utilization of industrial wastes. Any aluminosilicate source forms a potential raw material for geopolymerisation. There has been copious studies on geopolymers synthesized with fly ash as a base material. According to past studies, the reaction between fly ash and alkaline activators is quite slow at ambient temperatures. Hence, most of such investigations have adopted thermal curing method in the production of fly ash based geopolymers [1-4].

There are other aluminosilicate industrial wastes whose potential as a geopolymer binder are yet to be established and there is ample scope for research in the field of geopolymerisation of these materials. Red mud is one such industrial waste generated as a byproduct in the extraction of alumina from bauxite through Bayer’s process. India alone produces about 14 million tons of red mud annually and it dumped in already existing inventory of red mud pond [5].

Red mud as binder possesses little pozzolanic property and has to be mixed with another pozzolanic aluminosilicate material [6]. The optimum percentage of red mud in the geopolymer binder was found to be 30% [6, 7]. The present investigation is undertaken to study the properties as a mortar and to examine the effect of curing method on its properties.

2. EXPERIMENTAL PROGRAM

Red mud was procured from Hindalco, Belgaum. The elemental composition of red mud comprises of Fe$_2$O$_3$-40%, SiO$_2$-9.9%, Al$_2$O$_3$-18.1%, Na$_2$O-5.6%, CaO-2.3%, TiO$_2$- 9%.

Particle size analysis for red mud was done with the help of laser particle size analyser, Mastersizer of Malvern Instruments having size range of 0.05 µm to 900 µm. Red mud particles are characterized by rustic colour and are extremely fine and cohesive with 90% passing 75 µm. The fineness of unprocessed red mud was obtained as 33650 m$^2$/kg whereas 39400 m$^2$/kg for the pulverized red mud. Microsilica was used along with unprocessed red mud for heat curing, whereas GGBS was blended with processed fly ash and red mud for ambient curing. Natural sand has been used as fine aggregate for the preparation of mortar. Alkaline activators sodium hydroxide (NaOH) solution and sodium silicate (Na$_2$SiO$_3$) were used instead of water. The ratio of Na$_2$SiO$_3$/NaOH/ was kept as 2.5.

Firstly the raw materials of binder which are fly ash, red mud and microsilica/GGBS were mixed in dry condition. Thereafter fine aggregate was mixed in different proportions as scheduled. Next, alkaline solution was added to the homogenous dry contituents and mixed thoroughly. After determining the workability, the mortar was casted into different moulds depending upon the type of test conducted. For compression test, the mould was a 70.6 mm cube. Briquette moulds were used for the tensile test whereas cylinders of 150 mm diameter and 300 mm height were used for determining modulus of elasticity of the mortar. Heat curing was undertaken at 60°C for 24 hrs. For ambient curing, moulds were covered and kept at room temperature and uncontrolled humidity for 7 days. Water content was fixed at 230 l/m$^3$ which resulted in a flow value of 105±5% for all the specimens.

Compressive strength was determined for both heat cured and ambient cured mortar. The test for all the cubes was conducted as per the guidelines listed in IS 2250: 1981. The results are investigated in accordance with different parameters influencing the strength. Various parameters involved in the synthesis of thermally treated and ambient cured mortar are represented in tables 1 and 2 respectively. Mortar mix used for the study for heat cured mortar in terms of binder: fine aggregate ratio was 1:3, 1:4 and 1:6 for RM10, RM30 and RM50 as binder. Molarity varied from...
Effect of Curing Methods On The Property of Red Mud Based Geopolymer Mortar

6M to 12M. For ambient cured mortar, the molarity adopted was 6M, 8M and 10M for 30% and 50% red mud with binder: fine aggregate ratio as 1:3.

Table 1 Description of parameters involved in synthesis of mortar.

<table>
<thead>
<tr>
<th>Thermally cured</th>
<th>Ambient cured</th>
</tr>
</thead>
<tbody>
<tr>
<td>10:80:10 (RM10), 30:60:10 (RM30), 50:40:10 (RM50)</td>
<td>30:60:10 (GRM30), 50:40:10 (GRM50)</td>
</tr>
<tr>
<td>Mortar proportion [binder:fine aggregate]</td>
<td>Mortar proportion [binder:fine aggregate]</td>
</tr>
<tr>
<td>1:3, 1:4, 1:6</td>
<td>1:3</td>
</tr>
<tr>
<td>NaOH concentration in terms of molarity M</td>
<td>NaOH concentration in terms of molarity M</td>
</tr>
<tr>
<td>6M, 8M, 10M, 12M</td>
<td>6M, 8M, 10M</td>
</tr>
</tbody>
</table>

3. RESULTS AND DISCUSSION

3.1. Compressive strength
The results on thermally treated paste showed an increase in strength with molarity, though there was a small difference in the strengths paste of 10M and 12M NaOH concentration. For mortars, the optimum molarity is found to be 10M for all the three percentages of red mud variation and for all mortar compositions i.e. 1:3, 1:4 and 1:6 binder to fine aggregate ratio, fig. 1. Greater molarity obstructs the leaching of aluminium and silicate ions resulting in deceleration of the geopolymerisation process. Also higher concentration of OH- ions leads to early precipitation of aluminosilicate gel, thus hindering geopolymerisation [8]. The strength of the mortar cubes varied from 1.53 Mpa to 4.66 Mpa.
As observed from fig. 2, the mortar strength initially rises with increase in red mud content in the binder and attains maximum strength at 30% red mud. A steep fall in strength is observed as the red mud percentage in the binder increases from 30% to 50%.

Increase of molarity causes a reduction in 7 day strength of ambient cured red mud based geopolymer mortar, fig. 3. The amount of silica and alumina leached attains optimization at 6M itself. Increasing the molarity further, hinders with the geopolymerisation process due to presence of excess of OH$^-$ ions. This result is contrary to the heat cured mortar that uses unprocessed red mud.

Figure 1 Variation of compressive strength with molarity for RM10, RM30 and RM50 mortar.

Figure 2 Variation of compressive strength with red mud percentage.

Figure 3 Variation of compressive strength of ambient cured mortar.
mud. Greater molarity of NaOH solution is needed for leaching optimum quantity of silica and alumina for unprocessed red mud and fly ash. Also, 30% red mud in the binder composition (GRM30) had better strength than 50% red mud (GRM50). Highest strength of 11.8 Mpa is obtained at 6M for GRM30.

Table 1 of IS 1905-1987 lists different grades of mortar and minimum compressive strengths at 28 days. The range of compressive strength in this table is between 0.5 to 10 MPa for different proportions of cement based mortar. Fig. 4 shows the comparison of permissible compressive strength of the cement mortar (CM) and red mud geopolymer mortar for binder to aggregate ratio as 1:3. The strength of mortars in the fig. 4 is for the molarity which ensued the maximum strength. For GRM30 and GRM50, 6M concentration of NaOH resulted in the maximum strength whereas for RM10, RM30 and RM50, the optimum molarity was 10M. From the fig. 4, it is observed that GRM30 exceeded the required 28 compressive strength as mentioned in IS 1905-1987.

![Compressive strength of thermally cured, ambient cured and cement mortar.](image)

### 3.2. Tensile Strength

Tensile strength test was conducted at the optimum molarity for all binders. GRM30 and GRM50 were test for 6M concentration and RM10, RM30 and RM50 at 10M NaOH concentration. Ratio of binder: fine aggregate was taken as 1:3 for all the variations. Standard briquette mould used for the test is shown in fig. 5. Typical failure pattern of the sample is illustrated in fig. 6. The results are represented table 2 and shown graphically in fig. 7 for better understanding. Tensile strength of ambient cured mortar was found to be greater than that of thermally cured. Maximum tensile strength obtained is 1.6 N/mm\(^2\) for GRM30. Ratio of compressive strength to tensile strength varied from 0.08 to 0.14 for water/binder (w/b) ratio at 0.57, as presented in table 2. Generally the tensile of cement mortar is approximately 10% of its compressive strength. Singh et al. [9] have suggested the following relationship between compressive strength and 28 days split tensile strength of all cement mortars.

\[ f_{ct} = 0.21(\sigma_c)^{0.66} \]

Where, \( f_{ct} \) = 28 day tensile strength of mortar,
\( \sigma_c \) = 28 day compressive strength.
Tensile strength for all the variations of mortar were calculated based on the above equation and compared with the experimental values. Tensile strength of thermally cured mortar were found to be same or lower than the those obtained from the empirical relationship [9] but the tensile strength of ambient cured mortar exceeded the theoretical values.

**Figure 5** Standard briquette mould.

**Figure 6** Failure pattern of specimen in tensile test

**Figure 7** Tensile strength and compressive strength of mortar.

**Table 2** Tensile strength

<table>
<thead>
<tr>
<th>SAMPLE</th>
<th>WATER/BINDER RATIO (N/MM²)</th>
<th>COMRESSIVE STRENGTH (N/MM²)</th>
<th>TENSILE STRENGTH OBTAINED (N/MM²)</th>
<th>TENSILE STRENGTH BY [9] N/MM²</th>
<th>TENSILE STRENGTH/COMPRESSIVE STRENGTH</th>
</tr>
</thead>
<tbody>
<tr>
<td>RM10</td>
<td>0.57</td>
<td>4.5</td>
<td>0.46</td>
<td>0.57</td>
<td>0.10</td>
</tr>
<tr>
<td>RM30</td>
<td></td>
<td>4.7</td>
<td>0.58</td>
<td>0.58</td>
<td>0.12</td>
</tr>
<tr>
<td>RM50</td>
<td></td>
<td>2.9</td>
<td>0.24</td>
<td>0.42</td>
<td>0.08</td>
</tr>
<tr>
<td>GRM30</td>
<td></td>
<td>11.8</td>
<td>1.6</td>
<td>1.07</td>
<td>0.14</td>
</tr>
<tr>
<td>GRM50</td>
<td></td>
<td>8.4</td>
<td>1.17</td>
<td>0.86</td>
<td>0.14</td>
</tr>
</tbody>
</table>
3.3. Modulus of Elasticity

Stress strain behavior of red mud blended with fly ash mortar with binder variation as RM10, RM30, RM50, GRM30 and GRM50 were investigated for 1:3 mortar mix. Cylinders of 150mm diameter and 300mm length were casted and cured for determining the modulus of elasticity of the mortar. The planar loading faces perpendicular to the axis were capped with rich mortar and levelled. Two struts were fixed linearly along the longitudinal axis of the cylinder 150 mm apart. A demec gauge of length 150 mm were secured against the struts to measure the longitudinal strain. A gradual compressive load was applied to the specimen. Strain was measured through demec gauge reading at regular load interval up to approximately 75% of the assessed ultimate load after which the demec gauge was removed. The compression loading was continued to be increased till the ultimate value was reached. Modulus of elasticity was obtained from the normalised stress strain graph plotted. Ambient cured mortars were found to be stiffer than the thermally cured ones.

\[
\begin{align*}
\text{Normalised stress strain curve for RM10 (1:3) mortar} & \\
\text{y} &= -204608x^2 + 1666.3x \\
R^2 &= 0.9084
\end{align*}
\]

\[
\begin{align*}
\text{Normalised stress strain curve for RM30 (1:3) mortar} & \\
\text{y} &= -869083x^2 + 2687x \\
R^2 &= 0.9123
\end{align*}
\]

\[
\begin{align*}
\text{Normalised stress strain curve for RM50 (1:3) mortar} & \\
\text{y} &= -64465x^2 + 676.13x \\
R^2 &= 0.9906
\end{align*}
\]

\[
\begin{align*}
\text{Normalised stress strain curve for GRM30 (1:3) mortar} & \\
\text{y} &= -498550x^2 + 4693.7x \\
R^2 &= 0.9893
\end{align*}
\]
4. CONCLUSION
Following conclusions could be drawn within the framework of research:

1. Addition of 30% red mud in the geopolymer mortar enhanced its strength for all binder: aggregate ratio.
2. The optimum molarity for thermally cured mortar was 10M whereas ambient cured mortar reached its maximum strength at 6M.
3. Ambient cured mortar exhibited greater stiffness and better compressive and tensile strength than the thermally cured mortar.

REFERENCES


Effect of Curing Methods On The Property of Red Mud Based Geopolymer Mortar

