Study of deformation properties of alkali activated concretes using active aggregates

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Abstract. Results of study of deformation properties of fine-grain concrete are shown using slag alkali activated cement and active aggregate. It had been shown that expansion deformations of specimens, supplying process of alkaline corrosion of aggregate in concrete, directly combined with component composition and conditions of hardening of material. It was shown that using alkaline component in the state of dry salt shrinkage deformations are varying in the shorter ranges comparing to concrete with the soluble glass. Introduction of active mineral admixture leads to the decreasing of deformations comparing to the compositions without admixture. Different conditions of hardening of the specimens are also influence well on the development of shrinkage deformations. It is shown that drying of specimens with active process of alkaline corrosion of concrete makes it possible to stop development of expansion deformations in concrete. Hydrophobization of the dried specimens make it possible to store linear characteristics of specimens. Hydrophobization of without drying leads to the intensification of structure formation processes and higher rates of development of deformations. Traditional method of protection of concrete constructions (covering by painting materials) is not able to prevent, but also possible to activate development of destructive processes of alkaline corrosion of concrete.

1. Introduction
The problem of use aggregates containing active grains is a target of studies of different scientists all over the world for a various years [1-5]. Today this problem rises sharper because of replacements of gas fuel in the cement production by coal, resulting in rising of specific content of alkalis in the cement. In general, cements are meeting requirement of standards by alkalis content [6-8], but increasing of their specific content is dangerous because of possibility of alkaline corrosion of aggregates in concrete [9-11].

Modern production is oriented on constant search of cheaper materials and reducing of materials costs [12-14]. Some time it can be realized by replacement of aggregated by other, cheaper materials. But quality assurance during such replacement is providing not every time in the satisfied level – only a few characteristics are verifying, like crashing, frost resistance, compressive strength, fraction of aggregates, and presence of needle-like grains and so on. However, such cheap aggregated also can content active grains that limit their application. Combining of two factors – higher alkalis content in the cement and presence of active grains in the aggregate composition leads to the risk of development of destructive processes in the hardened concrete body – alkaline corrosion of concrete [15].

It is well-known possibility to prevent development of alkaline corrosion of concrete by modifying of concrete mix by active mineral admixtures [16-18], which are rich on active silica that makes it possible to change destructive gain of the process on constructive and also shift this processes in time. But such modification have to be done on the stage of concrete mix design and there are have to be information about presence of active grains in the aggregate composition that is impossible because of underlined higher. Moreover, introduction of such active mineral admixtures as a partial cement replacement could provide some strength drop [19-22].
From the point of view of exploitation of constructions under influence of alkaline corrosion of concrete, today is only one solution proposed – construction has to be destroyed and rebuilt. Such approach is very financial- and source demanding and needs a lot of time and logistic sources (for example, in the USA the Hoover Dum had been totally reconstructed).

From the rationality of repairing work point of view, it is interesting to study possibility to stop the destructive process in the concrete and provide possibility to repair existing constructions with alkaline corrosion processes. The previous works shows possibility to stop strength development, making it possible to predict possibility to regulate structure formation processes in the destined direct [23-26]. However, the most actual question is possibility to stop expansion deformations in material.

The aim of the study is determination of regulations of influence of alkali activated cement mix design (type and characteristics of alkaline component and alumina silicate component) and hardening and storing conditions on deformation properties of fine grain concretes on their basis using active aggregate.

2. Materials and test methods
For investigation of possibility to influence on internal corrosion of alkali activated concrete gain the basalt rock was chosen as an active aggregate. The aggregate, taking into account results of previous studies [27-29] was represented by the fraction 0-2.5 mm. Chemical composition of basalt rock is given in Table 1.

| Oxides content, % by mass | Mass loses, % | Basalt |
|---------------------------|---------------|--------|
| SiO₂ | Al₂O₃ | Fe₂O₃ | FeO | TiO₂ | MnO | CaO | MgO | P₂O₅ | K₂O | Na₂O | SO₃ |
| 50.42 | 14.0 | 6.14 | 8.37 | 2.66 | 0.243 | 8.04 | 5.56 | 0.316 | 0.71 | 2.27 | 0.07 | 0.77 | 99.57 |

As main calcium - alumina silicate component of alkali activated cement was chosen granulated blast furnace slag (Kamenske, Ukraine), ground to the specific surface 450±20 m²/kg by Blaine. Chemical composition of the slag is given in Table 2.

| Oxides content, % by mass | GGBS | Mo |
|---------------------------|------|----|
| SiO₂ | Al₂O₃ | CaO | MgO | MnO | TiO₂ |
| 37.90 | 6.85 | 44.6 | 5.21 | 0.106 | 0.35 |

As a hydrophobization agent was used admixture on the basis of silicon hydro siloxane liquid 136-157M, produced by «ANTALCOM» ltd.
As an active mineral admixture was used metakaolin from Glukhovetsky factory, ground to the specific surface 1000 m²/kg by Blaine.
As alkaline components were used sodium carbonate (soda ash) in the state of dry salt and soluble glass with silicate modulus Mₕ=1,0, obtained by correlation of modulus of initial product – soluble glass with Mₕ=2,96. Characteristics of initial high-modulus soluble glass are given in Table 3.

| Initial density of soluble glass, kg/m³ | Oxides content, % by mass in liquid state |
|----------------------------------------|-----------------------------------------|
| SiO₂ | R₂O₃ | Na₂O | CaO |
| 1400 | 2.96 | 28.5 | 0.19 | 9.37 | 0.15 |

As a reference material and also as an alumina silicate component of alkali activated cements was taken OPC Grade 42.5 manufactured by PAT “Volyncement”. Chemical-mineralogical composition of cement is given in Table 4.
Table 4. Chemical-mineralogical composition of OPC grade 52.5.

| Oxides Content, % by mass | Minerals content, % by mass |
|---------------------------|-----------------------------|
| SiO₂ | Al₂O₃ | CaO | MgO | Fe₂O₃ | SO₃ | R₂O | Mass loses | C₃S | β-C₃S | C₃A | C₄AF |
| 21.82 | 5.30 | 65.91 | 1.11 | 4.86 | 0.99 | 0.22 | 0.2 | 61.2 | 17.7 | 5.9 | 15.1 |

Specimens were prepared from cement: sand mortar in the ratio 1:2.25 according to DSTU B V.2.7-185 demands using mixer «Hobart». Tests of specimens were done according to DSTU B V.2.7-181 recommendations. Deformations were tested on the specimens-beams 2.5×2.5×25.4 cm using mentioned ratio. On the tool with indicator type IP-04 with discretion rate 0.01 mm.

In accordance to the test methodic of influence hardening conditions on properties of alkali activated concrete specimens were storied in normal conditions (20±2°C and relative humidity 95±5%) to the moment of expansion appearance. After that specimens were divided onto four groups. One group was dried to the constant mass and then returned to the curing chamber to be storied in normal conditions. Second group also was dried to the constant mass and covered by hydrophobic agent and also returned to the chamber. Third group was not dried, but cover by hydrophobic agent and then returned to the chamber. Control specimens keep studying in normal conditions.

3. Test results and discussions

Tests of shrinkage/expansion deformations were done using cement systems, chosen from the previous study results.

Systems under study:
1. Alkaline OPC (OPC + soluble glass)
2. Alkaline OPC (OPC + soluble glass) + 10% metakaolin (MK)
3. Slag alkali activated cement (LCEM-1) with extra alkaline component
4. Slag alkali activated cement (LCEM-1) with extra alkaline component + 10% MK
5. OPC Grade 42.5
6. OPC Grade 42.5 + 10% MK

Alkaline component in the system LCEM-I was represented by dry salt of sodium carbonate. Test results are given in Table 5 and on Figure 1. Analysis of obtain results shows that all systems under study are characterized by shrinkage deformations in all diapason of study. It can be noted that the highest shrinkage belongs to the systems using soluble glass (alkaline OPC), and the lowest – slag alkali activated cement LCEM-I. This could be explained by presence in the systems with soluble glass higher content of gel phases, which, as it well-known, are present significant less in the systems with dry alkaline component.

Table 5. Shrinkage/expansion deformations of fine-grain concretes using basalt rock aggregates.

| № | Composition | Shrinkage/expansion deformations, mm/m, at the age, days |
|---|-------------|---------------------------------------------------|
|    |             | 2       | 7       | 28      | 90      | 180     |
| 1  | Alkaline OPC (OPC + soluble glass) | -0.23 | -0.45 | -0.63 | -0.55 | -0.51 |
| 2  | Alkaline OPC (OPC + soluble glass) + 10% metakaolin (MK) | -0.30 | -0.49 | -0.61 | -0.49 | -0.36 |
| 3  | Alkali activated cement (LCEM-1) with extra alkaline component | -0.21 | -0.33 | -0.44 | -0.43 | -0.40 |
| 4  | Slag alkali activated cement (LCEM-1) with extra alkaline component + 10% MK | -0.15 | -0.26 | -0.31 | -0.33 | -0.32 |
| 5  | OPC Grade 42.5 | -0.25 | -0.41 | -0.50 | -0.44 | -0.40 |
| 6  | OPC Grade 42.5 + 10% MK | -0.19 | -0.27 | -0.41 | -0.30 | -0.23 |
Figure 1. Shrinkage/expansion deformations of fine-grain concretes using basalt rock aggregates.

It has to be mentioned that all systems are characterized by reducing of shrinkage in time, showing continuation of structure formation processes and development of ASR reaction in the concrete body.

The best properties has the system on slag alkali activated cement (LCEM-I) themselves, and also with the metakaolin admixture. They were characterized by slow development of shrinkage deformations and some changes of process because of processes of alkaline corrosion of aggregate gain and development of expansion deformations.

Tests of influence of hardening conditions and storing on deformation properties of fine grain concretes were done on the bases of slag alkali activated cement system (LCEM-I) with and without metakaolin admixture. Test results are given in Table 6 and on Figure 2.
Figure 2. Shrinkage/expansion deformations of fine-grain concretes depending from hardening conditions a) on the LCEM-I basis; b) on the LCEM-I basis and metakaolin admixture.

Analysis of the obtain results showed that hardening conditions are influence well on deformations variations. Thus, it was shown that in case of drying of specimens to the constant mass expansion of the specimens is stopping. This could tell about stop of structure formation processes inside the material because of vanishing of liquid phase, that is necessary condition for the reaction. At the same time, it has to be mentioned that difference between dried specimens and specimens, hydrophobizated after drying, from the point of view of deformations is not significant. This also can prove that hygroscopic characteristics of the concrete are not high enough to replace the water content necessary to continue reaction after being dried. Hydrophobization in that case can serve as a guaranty of storing of low moisture content and reducing of risk of destructive reaction in the future.

Table 6. Shrinkage/expansion deformations of fine-grain concretes depending from hardening conditions.

| Composition                        | Hardening conditions | Shrinkage/expansion deformations, mm/m, at the age, days |
|------------------------------------|----------------------|--------------------------------------------------------|
|                                    |                      | 28       | 90       | 180      |
| Slag alkali activated cement (LCEM-1) | normal conditions   | -0.44    | -0.43    | -0.40    |
|                                    | drying               | -0.44    | -0.44    | -0.43    |
|                                    | hydrophobization     | -0.3     | -0.24    | -0.12    |
|                                    | drying and           | -0.44    | -0.44    | -0.43    |
|                                    | hydrophobization     |                      |          |          |
| Slag alkali activated cement (LCEM-1) +10% MK | normal conditions   | -0.31    | -0.33    | -0.32    |
|                                    | drying               | -0.31    | -0.31    | -0.31    |
|                                    | hydrophobization     | -0.28    | -0.23    | -0.21    |
|                                    | drying and           | -0.31    | -0.31    | -0.31    |
|                                    | hydrophobization     |                      |          |          |

Hydrophobization of fine grain concrete without drying leads to intensification of specimen’s expansion. Combining this information with the strength properties, obtain as a result of previous studies, the conclusion can be done about intensification of structure formation processes via self-
steaming of the specimens. That fact could be dangerous from the point of view of traditional methods of concrete structures protection, namely – covering of construction by the paint cover.

4. Conclusions

Thus, it was shown that from the point of view of shrinkage/expansion deformations the best systems are alkali activated cement LCEM-I as it is and with metakaolin admixture (<0.44 and -0.31 mm/m correspondently at the age of 28 days of normal hardening), which, beside this, also showed minimal shrinkage drop at the later terms of hardening, witnessing about decreasing of development of ASR reaction in concretes using such systems. Drying of concrete specimens makes it possible to stop expansion deformation in concrete, and following hydrophobization makes it possible to provide stability of linear dimensions, opening possibility to prolong exploitation terms of constructions under influence of alkaline corrosion of concrete.

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