ALKALI-ACTIVATED FLY ASH CONCRETE (CONCRETE WITHOUT CEMENT)

Miroslav Mikoč, Ivan Bjelobrk, Josip Korajac

In this work, alkali-activated fly ash was used as a binder instead of Portland cement at the preparation of concrete. Sodium hydroxide and water glass were used as alkali activators. Fractions of natural aggregate of 0-4 mm, 4-8 mm and 8-16 mm were replaced by air-cooled granulated steel slag fraction of 4-8 mm and 8-16 mm and the fraction of river sand was replaced with silica fume. The obtained samples were cured at 2 different temperatures. The first was cured at room temperature and the other was steam-cured for 8 hours and left at room temperature until the tested date. The compressive strength test was investigated by using cube samples 150 x 150 x 150 mm after 3 and 28 days. The results of the present work have shown that low-calcium fly ash-based geopolymer concrete can substitute the use of Portland cement in concrete.

Keywords: fly ash, geopolymer, silica fume, slag, sodium hydroxide, water glass

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According to Glukhovsky [4] the first steps consist of a breakdown of the covalent bonds Si-O-Si and Al-O-Si which happens when the pH of the alkaline solution raises, so those groups are transformed in a colloid phase. Then an accumulation of the destroyed products occurs, which interacts among them to form a coagulated structure, leading in a third phase to the generation of a condensed structure. The empirical formula of geopolymer is:

\[ M_n\left[(-SiO_2)_z-AlO_2\right]_n \cdot wH_2O \]

where

- \( M \) is monovalent cation, usually an alkali (K⁺, Na⁺)
- \( n \) is the degree of polycondensation
- \( z \) is (the \( \frac{SiO_2}{Al_2O_3} \) ratio) = 1, 2 or 3
- \( z \) can also be larger than 3, up to 32.

Figure 1 Geopolymer structure

Slika 1. Struktura geopolimera
The inorganic polymer network is in general a highly-coordinated 3-dimensional aluminosilicate gel, with the negative charges on tetrahedral Al(III) sites charge-balanced by alkali metal cations (Fig. 1).

Geopolymers possess excellent physico-chemical and mechanical properties, including low density, micro-porosity, negligible shrinkage, high strength, great surface hardness and significant thermal stability, fire and chemical resistance [5, 6, 7, 8].

2 Experimental program
Eksperimentalni dio

2.1 Materials
Materijali

The fly ash with specific surface area of 0.29 m$^2$/g from the Tuzla Thermal Power Station was used as the binder instead of Portland cement.

Due to the relatively low calcium content, this fly ash should be classified as Class F according to the ASTM C 618 definitions [9].

The sodium hydroxide in the form of tiny granules with 98 % purity and water glass (Na$_2$O = 14.7 %, SiO$_2$ = 29.4 % and H$_2$O = 55.9 %) were used as alkali activators.

For the preparation of the MIX 1 were used fractions of the natural gravel of 0-4 mm, 4-8 mm, 8-16 mm and river sand. In the MIX 2 fractions of the river sand have been replaced with granulated air-cooled steel slag fractions of 4-8 mm and 8-16 mm from the steel production in Split. In the MIX 3 fractions of the natural gravel have been replaced with silica fume produced by Elkem in Norway.

The chemical compositions of the fly ash, slag, and silica fume are shown in Tab. 1.

<table>
<thead>
<tr>
<th>Components</th>
<th>Fly ash, mass %</th>
<th>Slag, mass %</th>
<th>Silica fume, mass %</th>
</tr>
</thead>
<tbody>
<tr>
<td>CaO</td>
<td>5.29</td>
<td>31.52</td>
<td>2.55</td>
</tr>
<tr>
<td>SiO$_2$</td>
<td>55.80</td>
<td>14.24</td>
<td>91.50</td>
</tr>
<tr>
<td>Al$_2$O$_3$</td>
<td>19.20</td>
<td>7.40</td>
<td>1.75</td>
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<tr>
<td>Fe$_2$O$_3$</td>
<td>8.85</td>
<td>25.74</td>
<td>-</td>
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<tr>
<td>MgO</td>
<td>2.88</td>
<td>7.42</td>
<td>1.00</td>
</tr>
<tr>
<td>MnO</td>
<td>-</td>
<td>3.80</td>
<td>-</td>
</tr>
<tr>
<td>SO$_3$</td>
<td>-</td>
<td>0.44</td>
<td>-</td>
</tr>
<tr>
<td>Na$_2$O</td>
<td>2.00</td>
<td>0.13</td>
<td>0.85</td>
</tr>
<tr>
<td>K$_2$O</td>
<td>0.26</td>
<td>0.08</td>
<td>0.70</td>
</tr>
<tr>
<td>LOI</td>
<td>5.60</td>
<td>4.71</td>
<td>1.60</td>
</tr>
<tr>
<td>Total</td>
<td>99.88</td>
<td>95.48</td>
<td>99.85</td>
</tr>
<tr>
<td>Density, kg/m$^3$</td>
<td>1910</td>
<td>3410</td>
<td>2210</td>
</tr>
<tr>
<td>Blaine, m$^2$/kg</td>
<td>2930.00</td>
<td>11334.00</td>
<td></td>
</tr>
</tbody>
</table>

2.2 Designing of composition samples
Projektiranje sastava uzoraka

Geopolymer concrete can be manufactured by adopting the conventional techniques used in the manufacture of Portland cement concrete.

The obtained results of investigation of compressive strength of prepared 3-mixtures of geopolymer concrete are shown in Tab. 3 and presented by diagram in Fig. 2.

The influence of chemical ratios SiO$_2$/Al$_2$O$_3$ on the compressive strength of geopolymer concrete is shown in Fig. 3.

Geopolymers possess excellent physico-chemical and mechanical properties, including low density, micro-porosity, negligible shrinkage, high strength, great surface hardness and significant thermal stability, fire and chemical resistance [5, 6, 7, 8].

Assuming that the density of concrete is 2400 kg/m$^3$ and mass fraction of aggregate 77 % of the mass of concrete, the total mass fraction of aggregates in concrete is:

$$0.77 \times 2400 \text{ kg/m}^3 = 1848 \text{ kg/m}^3.$$  

Mass of individual fractions of aggregate is:

- 15 % aggregate, fraction 8-16 mm: 277 kg
- 20 % aggregate, fraction 4-8 mm: 370 kg
- 35 % aggregate, fraction 0-4 mm: 647 kg
- 30 % sand: 554 kg

Total:

$1848 \text{ kg}$

The mass of fly ash and alkaline solution is:

$2400 - 1848 = 552 \text{ kg/m}^3$.

The ratio of mass alkaline solution and fly ash is 0.35, so the mass of fly ash is

$\frac{552}{1+0.35} = 408 \text{ kg/m}^3$.

and the mass of alkaline solution is:

$552 - 408 = 144 \text{ kg/m}^3$.

The water glass to sodium hydroxide mass ratio was fixed as 2,5 and the mass of sodium hydroxide solution is

$\frac{144}{1+2.5} = 41 \text{ kg/m}^3$,

and the mass of water glass is:

$144 - 41 = 103 \text{ kg/m}^3$.

Mass fractions of components for the four concrete cubes volume 13.5 dm$^3$ (1.5 × 1.5 × 1.5 dm × 4) are shown in Tab. 2. The concentration of 18 M sodium hydroxide was prepared by mixing of tiny granules with water.

3 Results and discussion
Rezultati i rasprava

The obtained results of investigation of compressive strength of prepared 3-mixtures of geopolymer concrete are shown in Tab. 3 and presented by diagram in Fig. 2.

The influence of chemical ratios SiO$_2$/Al$_2$O$_3$ on the compressive strength of geopolymer concrete is shown in Tab. 4.

Each chemical ratio is calculated from both solid and liquid parts of the paste. For example, SiO$_2$ for MIX 2 was obtained from fly ash, slag and water glass.
Samples of MIX 1 with a fraction of natural aggregate and mass ratio of silica to alumina of 3.3 had a low compressive strength after 3 and 28 days cured at room temperature. Samples of MIX 1 which were steam-cured for 8 hours then left at room temperature had also low compressive strength after 3 and 28 days.

Samples of MIX 2 with the mass ratio of silica to alumina of 2.5 in which the fraction of natural aggregate was replaced with fraction of slag had good compressive strength after 3 and 28 days cured at room temperature. Samples of MIX 2 which were steam-cured for 8 hours then left at room temperature had a very high compressive strength after 3 and 28 days.

Samples of MIX 3 where the fraction of natural aggregate was replaced by fraction of slag and sand fraction of silica fume, with mass ratio of silica to alumina of 5.2 had good compressive strength after 3 and 28 days curing at room temperature.

Samples of MIX 3 which were steam-cured for 8 hours then left at room temperature had a high compressive strength after 3 and 28 days.

4 Conclusions

Zaključci

1) MIX 1 exhibited very low compressive strength and it is not suitable for use as concrete.
2) With a double alkali activation of fly ash and granulated slag in the MIX 2 excellent compressive strength has been achieved after 3 and 28 days (Fig. 2). MIX 2 has the potential to replace Portland cement in concrete.
3) Higher steam-cured temperature significantly affects the early strength of geopolymer concrete more than that of the late strength.
5

References

Literatura


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