Experimental studies of the deformation properties of concrete based on sulfate-resistant slag Portland cement as a material for hard coatings of agricultural airfields

O Yanin¹, a, T Yemelianova¹, b and S Novikova¹, c
¹Kherson State Agrarian and Economic University, Stritenskaya, 23, Ukraine

E-mail: ⁰yanin_a@ukr.net, ⁰e.tatyana.2014@ukr.net, ⁰novikova_svetla@ukr.net

Abstract. The paper presents the results of experimental studies of the deformation properties of concretes based on sulfate-resistant slag Portland cement intended for hard coatings of agricultural tracks and airfields. The effect of concrete hardening conditions on the value of its relative shrinkage deformation has been studied. The role of surfactants (plasticizers) as an additional ingredient to concrete is also investigated. Based on these experimental tests, the regularities of the development of plastic deformations formed in concrete in time at a constant load are revealed. The results of the two series of experiments have made it possible to demonstrate the influence of concrete hardening conditions on the values of creep deformation that are also described and analyzed. This article analyzes the kinetics of concrete shrinkage deformations without additives, comparing the results with those for concrete with the addition of a lignosulfonate superplasticizer and also taking into account various modes of heat and humidity treatment of concrete. A comparison of the deformation properties in concrete with sulfate-resistant Portland slag cement with the deformation properties of concrete based on ordinary Portland cement is carried out. The conclusion is made about suitability of concrete with Portland slag cement for use in construction of hard coating for agricultural tracks and airfield runways.

1. Introduction
To improve the efficiency and reduce the cost of rigid concrete coatings of agricultural tracks and airfields, it becomes necessary to develop new solutions in the field of materials science. In particular, the reduction in the cost of cement, which is part of concrete, is promising direction. The corrosion resistance of the coating is also of great importance. In this case, to determination of the coating deformation it seems important, since this is associated with the safety of aviation and automobile transport.

2. Formulation of the Problem
Since slag Portland cement is a new material in the construction of pavements of agricultural tracks and airfields, determination of the deformation modulus, and to study the creep and shrinkage of concrete based on this material is the scientific and practical interest.

Studies of the deformation properties of concrete are devoted to the work of many scientists [1-10]. A A Gaikovich and R V Ovchinnikov substantiated the possibility of obtaining concretes of different strengths with given properties based on a cement-ash binder. This made it possible to achieve a reduction in the cost of production by 8.5%, which is equivalent to saving almost 100 kg of cement per 1 m³ of concrete mixture [1-3].

The influence of the mineral-chemical additive of the boiler slag on the hardening of cement is considered in the works of Korovkin M O, Eroshkina N A, Zamchalnin M N. It has been proven that replacement of the 8–15% of cement by crushed slag reduces the mobility of the mixture, but with an increase its consumption to 20%, workability remains the same as for compositions without additives [4]. To eliminate the negative effect of slowing down the rate of cement hardening with the introduction of slag, it is proposed to introduce a hardening accelerator into the complex additive
The works of Belov V V, Subbotin S L, Kulyaev P V are devoted to the study of the deformative properties of concretes with a finely dispersed limestone component. The use of this additive made it possible to reduce the creep and shrinkage of concrete in comparison with concretes without additives [7].

The possibility of using in construction of fine-grained slag concrete on the basis of sifting out from of crushing cast slag crushed stone is substantiated in the works of such scientists as B A Bondarev, N N Chernousov, R N Chernousov, V A Sturov. Due to the introduction into the composition of the cinder-concrete mixture the steel fiber, which has high tensile strength and increased modulus of elasticity, it has become possible to abandon the rod reinforcement in some structures [8].

Studies [9] have shown that the use of high-strength concretes can increase the service life of the structures of cement-concrete road surfaces or achieve significant material savings due to the thinner slab thickness. The use of complex plasticizing additives made it possible to obtain road concretes of C35 / 40 and higher classes [9-10].

The work [11] is devoted to the study of the strength properties and frost resistance of concretes based on slag Portland cement. It substantiates the possibility and feasibility of using sulfate-resistant slag Portland cement for the construction of rigid coatings of agricultural tracks and airfields. At the same time, it is important to determine the deflection of the coating from the load and volumetric deformations of concrete. Therefore, it became necessary to study the deformation characteristics of such concrete.

The aim of the work is to experimentally determine the deformation modulus of concrete on sulfate-resistant slag Portland cement under different hardening conditions; revealing the influence of concrete hardening conditions on the value of its relative shrinkage and creep deformation; study of the effect of additives of surfactants - plasticizers in the form of lignosulfonate on the deformation characteristics of concrete.

### 3. Materials and methods

Samples in the form of a prism with dimensions of $10 \times 10 \times 30$ cm were made for the experimental determination of the modulus of deformation of concrete on sulfate-resistant slag Portland cement binder [1, 12, 13]. They were tested at the age of 28 days.

For testing, samples of grades CK 5, CK 3 and CK 9 were selected, which after thermal and moisture treatment were in normal hardening conditions and had the composition shown in table 1 [13]. Determination of the concrete deformation modulus for these samples was carried out by loading them with a load equal to 0.3 - 0.5 of the prismatic strength (fcd) and measuring the corresponding deformations. For this, metal corners were glued to the samples on four sides before testing in order to install dial indicators, figure 1.
Figure 1. Installation scheme for determining the modulus of concrete deformation and for examining it for shrinkage and creep: 1 – dial indicator; 2 – corners; 3 – sample.

The deformation modulus was determined by dividing the vertical stress in the sample by the corresponding averaged relative deformation.

Samples in the form of a prism with dimensions of $10 \times 10 \times 30$ cm were made to study the shrinkage deformations of concrete on a slag Portland cement binder. They began to be tested at the age of one day. As in the determination of the deformation modulus, metal corners were glued to the samples before the study to establish dial indicators, figure 1.

The samples were regularly monitored and the readings of indicators were periodically taken. It is made it possible to determine the relative deformations of concrete shrinkage at various points in time. The maximum duration of the experiments was 250 days. For the study samples of grades CK 1, CK 3, CK 5, CK 9, CK 11, CK 13 and CK 17 [11] were selected, the hardening they took place under normal conditions at a humidity of 90 - 95% [11].

In total, several series of experiments were carried out, which made it possible to reveal the influence of concrete hardening conditions on the value of its relative shrinkage deformation. In addition, the role of surfactant additives - plasticizers introduced into concrete was investigated.

As you know, concrete creep is the phenomenon of a gradual increase of deformation under a constant load. Creep is not only a negative phenomenon, since it indicates the relaxation of stresses in time [14].

Typically, in a creep study, concrete specimens are loaded with a load that is about 30% of the breaking value. Taking into account the importance of this characteristic, concrete on slag Portland cement was subjected to tests, which made it possible to reveal how its plastic deformations develop over time under constant load.

Samples were made of concrete on slag Portland cement with dimensions of $10 \times 10 \times 30$ cm to carry out these tests, which began to be tested at the age of 7 days. As in the previous cases, corners were glued to the samples to establish dial indicators, figure 1.

Samples of grades CK 3 and CK 9 were selected (table 1 [11]) to test concrete for creep. They hardened after thermal and moisture treatment under normal conditions. After a constant load equal to 30% of the destructive load was applied to the samples, they were regularly monitored and readings of indicators were periodically taken.

Two series of experiments were carried out, which made it possible to reveal the influence of concrete hardening conditions on the values of creep deformation. The maximum duration of the experiments was 220 days.
4. Research results
The results of determining the modulus of concrete deformation are given in table 1.

Table 1. Results of determining the deformation modulus of concrete on sulfate-resistant slag Portland cement grade 400.

| Sample group number | Sample brand | Curing conditions | Modulus of concrete deformation, MPa, under load |
|---------------------|--------------|-------------------|-----------------------------------------------|
|                     |              |                   | $0.3f_{cd}$                                   | $0.5f_{cd}$ |
| 1                   | CK5          | M                 | $3.04 \times 10^4$                           | $2.65 \times 10^4$ |
| 2                   | CK3          | M1                | $2.5 \times 10^4$                            | $2.21 \times 10^4$ |
| 3                   | CK9          | Ж1                | $2.74 \times 10^4$                           | $2.35 \times 10^4$ |

As can be seen from table 1, the values of the modulus of deformation of concrete on slag Portland cement coincide practically with the data given in the literature for heavy concrete on Portland cement [15, 16, 17].

The study results of the concrete shrinkage deformations are presented in figures 2 and 3.

Figure 2. The study results of concrete shrinkage deformations on sulfate-resistant slag Portland cement without plasticizing additives.

The greatest amount of shrinkage is observed in samples hardened under normal conditions without preliminary thermal and moisture treatment (CK 1). Below there is a curve corresponding to a softer mode of thermal and moisture treatment (CK 5). The smallest shrinkage was observed in specimens hardened in a more severe mode (CK 3).
Figure 3. The study results of concrete shrinkage deformations on sulfate-resistant slag Portland cement with the introduction of a superplasticizer in the form of lignosulfonate (LCT).

As can be seen from the graph of the kinetics of shrinkage deformations of concrete without additives, figure 2, the curves are characterized by reaching a plateau parallel to the abscissa axis by 40-50 days. Subsequently, shrinkage deformations begin to increase from the moment of time 150 days, and second part of the curve has a damping character by 250 days. The noted regularities also take place for the graphs of the kinetics of concrete shrinkage deformations with additives, figure 3, but they are less pronounced.

It is known that concrete shrinkage deformations arise from a reduction in the volume of the cement-water system during cement hydration [18-21]. The values of the concrete relative deformation of shrinkage on ordinary Portland cement by 180 days at a water-cement ratio of 0.4 are 4-8·10⁻⁵, depending on the ratio between the aggregate and the cement [22].

The data obtained as a result of experimental studies indicate that, in general, the relative shrinkage deformations of concretes on a slag Portland cement binder, both with and without additives, are in close to the values of the concrete relative shrinkage deformations on ordinary Portland cement in order of magnitude.

The study results of concrete on sulfate-resistant slag Portland cement on creep are presented in the form of a graph, figure 4.
Figure 4. The study results of concrete on sulfate-resistant slag Portland cement on creep.

Time was plotted along the horizontal axis on the graph, and the creep characteristic $\varphi$ was plotted along the vertical axis. It is the ratio of the amount of plastic deformation at a given time to the amount of elastic deformation at the time of loading. The obtained data indicate that, in all experiments, creep deformations are damped. They are lower in samples that have undergone thermal and moisture treatment in a milder mode (lower curve).

In accordance with the data available in the literature [14-22], the value of the creep relative deformation of concrete on Portland cement when using gravel aggregate is about $6 \cdot 10^{-4}$ 0.5 years after the start of loading.

From the graph shown in Figure 4, it can be seen that the greatest value of the creep characteristic for concretes based on slag Portland cement is $0.9 - 1.1$. It corresponds to the value of the relative creep deformation, equal to $(2.7 - 3.2) \cdot 10^{-4}$ also half a year after the start of loading. It follows from this that the relative creep deformations for concretes both on slag Portland cement and ordinary Portland cement are of the same order.

5. Conclusions

Experimental studies of the deformation properties of concretes on sulfate-resistant slag Portland cement have shown that it has:

1) shrinkage deformations of the same order as that of concrete on Portland cement;
2) the same order of magnitude of creep deformation as for concretes on Portland cement. This magnitude has a damping character at loads of 30% of the destructive value.

The following conclusions can be drawn based on the analysis of the kinetics of the development of concrete shrinkage deformations on a slag Portland cement binder:

1) the nature of the curves for all, without exception, samples hardened under different conditions with and without additives of a superplasticizer in the form of lignosulfonate is the same;
2) for concretes without additives, the kinetic curves of the development of shrinkage deformations have virtually the same shape, and the quantitative differences between them are relatively small;
3) the curves of the kinetics of shrinkage deformations of concretes with additives under various
conditions of hardening are more closely spaced. The influence of the modes of thermal and moisture treatment on shrinkage deformations for concretes with additives is less pronounced.

The deformation moduli of concrete on sulfate-resistant slag Portland cement under different hardening conditions practically coincide with the values of the deformation modulus for heavy concretes on Portland cement.

The creep characteristic for concretes based on slag Portland cement is close in order of magnitude to the corresponding characteristic of concrete on ordinary Portland cement.

It was found that elastic deformations and shrinkage and creep deformations are among the structure-sensitive characteristics. This can explain the influence of the steaming mode on their values.

Thus, the studies carried out have shown that concrete based on slag Portland cement binder under use plasticizing additives, in all basic deformation characteristics is at the level of concrete on Portland cement binder and can be used for the construction of prefabricated coverings for agricultural airfields.

References

[1] Ovchinnikov R V and Avakyan A G 2014 Modifikatsiya portlandtsementa zoloshlakovymi otkhodami Novyye tehnologii 02

[2] Cherepanov A A and Kardash V T 2009 Kompleksnaya pererabotka zoloshlakovykh otkhodov TETS (rezulyat’ty laboratornykh i polupromyshlennykh ispytanii) Geologiya i poleznynye iskopayemyye Mirovogo okeana 2 98

[3] Fedynin N I 1998 Ros’ chastits nesgorevshego topliva v formirovanii svoystv yacheistogo zolobotona Stroitel’nye materialy 9 pp 26–29

[4] Korovkin M O, Yeroshkina N A and Zamchalin M N 2015 Vliyaniye mineral’no-khimicheskoy dobavki na osnove kotel’nogo shlaka na tverdeniye tsementa Sovremennyye problemy nauki i obrazovaniya

[5] Tkach Ye V, Rakimov M A, Toimbayeva B M and Rakimova G M 2012 Vliyaniye organomineral’nogo modifikatora na fiziko-mekhanicheskiye i deformativnyye svoystva betona Fundamental’nye issledovaniya 3-2 pp 428–431

[6] Anisimov S N, Kononova O V, Leshkanov A Yu and Smirnov A O 2014 Issledovaniye vliyaniya kompleksa modifikatorov na kinetiku tverdeniya betonov Sovremennyye problemy nauki i obrazovaniya 4

[7] Belova V V, Subbotina S I and Kulyayeva P V 2015 Prochnostnyye i deformativnyye svoystva betonov s korrozionnymi mikronapolnitelyami Stroitel’nye materialy 3 pp 25–29

[8] Bondarev B A, Chernousov N N, Chernousov R N and Sturova V A 2017 Issledovaniye deformativnykh svoystv stale-fibroshlakobetona pri osevom rastyazhenii i szhatii s uchetom yego vozrasta Vestnik Permskogo natsional’nogo issledovatel’skogo politekhnicheskogo universiteta. Stroitel’stvo i architektura 8(1) pp 18–31 DOI: 10.15593/2224-9826/2017.1.02

[9] Hamelyak I P 2011 Pro efektyvnist’ vykorystannya vysokomitsnoho tsementobetona dlya buduvnyctvya zhmostatkykh pokrytvy Avtomobil’ni dorohi i dorozhnyye buduvnyctvya (Kyiv: NTU) 81 30

[10] Chistyakov V V, Shurgaya A G, Doroshenko Yu M and Chizhenko N P 2012 Modifikatsirovannyye tsementobetony dlya pokrytvyi dorog Stroitel’nye materialy, izdeliya i sanitarnaya tekhnika 43 212

[11] Yanin O, Yemelianov T and Novikova S 2020 Experimental investigations of concrete on slag portland cement as a coating material for agricultural aerodromes Key Engineering Materials 864 pp 19–26

[12] Weiia Y and Hansen W 2013 Early-age strain–stress relationship and cracking behavior of slagcement mixtures subject to constant uniaxial restraint Construction and Building Materials 49 pp 635–642

[13] Said Kenai, Walid Yahiaoui and Belkacem Menadi Effect of granulated blast furnace slag on the durability of self-compacting concrete in hot environment Service Life of Cement-Based Materials and Structures 79
[14] Pane I and Hansen W 2002 Early age creep and stress relaxation of concrete containing blended cements Materials and Structures 35(2) pp 92-96
[15] Eurocode-2 2004 Design of Concrete Structures Part 1-1: General Rules and Rules for Building: EN 1992-1-1 Brussels: CEN 225
[16] DBN V.2.6-98:2009 2011 Betonni ta zalizobetonnii konstruktsiy (Osnovni polozheniya) Ministerstvo rehional'noho rozytku ta budinytystva Ukrayiny Kyiv 71
[17] Proyektirovaniye zhelezobetonnikh konstruktsiy: Spravochnoye posobiye 1985 Pod red. A B Golyshova (Kyiv: Budivel'nik) 496
[18] Lu T, Li Z and Breugel K 2020 Modelling of autogenous shrinkage of hardening cement paste Construction and Building Materials 264 120708
[19] Malbois M, Socie A, Darquennes A, De Sa C and Benboudjema F 2016 Experimental and numerical analysis of drying shrinkage on cement-based materials Int. RILEM Conf. on Materials, Systems and Structures in Civil Engineering 1 (Denmark: Lyngby/Technical University) 325
[20] Wei Y, Hansen W, Biernacki J J and Schlangen E 2011 Unified shrinkage model for concrete from autogenous shrinkage test on paste with and without ground-granulated blast-furnace slag ACI Mater. J. 108 pp 12-20
[21] Li Z, Lu T, Liang X, Dong H and Ye G 2020 Mechanisms of autogenous shrinkage of alkali-activated slag and fly ash pastes Cement and Concrete Research 135 106107
[22] Nevill' A M 1972 Svoystva betona: Sokr. per. s angl. (Moskva) 344