Effect of Volcanic Tuff on the Concrete

Compressive Strength

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Abstract

Volcanic tuff is a local material that is available at different locations in Jordan. Three different types of this material (known as yellow, grey and brown volcanic tuff) were used in this study. A comprehensive experimental investigation was conducted to assess the effect of volcanic tuff, as a fine aggregate, on the concrete compressive strength. The experimental program consisted of testing 14 standard cubes with zero percent volcanic tuff, and 220 standard cubes containing tuff of different percentages ranging from 10 to 80%. Four grades of concrete strengths were selected (20, 30, 40, and 50 MPa). The data from the experiments were analyzed to determine the optimal percentage of volcanic tuff that could be used in concrete mixes. The analysis showed that replacing the fine aggregate by 20% volcanic tuff will improve the concrete compressive strength by 10% for brown and grey tuff and 15% for yellow tuff.

Keywords: Volcanic Tuff, Concrete Compressive Strength

Introduction

Concrete was first adopted as a structural material during the nineteenth century; compressive strength was perhaps the only criterion in the proportioning of a concrete mix.

The concepts of workability, durability and other factors influencing the mix proportions, as they are understood now are of comparatively recent origin. The role of mixing water was not clearly understood except in so far as it helped concrete to become plastic for easy compaction.

It was also realized that use of aggregates having less voids resulted in stronger concrete. Some of the earlier mix design methods are based on the principles of minimum voids and maximum density.

Good or bad concrete is made from the same discrete materials like, grains of sand, gravel or pieces of crushed rock and the innumerable fine particles of cement powder mixed
with water. Ever since the time of Romans, there has been a continuous effort by research workers in the field of cement and concrete technology to produce better cements which resulting more improved quality in concrete. In the beginning of 20th century, reinforced concrete used as an alternative to steel construction, which lead to the need of development and use of low and medium strength concrete’s.[1,3,4]

Recent developments in the field of concrete mix design indicated the possibility to produce ultra-high strength concrete, which has any desired 28 day cube compressive strength reaching 100 MPa, without recourse to unusual material or processing and without incurring any significant technical difficulties. The fundamental requirement of a concrete mix, that it should be satisfactory fresh as well as hardened state, possessing certain minimum desirable properties like workability strength and durability. Besides these requirements it is essential that the concrete mix is prepared as economically as possible by using the least possible amount of cement content per unit volume of concrete, with due regard to the strength and durability requirements. Since mixing several discrete materials produces concrete, the numbers of variables governing the choice of mix proportions are necessarily large. Moreover since no researches found about Natural Volcanic Tuff is using in concrete.[7,9]

This research work in field to identify the significant parameters controlling the proportions of ingredients in the mix by using proportion of Natural Volcanic Tuff in concrete to study the effects of these materials on the concrete strength. That shows impressive results in case of study by increasing strength, lowering cost, and environmental profit.

Pozzolan (Volcanic Tuff)

Pozzolan is a siliceous or siliceous/aluminous material which, when mixed with lime and water, forms cementations compounds. Natural pozzolan are found in many parts of the world and have been used in concrete for over 2,300 years. Fly ash is a processed pozzolan, meaning it is a derivative of coal used as fuel, and has very similar qualities as natural pozzolan. Natural Pozzolan is a finely-divided material that reacts with calcium hydroxide and alkali’s to form compounds possessing cementations properties. Pozzolan are present on earth’s surface such as diatomaceous earth, volcanic ash, opaline shale, pumice, and tuff. These materials require further processing such as calcimine, grinding, drying, etc., volcanic tuffs and pumice, are found principally in east and south regions in Jordan. Natural pozzolan have been used in dams and bridges to lower the heat of hydration and increase resistance of concrete to sulfate attack and control the alkali-silica reaction. Usually the pozzolan deposit must be in the vicinity of the project to support mining and processing costs. The chemical-mineralogical composition of the pozzolan materials is presented in Table 1.[5,6,10]

<table>
<thead>
<tr>
<th>Designation of sample</th>
<th>Yellow Pozzolan</th>
<th>Grey Pozzolan</th>
<th>Brown Pozzolan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pozzolan sample location</td>
<td>Tal Rimah*</td>
<td></td>
<td>Jabl Ata’a’tah*</td>
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<tr>
<td>Chemical composition</td>
<td></td>
<td></td>
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</table>
Effect of volcanic tuff

<table>
<thead>
<tr>
<th>L.O.I.</th>
<th>14.9</th>
<th>4.30</th>
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<tbody>
<tr>
<td>SiO₂</td>
<td>39.0</td>
<td>43.50</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>13.0</td>
<td>14.10</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>11.4</td>
<td>12.30</td>
</tr>
<tr>
<td>CaO</td>
<td>8.70</td>
<td>8.30</td>
</tr>
<tr>
<td>MgO</td>
<td>8.70</td>
<td>10.40</td>
</tr>
<tr>
<td>SO₃</td>
<td>0.02</td>
<td>0.06</td>
</tr>
<tr>
<td>K₂O</td>
<td>1.80</td>
<td>1.50</td>
</tr>
<tr>
<td>Na₂O</td>
<td>0.30</td>
<td>2.00</td>
</tr>
<tr>
<td>TiO₂</td>
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<td>2.30</td>
</tr>
<tr>
<td>Mn₂O₃</td>
<td>0.10</td>
<td>0.11</td>
</tr>
<tr>
<td>P₂O₅</td>
<td>0.35</td>
<td>0.45</td>
</tr>
<tr>
<td>CP</td>
<td>0.01</td>
<td>0.03</td>
</tr>
<tr>
<td>Total</td>
<td>100.58</td>
<td>99.35</td>
</tr>
<tr>
<td>CO₂</td>
<td>3.17</td>
<td>0.66</td>
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</table>

**Mineralogical Composition**

<table>
<thead>
<tr>
<th>Minerals of primary origin</th>
<th></th>
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<tbody>
<tr>
<td>- Plagioclase</td>
<td>≤ 5</td>
</tr>
<tr>
<td>- Olivine</td>
<td>5 - 10</td>
</tr>
<tr>
<td>- Pyroxene</td>
<td>≤ 5</td>
</tr>
<tr>
<td>- Magnetite / Limonite</td>
<td>5 - 10</td>
</tr>
<tr>
<td>- Glassy phase</td>
<td>30 - 40</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Minerals of secondary origin</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>- Calcite</td>
<td>10</td>
</tr>
<tr>
<td>- Chabazite + Mg-Phillipsite</td>
<td>-30</td>
</tr>
</tbody>
</table>

* Theses are names of regions in Jordan that are rich of natural pozzolan

In this research, volcanic tuff (pozzolan) materials brought from dear Al-Kahf and Al-Rashadia were used as additives in the mix design. Three types of volcanic tuff are used in this study. These types are classified based on its color and known as brown, yellow and grey volcanic tuff. The necessary tests were conducted on these materials.[7,8,9]

**Results and discussion**

The results of last tests are shown in Table 2.

**Table 2: Specific gravity (S₇) test for the volcanic tuff according to ASTM: C-128**

<table>
<thead>
<tr>
<th>Specific gravity (S₇)</th>
<th>Brown</th>
<th>Yellow</th>
<th>Grey</th>
</tr>
</thead>
<tbody>
<tr>
<td>S₇ Oven Dried</td>
<td>1.64</td>
<td>1.84</td>
<td>1.99</td>
</tr>
<tr>
<td>S₇ Bulk</td>
<td>2.05</td>
<td>2.16</td>
<td>2.21</td>
</tr>
</tbody>
</table>
Depending on the mix proportions obtained from the mix design tables, concrete cubes were made with dimensions \((15 \times 15 \times 15) \text{ cm}\), and a compaction rod 25 mm in diameter, 31 cm length, and weigh 1.8 kg. Usually the ASTM specifications requires to make \((6)\) cubes, three of them to be test after \((7)\) days, and the rest of them to be test after \((28)\) days to gain the required compressive strength. The priorities of the project was to know the effects of the volcanic tuff on the concrete mixes, so only four cubes was made for each grade, one was tested at \((7)\) days and three cubes at \((28)\) days. The following tables and figures show the results of cubes tested after 7 and 28 days.

### Mix design

<table>
<thead>
<tr>
<th>S(_G) Apparent</th>
<th>2.79</th>
<th>2.72</th>
<th>2.55</th>
</tr>
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<tbody>
<tr>
<td>Absorption %</td>
<td>25.09</td>
<td>17.65</td>
<td>11.06</td>
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</table>

**Figure 1:** Relation between % of volcanic tuff and strength
Effect of volcanic tuff

Figure 2: Relation between % of volcanic tuff and strength

Figure 3: Relation between % of volcanic tuff and strength
Figure 4: Relation between % of volcanic tuff and strength

Figure 5: Yellow tuff relations for shown grades
Effect of volcanic tuff

Figure 6: Gray tuff relations for shown grades

Figure 7: Brown tuff relations for shown grades
Table 3: Summary of results for cubes test and the percentage effect of brown volcanic tuff

<table>
<thead>
<tr>
<th>Grade (MPa)</th>
<th>Additional tuff %</th>
<th>Strength (MPa)</th>
<th>% increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>20.6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>20.6</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>24.0</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>24.3</td>
<td>15.2</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>20.1</td>
<td>-2.4</td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>17.7</td>
<td>-14</td>
<td></td>
</tr>
<tr>
<td>33.8</td>
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<tr>
<td>0</td>
<td>33.8</td>
<td>0</td>
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<td>10</td>
<td>36.2</td>
<td>6.62</td>
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<td>20</td>
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<td>333</td>
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<td>272</td>
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<td></td>
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<tr>
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<td>436</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>338</td>
<td>-14.2</td>
<td></td>
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<tr>
<td>20</td>
<td>450</td>
<td>3.21</td>
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<td>30</td>
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<td>286</td>
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<tr>
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<td>523</td>
<td>4.2</td>
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<tr>
<td>20</td>
<td>564</td>
<td>11.1</td>
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<td>30</td>
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<tr>
<td>40</td>
<td>363</td>
<td>-38</td>
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</table>
Table 4: Summary of results for cubes test and the percentage effect of gray volcanic tuff in strength.

<table>
<thead>
<tr>
<th>Grade</th>
<th>Additional tuff %</th>
<th>Strength</th>
<th>% increase</th>
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<td>206</td>
<td>0</td>
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<td>10</td>
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<td>20</td>
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<td></td>
<td>40</td>
<td>187</td>
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<tr>
<td></td>
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<tr>
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<td>10</td>
<td>325</td>
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<td></td>
<td>50</td>
<td>398</td>
<td>-20.56</td>
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</tbody>
</table>
Table 5: Summary of results for cubes test and the percentage effect of yellow volcanic tuff in strength.

<table>
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<tr>
<th>Grade</th>
<th>Additional tuff %</th>
<th>Strength</th>
<th>% increase</th>
</tr>
</thead>
<tbody>
<tr>
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<td>206</td>
<td>0</td>
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<td>207</td>
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<tr>
<td></td>
<td>70</td>
<td>423</td>
<td>-15.57</td>
</tr>
</tbody>
</table>
Effect of volcanic tuff

\[
\% \text{ of increase} = \frac{\text{Strength after adding tuff} - \text{Strength at zero tuff}}{\text{Strength at zero tuff}} \times 100
\]

CONCLUSIONS

After the work is done, the results of the three additive materials (Brown, Yellow, Gray) are shown in tables (3, 4 and 5) respectively.

From observations, the cubic strength has been increased from (10 – 19.9) % at 20 % of the additive materials, and after this percentage the cubic strength has been decreased for all gradations for all additive materials.

The behavior of the additive materials during mixing:

1. For the Brown material, there was a difficulty in the workability at 20 % of the additive material.
2. For the Grey material, there was a difficulty in the workability at 30 % of the additive material.
3. For the Yellow material, there was a difficulty in the workability at 30 % of the additive material.

The reasons for why the cubic strength has been decreased after adding 20 % of the additive materials.

1. The absorption percentages for the volcanic tuffs as follows:
   - Brown material = 25.1 %
   - Grey material = 11.1 %
   - Yellow material = 17.7 %

2. Super plasticizer (Conplast 432 MS*) was used to improve the workability without increasing the percentages of water.

Why the strength increased after adding 20 % of volcanic tuff instead of Wadi sand?

It's known that the pozzolan materials react with water to have cementic properties, despite of this material absorb part of W/C ratio, the W/C ratio still optimum.

The strength obtained from the volcanic materials (which became cementic); besides the cement strength will increase the total strength for the mix design.

Why the strength decreased at a percentage greater than 20%?
At a percentage greater than 20%, the volcanic tuff materials have a high absorption ratio and it will decrease W/C ratio needed for reaction (bad workability) which affects the strength of mixes.

References


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