COMPARISON OF PROPERTIES OF VARIOUS TYPES OF MORTARS EXPOSED TO FIRE

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ABSTRACT

Fire is the rapid exothermic oxidation process causing combustion of materials and forming various reaction products. Cement mortar is the largest amount of material that envelopes the major parts of any structures and when a fire breaks out, it acts as a thermal barrier. Usually, mortars have good fire resisting properties. But some changes in physical and chemical properties of mortar might occur when exposed to fire. This paper focuses on investigating the effects of fire on various types of mortars made with locally available slag fine aggregate, river sand, brick fine aggregate and coarse sand. After burning, the effects of air cooling and water cooling are also compared. The study covers four types of mortars each with three different water-cement ratios. The mortar samples were burned in open fire for two hours. An equal number of samples were cooled in air and water after burning. Compressive Strengths according to ASTM C109 and Flexural Strengths according to ASTM C348 were evaluated for comparing the loss of strength due to fire exposure. Moreover, the changes in their properties due to the variation of the cooling process were also investigated.

Introduction

One of the most important factors that influence the durability of any structure is its resistance to fire on higher temperature (Shoaib, 2001). When a fire breaks out, the first construction material that comes in contact with fire is cement mortar. By choosing cement mortar made of appropriate material, it is possible to minimize the adverse effects of fire (Aydin, 2008). Both in concrete and cement mortar the aggregate expands on heating while the cement paste shrinks beyond the point of maximum expansion and these two opposing actions weaken the material causing cracks in concrete or cement mortar (Lea, 1998). The behavior of concrete or mortar on heating depends mainly on the types of aggregate used in it (Poon, 2001). Siliceous aggregate containing quartz such as quartz sand expands steadily up-to 573°C. At this temperature, α-quartz transforms into β-quartz and undergoes sudden expansion and causes disruptive action in concrete (Taylor, 1990). On the other hand, sandstone shrinks on heating and counteracts with the expansion of the other grains resulting in higher loss of strength (Ghosh, 1983). No crystalline basic material like limestone, basic igneous rocks, and lightweight aggregates like crushed bricks and induction furnace slag expands steadily and have low thermal conductivity. Therefore, performs as a good fire-resistant aggregate (Mehta, 1997). Hydrated Portland cement contains a higher amount of Ca(OH)₂ which loses its water above 400-500°C leaving CaO. If this CaO (quick lime) becomes wetted, again it hydrates back to Ca(OH)₂ accompanied by an expansion in volume (Ramachandran, 1969).

Methodology

Comparison of compressive and flexural strength of four different types of mortar with each of them having three different water-cement ratios under normal condition (unburnt condition) and under fire exposure condition was made. Four different types of mortars were made using locally available induction furnace slag fine aggregate (Slag fine aggregate), river sand, fine aggregate from burnt clay brick and coarse sand. Water-cement ratios of 0.4, 0.5 and 0.6 were used for all of them. Compressive strength tests were conducted on 50 mm cube specimens following ASTM C109 and flexural strength tests were conducted on 4 cm x 4 cm x 16 cm prism specimens following ASTM C348 after 28 days of curing. The mortar samples were burned in open fire for two hours. 72 number of samples were cooled with water after burning and 72 number of samples were kept in normal atmospheric condition for cooling after burning. The test was conducted under control temperature. The temperature was continuously measured with the help of Infrared Thermometer and the temperature was controlled through a continuous supply of wood and kerosene as fuel. The process of burning during

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the mortar samples is illustrated in Figure 1.

![Figure 1. Burning of cement mortar samples under controlled temperature.](image)

The temperature development with time is shown in Figure 2.

![Figure 2. Temperature development with time](chart)

**Compressive Strength Test on Mortar**

Compressive strength test was determined using standard procedure ASTM C109 and was represented to nearest 0.1 MPa.

**Flexural Strength Test on Mortar**

The test was conducted according to ASTM C348. The test procedure is demonstrated in Figure 3.

![Figure 3. The test procedure for determining the flexural strength of cement mortars. (a) Test setup, (b) Samples after testing](images)
Flexural strength was determined following ASTM C348 and by using Eq. 2 and was represented to nearest 0.1 MPa.

\[ S_f = 0.0028P \]  

Where, \( S_f \) = Flexural strength (in MPa)

\( P \) = Total maximum calibrated load (in N)

**Properties of Fine Aggregates Used in Various Mortars**

Various engineering properties of four different kinds of fine aggregates used in four different types of cement mortars are presented in Table 1.

| Test parameters                        | Standard Test Method | Obtained Values | | | |
|----------------------------------------|----------------------|-----------------|-----------------|-----------------|-----------------|-----------------|-------------------|
| Unit Weight (Bulk Density)             | ASTM C29             | 1630 Kg/m³      | 1310 Kg/m³      | 1540 Kg/m³      | 1450 Kg/m³      |
| Voids in Aggregates (Compacted by Rodding) | ASTM C29             | 40%             | 34%             | 40%             | 38%             |
| Bulk Specific Gravity (OD)             | ASTM C128            | 2.74            | 1.95            | 2.59            | 2.50            |
| Water Absorption Capacity              | ASTM C128            | 3.90%           | 16.50%          | 1.00%           | 0.60%           |
| Gradation of Aggregates (FM)          | ASTM C136            | 3.64            | 3.44            | 3.07            | 1.20            |

All the fine aggregates were passing on number 4 standard sieve size (4.75 mm) and retained on number 200 standard sieve size (0.075 mm).

**Results and Discussions**

The summary of test results is presented in Table 2.

<table>
<thead>
<tr>
<th>Aggregate Type</th>
<th>W/C</th>
<th>Compressive Strength (MPa) After burning</th>
<th>Flexural Strength (MPa) After burning</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Normal Sample (unburnt)</td>
<td>Water Cooled Sample</td>
</tr>
<tr>
<td>Coarse Sand</td>
<td>0.4</td>
<td>42.6</td>
<td>33.1</td>
</tr>
<tr>
<td></td>
<td>0.5</td>
<td>40.8</td>
<td>27.7</td>
</tr>
<tr>
<td></td>
<td>0.6</td>
<td>36.9</td>
<td>18.6</td>
</tr>
<tr>
<td>River Sand</td>
<td>0.4</td>
<td>24.6</td>
<td>22.1</td>
</tr>
<tr>
<td></td>
<td>0.5</td>
<td>22.8</td>
<td>18.6</td>
</tr>
<tr>
<td></td>
<td>0.6</td>
<td>21.9</td>
<td>11.6</td>
</tr>
<tr>
<td>Brick Fine</td>
<td>0.4</td>
<td>35.8</td>
<td>32.8</td>
</tr>
<tr>
<td></td>
<td>0.5</td>
<td>25.3</td>
<td>24.5</td>
</tr>
<tr>
<td></td>
<td>0.6</td>
<td>23.8</td>
<td>15.6</td>
</tr>
<tr>
<td>Slag Fine</td>
<td>0.4</td>
<td>44.5</td>
<td>31.4</td>
</tr>
<tr>
<td></td>
<td>0.5</td>
<td>36.4</td>
<td>24.7</td>
</tr>
<tr>
<td></td>
<td>0.6</td>
<td>34.6</td>
<td>18.9</td>
</tr>
</tbody>
</table>
The results show that significant strength (50%-80% compressive and 70%-95% flexural strength) was lost for all four types of mortar when they were exposed to fire up to a temperature of 510°C for 2 hours. However, the strength (30%-40% compressive and 50%-60% flexural strength) was regained to a large extent when the mortars were cooled using water. This is illustrated in Figure 4 and Figure 5.

Figure 4. Variation of compressive strength with water-cement ratio for different types of mortars under different conditions.

Figure 5. Variation of flexural strength with the water-cement ratio for different types of mortars under different conditions.
From the above figures, it can be seen that mortars made of coarse sand and river sand showed a remarkable reduction of strength (70%-80% compressive and 85%-95% flexural strength) when exposed to fire than mortars made of slag fine and brick fine aggregate (50%-55% compressive and 70%-80% flexural strength). Besides, the regaining of strengths (35%-40% compressive and 55%-60% flexural strength) in contact with water was also remarkable for mortars made of coarse sand and river sand. Whereas, the difference of strength under various conditions was less remarkable for mortars made of slag fine and brick fine aggregate. The performance of different types of cement mortars as a thermal barrier during a fire incident largely depends on its thermal conductivity. Mortars made of slag fine and brick fine had a lower thermal conductivity (0.38 to 0.48 W m$^{-1}$ K$^{-1}$) compare to mortars made of river sand and coarse sand (0.60 to 0.65 W m$^{-1}$ K$^{-1}$) and that’s why mortar made of slag fine and brick fine showed better performance.

Conclusions

This paper investigated the behavior of four different kinds of mortar exposed to fire up to $510^\circ$ C for 2 hours and the effects of two different kinds of cooling process on their structural properties. The study also found that all the four types of mortars lost a significant level of strength (50%-80% compressive and 80%-95% flexural strength) when the samples were kept in normal atmospheric condition for cooling after burning. On the other hand, if the samples were cooled with water after burning it lost less strength. But it was still lower (20%-30%) than its normal strength. However, mortars made of slag fine aggregate and brick fine aggregate showed better performance than two other types of mortars (river sand and coarse sand) in case of exposure to fire. On the contrary, mortar made of river sand and coarse sand showed the worst performance in case of exposure to fire. Cement mortars are normally used as plaster and its contribution as a thermal barrier is usually neglected. As mortars made of slag fine and brick fine showed better performance after 2 hours burning in open fire with less reduction of strength, it can be concluded that using mortars made of slag fine and brick fine aggregate can ensure additional 2 hours fire rating to the RC structure. Under fire condition, cement mortar acts as a thermal barrier. Cement mortars don’t add any strength to structural members but in order to act as an efficient thermal barrier, its own strength is necessary and that’s why if a fire breaks out, it must be cooled with water for better strength gain of mortar. Choosing the right type of cement mortar can ensure improving the fire ratings of the structural members and better safety against fire.

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References

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