

Представлено результати дослідження впливу добавок модифікаторів на корозійну стійкість бетону для залізобетонних шпал за критеріями електричного опору, стійкості до лужної корозії та корозії внаслідок кристалізації запізненого та вторинного етtringіту. Наведені дослідження було виконано в рамках вирішення проблеми передчасного руйнування залізобетонних шпал, внаслідок прогресуючого тріщинотворення на стадії термообробки та подальшої експлуатації. Встановлено, що введення до складу бетону шпал пуцоланових добавок, що містять в своєму складі активний Al_2O_3 , дозволяє мінімізувати ризик корозії, що обумовлена реакцією кремнезему заповнювачів з лугами та корозії внаслідок кристалізації запізненого та вторинного етtringіту. Висока ефективність щодо названих видів корозії пуцоланових добавок, які вміщують активний Al_2O_3 , пояснюється зв'язуванням лугів в нерозчинні лужні гідралюмосилікати, що сприяють ущільненню системи зі зниженням вмісту іонів Na^+/K^+ в розчині. Зниження вмісту в поровому розчині лугів обумовлює блокування реакції «луг – кремнієва кислота» та підвищення температури стабільності етtringіту до більш високих значень. Це знижує потенційну кількість циклів утворення вторинного етtringіту та імовірність утворення запізненого етtringіту. Альтернативний механізм дії активного Al_2O_3 пуцолан полягає у зв'язуванні іонів SO_4^{2-} та Ca^{2+} з порового розчину у низкосольфатні форми гідросульфалюмінатів кальцію, що виключає кристалізацію запізненого та вторинного етtringіту.

Зниження витрати цементу та води за рахунок використання добавок-пластифікаторів дозволяє підвищити питомий електричний опір модифікованого бетону шпал вище рівня контрольного складу без добавок. Одержані результати надають можливість забезпечення проектної довговічності бетону залізобетонних шпал шляхом їх комплексної модифікації пластифікаторами та активними мінеральними добавками, що містять активний Al_2O_3 .

Ключові слова: реакція «луг – кремнієва кислота», запізнений етtringіт, вторинний етtringіт, електричний опір, метаколін, зола виносу, мікрокремнезем, пластифікатор

IMPROVING THE RESISTANCE OF CONCRETE FOR SLEEPERS TO THE FORMATION OF DELAYED AND SECONDARY ETTRINGITE, THE ALKALI-SILICA REACTION, AND ELECTRIC CORROSION

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1. Introduction

Existing issue on a premature destruction of reinforced-concrete sleepers that fail prior to reaching the estimated operational resource results in significant expenses and necessitates solving an integrated task on improving the macro- and microstructure of reinforced-concrete sleepers in order to ensure their design durability. An analysis of defects in railroad reinforced-concrete sleepers reveals that more than half of them occur due to the insufficient physical-mechanical and mineralogical characteristics of concrete. Reinforced-concrete sleepers demonstrate imperfection at the level of macro- and micro structure, which significantly reduces their durability. The macrostructural imperfection is primarily caused by mismatch to the requirements of the geometry and the size of the coarse aggregate. The microstructural imperfection of concrete in sleepers is predetermined by the use of poor-quality aggregates that are contaminated with inclusions of alumina, mica, reactive and alkali-containing minerals and the elevated content of alkali in cement. Concrete in sleepers is characterized by the increased number of pores and voids due to poor-quality vibrocompaction, or the exceeded stiffness of a concrete mix. Based on the results of studying the destruc-

tion of reinforced-concrete sleepers carried out at Dnipropetrovsk National University of Railroad Transport (Ukraine) in 2011, the probable causes are corrosion due to the crystallization of delayed and secondary ettringite and the alkaline corrosion of concrete. It is possible to control the specified types of corrosion by modifying the concrete of sleepers. In this case, according to DSTU B V.2.6-209:2016, in order to prevent the electric corrosion of concrete, the electrical resistance of concrete in sleepers with admixtures that electrolytes should not be less than the electrical resistance of concrete without admixtures.

Thus, it is a relevant task to investigate the ways to improve the microstructure of concrete in sleepers and to increase its resistance to corrosion as a result of crystallization of delayed and secondary ettringite, alkaline corrosion, and electrical corrosion of concrete, based on the criterion of electrical resistance.

2. Literature review and problem statement

One of the reasons of premature destruction of sleepers is microcracks that form at the stage of thermal-wet treatment

at temperatures above 50–60 °C, the cause of which is probably the delayed formation of ettringite. During operation of reinforced-concrete sleepers, the number and width of these cracks increase, due, probably, to the recrystallization of secondary ettringite [1]. The presence of aggregates in the composition of concrete, containing active silica, as well as the elevated content of alkaline metals in the cement composition (aggregates), can lead to cracking and destruction of concrete in sleepers due to alkaline corrosion [1, 2].

Resolving the issue of premature destruction of reinforced-concrete sleepers implies improving the technology of production (modes of heat-wet treatment, the use of modifier admixtures) with the optimization of both macro- and microstructural characteristics of concrete. That would ensure resistance to corrosion as a result of crystallization of delayed and secondary ettringite, alkaline corrosion, and electric corrosion from leakage currents [3].

A recent implementation of DSTU B. V.2.6-209:2016 allows the use of modifier admixtures in concrete for sleepers. This predetermines not only the improvement of the rheological characteristics of a concrete mix and the homogeneity of concrete in sleepers, but also a simultaneous reduction in the consumption of cement along with the acceleration of cement hydration and the increase of strength by concrete. Along with admixtures from the plasticizers group it is also promising to use active mineral admixtures in the concrete of sleepers. Thus, a series of recent studies addressed the influence exerted on the properties of concrete by mineral modifiers such as fly ash [4–6], silica fume [7, 8], and metakaolin [9–11]. It is known that control over the «alkali-silica reaction» of aggregates would require using more than 7 % of silica fume and metakaolin [11–13], and more than 20 % of fly ash [11, 14]. Given the relatively high cost of silica fume and metakaolin, as well as a substantial increase in the consumption of plasticizers when using them, it is expedient to investigate the effectiveness of these pozzolans for blocking the «alkali-silica reaction» at smaller doses.

It is known that the effect of temperatures over 60–70 °C on concrete can lead to the recrystallization of delayed and secondary ettringite, while the elevated content of alkali (Na^+/K^+) in cement lowers the temperature of ettringite decomposition to 50–60 °C [1]. According to experimental data from [15], the cyclic effect of a temperature of 80 °C on a cement system resulted in a substantial expansion of samples, while the increased content of potassium carbonate in cement increased the expansion by 2 times. The findings in [16] indicate that the use of superplasticizers leads to a slow formation of ettringite and accelerates the formation of mono sulfate. Paper [17] studies the stability and morphology of ettringite when using superplasticizers of different types. It was determined that ettringite stability is increased only when using a superplasticizer of the naphthalene sulfonate type, while the application of superplasticizers of other types led to a decrease in ettringite stability. To prevent corrosion as a result of crystallization of delayed and secondary ettringite, it was proposed to create a sufficient reaction space by introducing pore-forming additives [1], which, for the case of concrete in sleepers, is considered impractical. Papers [18–20] noted a positive effect from 8 % of metakaolin and 20 % of fly ash on the control over expansion as a result of crystallization of delayed ettringite, which is associated with both the pozzolanic effect and the content of active Al_2O_3 . Whereas the replacement of cement with 8 % of silica fume does not make it possible to control long-term

expansion due to the crystallization of delayed ettringite, although the onset of expansion is delayed [19, 20]. Papers [21, 22] note a significant influence over the expansion of the high specific surface of pozzolan. It is expedient to study the efficacy of pozzolan, which contains active Al_2O_3 , in terms of control over the crystallization of secondary ettringite, whose mechanism and the conditions for formation differ from the mechanism and conditions for a delayed ettringite formation [1]. So, in contrast to delayed ettringite, the recrystallization of monosulfate (formed at the decomposition of primary ettringite as a result of cyclic temperature influences) into secondary ettringite does not require the Ca^{2+} ions, the ions of SO_4^{2-} would suffice [1].

In accordance with DSTU B. V.2.6-209:2016, the use of admixtures modifiers requires the confirmation of stability of the modified concrete for sleepers to electric corrosion based by the criterion of electrical resistance. Concrete has a relatively high electrical resistance, but in a water-saturated state its conductivity can increase significantly because liquid in concrete capillaries is the electrolyte [3]. The main measures to fight the electric corrosion of reinforced concrete are to reduce leakage currents, to use electric protection of structures, to apply insulating coatings and improve the electrical resistance of reinforced concrete itself [3, 23].

Thus, based on the results from a literature analysis, it is possible to argue about a possibility to block alkaline corrosion and corrosion as a result of crystallization of delayed ettringite by modifying the concrete of sleepers with pozzolans that contain active Al_2O_3 . It is necessary to refine the minimal effective concentrations of these admixtures as regards the specified types of corrosion. It is also needed to investigate the efficacy of pozzolans containing active Al_2O_3 , regarding control over recrystallization of secondary ettringite. Application of admixtures in the concrete of sleepers predetermines the need to study stability of the modified concrete against electric corrosion by the criterion of electrical resistance.

3. The aim and objectives of the study

The aim of this work is to study the efficiency of comprehensive modification of concrete of organo-mineral admixtures in order to improve the concrete corrosion resistance of the pre-stressed railroad sleepers.

To accomplish the aim, the following tasks have been set:

- to investigate the efficiency of 5 % of silica fume and metakaolin for improving the resistance of concrete of sleepers against alkaline corrosion;
- to examine the efficiency of pozzolanic admixtures, containing active Al_2O_3 , for preventing the corrosion of concrete of sleepers as a result of crystallization of delayed and secondary ettringite;
- to estimate the effect of admixtures modifiers on the electrical resistance of concrete of sleepers.

4. Materials and methods to study the influence of modifier admixtures on the corrosion resistance of concrete in sleepers

In the study, we used Portland cement CEM I 42.5, produced by VAT «Volyn-Cement» (Dickerhoff AG, Ukraine). Pozzolanic admixtures: metakaolin (TOV «Zakhidna Kaolin

Company», Ukraine), silica fume (OFZ, Slovakia), aluminosilicate modifier Centrilit NC II (MC-Bauchemie, Germany). Aggregates: quartz river sand, sand of crushed granite, fractions 0.63...2.5 mm, crushed granite, fractions 5–0 mm. Admixtures of plasticizing group: «Sika», «MC-Bauchemie», «Mapei», etc. We studied the stability of concrete in sleepers against corrosion, due to the reaction between silica of aggregates and alkali, in line with DSTU B. V.2.7-171:2008 and DSTU B. V.2.2.7-71 (p. 4.22.3). The DSTU B. V.2.7-71 (p. 4.22.3) method implies the measurement of expansion of the concrete prisms in a hot ($80\pm 1^\circ\text{C}$) 1M solution of NaOH over 11 days. The criterion for assessing the stability of concrete to alkaline corrosion in line with this method is the indicator of deformation of concretes of control and basic compositions, which, for a corrosion-resistant concrete, should not exceed 0.1 %.

We examined corrosion resistance to crystallization of delayed and secondary ettringite according to the SVA method (proposed by the Expert Committee for «concrete technology» at Deutsches Institut für Bautechnik to study sulfate resistance of binders) [1]. Under this method, a binder is recognized as sulphate-resistant if the expansion of samples $1\times 4\times 16$ cm based on it (at $W/C=0.5$) does not exceed 0.5 mm/m after 91 days (180 days in line with the recent recommendations by DIBt) of aging in a 4.4 % solution of sodium sulfate.

We studied the impact of modifying admixtures on the resistance of reinforced-concrete sleepers against electric corrosion based on the criterion of specific electrical resistance in line with the DSTU B. V.2.6-209:2016 method. The method implies comparing the specific electrical resistance of basic composition without admixtures to the resistance of modified compositions of concrete.

5. Studying the efficiency of pozzolans in blocking the alkali corrosion of concrete in sleepers

When sleepers are manufactured, those aggregates that potentially contain active silica are mainly represented by the quarry sands from individual deposits, which should be replaced with inert ones in the first place. Given that the formulations of concrete for sleepers at enterprises include sand of crushed inert granite, whose reactive capability can be increased at crushing, we studied their potential impact on the alkaline corrosion of concrete.

In order to prevent the alkaline corrosion of concrete in sleepers, the effectiveness of a range of pozzolanic admixtures was considered. A positive effect of metakaolin is known, which is characterized by high reactivity and can reduce concentrations of the OH^- , Na^+ and K^+ ions in solution to non-critical levels, thereby minimizing the expansion of concrete due to the reaction between aggregates' silica and alkali [9, 11–13].

The results shown in Fig. 1 suggest that the examined aggregates have a certain reactivity, resulting in samples' expansion at heating in an alkaline solution, but the expansion does not exceed the permissible limit of 0.1 %. However, an increase in the content of a dusty component in the sand of crushed granite could lead to that the permissible values of expansion are exceeded. When adding 5 % and 10 % of metakaolin (by cement weight), there is not expansion of the examined samples (Fig. 1), which indicates blocking the reaction between aggregates' silica and alkali.

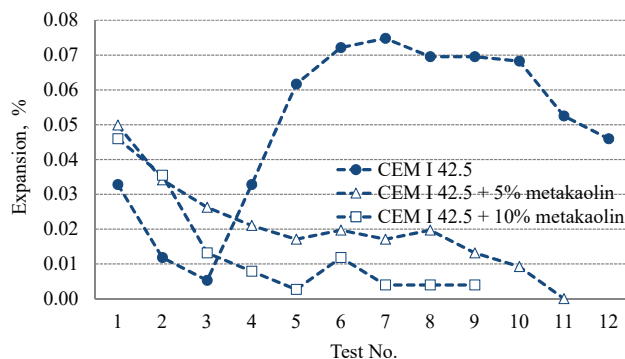


Fig. 1. Expansion (linear) of samples in a hot ($80\pm 1^\circ\text{C}$) solution of NaOH (1M)

Taking into account almost the same result when adding 5 and 10 % of metakaolin (Fig. 1), one can assume that 5 % of metakaolin (by weight of cement) is sufficient to minimize corrosion caused by the reaction between aggregates' silica and alkali.

When adding 5 % of silica fume by weight of cement, expansion of the examined samples slightly decreases (Fig. 2). However, when adding to cement 10 % of silica fume (Fig. 2), expansion of the examined samples remains almost at the control's samples. Thus, the examined silica fume is less effective at eliminating the threat of reaction between aggregates' silica and alkali than metakaolin.

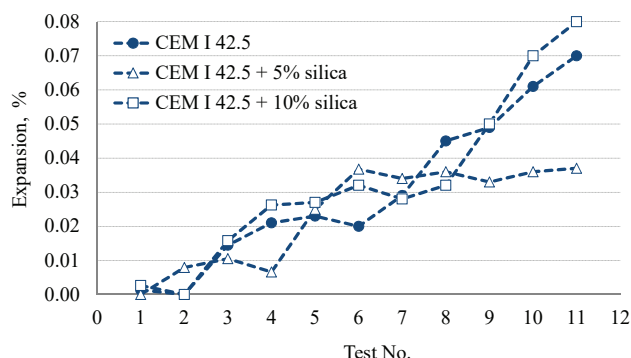


Fig. 2. Expansion (linear) of samples in a hot ($80\pm 1^\circ\text{C}$) solution of NaOH (1M)

The probable mechanism of metakaolin action consists in the interaction between active aluminosilicate and water-soluble alkali and in the formation of amorphous alkaline hydroaluminosilicates, which act constructively, promoting the compaction of the system [12]. A similar effect is observed when fly ash is introduced to cement composition, being a carrier of active Al_2O_3 , which also eliminates the risk of alkaline corrosion of concrete and reduces the deformation of expansion to acceptable values [12].

6. Studying the efficiency of pozzolans in preventing the corrosion of concrete in sleepers resulting from crystallization of delayed and secondary ettringite

When concrete for sleepers is exposed to heat treatment, primary ettringite formation can be partially suppressed and may occur during further utilization in a hardened concrete, which could lead to crack formation and a decrease in the strength of concrete for sleepers. Secondary ettringite can form even during the operation of concrete for sleepers under

conditions of a cyclical temperature exposure exceeding the limit of ettringite stability and may lead to its recrystallization. Such cyclical temperature and moisture loads could lead to premature destruction of concrete in sleepers.

Suppression of primary ettringite creation (decomposition) is observed at temperatures exceeding the temperature of its stability (typically >60–70 °C and >50 °C at the elevated content of Na⁺/K⁺ ions in a solution) [1]. As a result of crystallization of delayed (secondary) ettringite, the first to be damaged (destroyed) are the high-quality concretes with high durability and density, characterized by a small total pore volume, and, consequently, the reduced space for new formations. Such damage was found in sleepers made from a pre-stained concrete, as a result of low water-cement ratio (W/C=0.32) and a high cement content (460 kg/m³) [1].

Fig. 3 shows that the introduction of 6 % of metakaolin and the aluminosilicate modifier Centrilit NC II makes it possible to reduce the expansion of samples over the early periods of the influence of a sodium sulfate solution (according to the SVA method). The effect on the examined sulfate samples over the early periods of testing can be considered to be identical to the conditions for crystallization of delayed ettringite. Thus, the hydrated cement always contains a certain amount of calcium hydroaluminates, which, when the content of SO₄²⁻ and Ca²⁺ ions in a porous solution increases, are recrystallized into ettringite in a hardened concrete.

However, over longer testing periods and in the presence of an external source of sulfates, the expansion of samples with aluminosilicate pozzolans may exceed the expansion of a control sample without admixtures (Fig. 3).

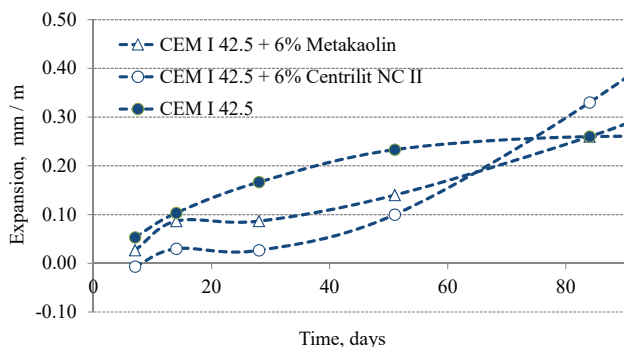


Fig. 3. Expansion (linear) of samples in a 4.4 % solution of Na₂SO₄ by the SVA method

The results of cyclical immersion of samples (every seven days) in a hot sodium sulfate solution (>60 °C) followed by their storage in the same solution at 20 °C are shown in Fig. 4. A combined influence exerted on the examined samples of sulfate and temperatures cycles can be considered as the most favorable one for the recrystallization of secondary ettringite (the elevated content of Na⁺ and SO₄²⁻ in a solution). The recrystallization of monosulfate (formed due to the decomposition of primary ettringite at temperatures above 50 °C in the presence of Na⁺ ions in a solution) into secondary ettringite does not require the Ca²⁺ ions; the presence only of SO₄²⁻ ions suffice. Therefore, while for blocking delayed ettringite it is sufficient to use silicate pozzolans to bind the Ca²⁺ ions, in the case of secondary ettringite, there is a need for active Al₂O₃ to bind the ions of SO₄²⁻ and Na⁺. According to data shown in Fig. 4, there is a significant acceleration in samples expansion (by ~10 times) compared to storage under normal conditions (Fig. 3). The content of fly ash

exceeding 17 % leads to a substantial decrease in the expansion of samples at the initial periods of cyclic tests (Fig. 4). However, the stabilization of samples expansion under such conditions is achieved only when the content of fly ash exceeds 28 %.

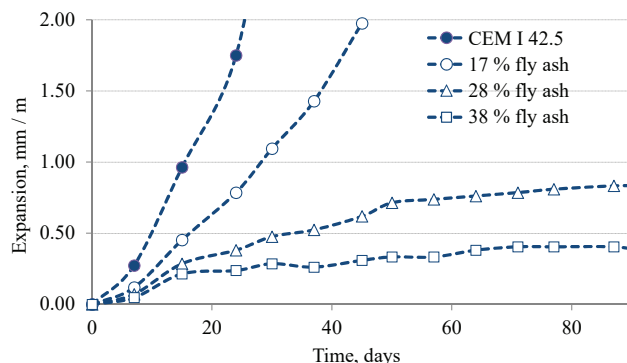


Fig. 4. Expansion (linear) of samples in a 4.4 % solution of Na₂SO₄ by the SVA method with a cyclical temperature influence >60 °C

The efficiency of fly ash and metakaolin, which contain active Al₂O₃, is due to binding, by active aluminosilicates, the active water-soluble alkali (Na⁺/K⁺) into the insoluble alkaline hydroaluminosilicates [12]. This leads to a decrease in the content of Na⁺/K⁺ ions in a porous solution [9] and, consequently, an increase in the stability of ettringite to temperatures above 60–70 °C. The alternative mechanism of action of active Al₂O₃ in pozzolans implies binding the ions of SO₄²⁻ and Ca²⁺ from the porous solution into the low-sulfate forms of calcium hydro-sulfoaluminates, which excludes the crystallization of delayed and secondary ettringite [10]. However, in the presence of an external source of sulfates, the amount of newly-formed ettringite in the systems with aluminosilicate pozzolans can exceed the amount of ettringite in the systems without admixtures.

7. Studying electrical resistance of the modified concrete for sleepers

The introduction of admixtures modifiers makes it possible to improve the rheological characteristics of a concrete mixture and the uniformity of concrete, to reduce cement consumption and to accelerate the durability acquisition by concrete for sleepers. However, in order to prevent electrical corrosion, the electrical resistance of concrete for sleepers with admixtures that are electrolytes should not be less than the electrical resistance of concrete without admixtures (according to DSTU B V.2.6-209:2016).

Data from Fig. 5 show that under the condition W/C=const (400 kg/m³ of cement) most admixtures plasticizers decrease the specific electrical resistance of concrete for sleepers. The electrical resistance at the level of a composition without admixtures characterizes the concretes, plasticized by polymers of the polycarboxylate type, containing a minimum amount of salt-electrolytes.

Among the factors that ensure the reduced concrete permeability is to decrease a W/C ratio. However, decreasing a W/C (at constant content of cement) requires the increased consumption of plasticizers; in this case, a value for specific electric resistance of the modified concrete for

sleepers increases slightly or even decreases. When reducing the consumption of cement to 350 kg/m^3 and at $W/C=0.30$ the specific electrical resistivity of the modified concrete for sleepers with the addition of MS PowerFlow 3100 rises to 1,100 OM·m and exceeds the electrical resistance of control composition without admixtures (Fig. 6). Additional introduction of 5 % of metakaolin (by weight of cement) increases electrical resistance of the modified concrete with MS PowerFlow 3100 to 1,200 OM·m (Fig. 6).

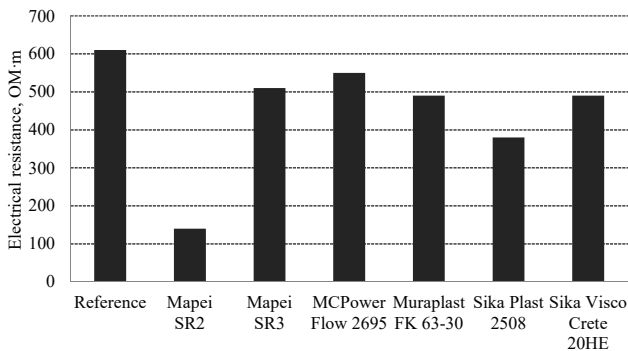


Fig. 5. Electrical resistance of concrete with 400 kg/m^3 of cement, 5 % metakaolin ($W/C=0.38$)

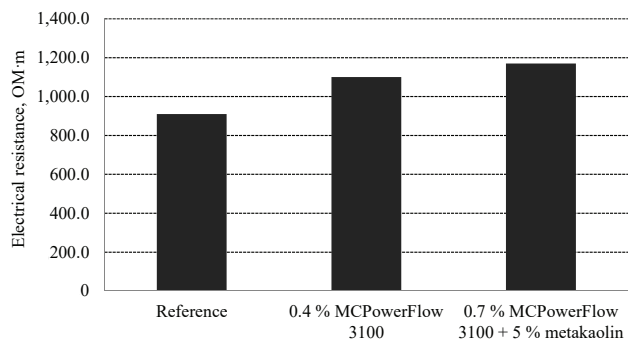


Fig. 6. Electrical resistance of concrete with 350 kg/m of cement ($W/C=0.30$)

Generalization of our experimental data indicates the presence of an inverse correlation between the electrical resistance of the modified concretes for sleepers and W/C – the ratio (Fig. 7) and the content of cement (Fig. 8); in this case, correlation coefficients do not exceed 0.37–0.39, respectively.

It should be noted that due to a relatively low accuracy of the method for determining the electrical resistance of concrete, effects exerted by the examined factors are comparable to an error in the experiment, which predetermines the low values of correlation coefficients. Thus, in the present study, the correlation coefficient is used to distinguish the most statistically significant factors affecting the electrical resistance of concrete (within the examined factor space).

The highest correlation (correlation coefficient is 0.45) is observed when one takes into consideration a combined influence of these factors, which in fact corresponds to an increase in the electrical resistance of the modified concrete for sleepers with a decrease in water content in a concrete mixture (Fig. 8).

Thus, the use of admixtures plasticizers could significantly increase the electrical resistance of the modified concrete for sleepers compared with concrete without an admixture, which is achieved by reducing the consumption of

cement and water in the composition of a concrete mixture. A weak positive effect in terms of an increase in electrical resistance is also observed when the concrete for sleepers is supplemented with 5 % of metakaolin.

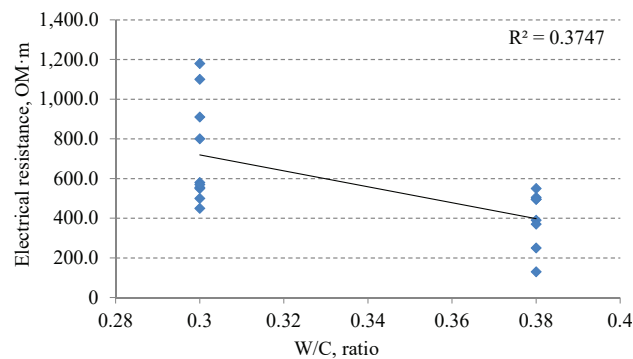


Fig. 7. Dependence of electrical resistance of the modified concrete on W/C

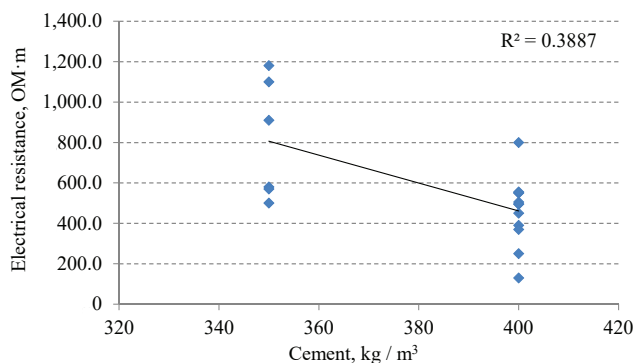


Fig. 8. Dependence of electrical resistance of the modified concrete on cement content

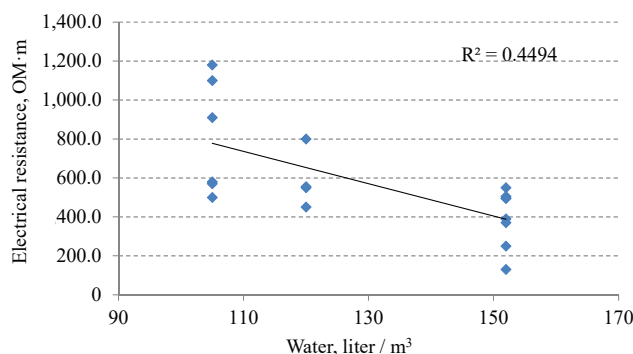


Fig. 9. Dependence of electrical resistance of the modified concrete on water content

8. Discussion of results from studying the influence of admixtures plasticizers on the corrosion resistance of concrete for sleepers

The probable mechanism of action of fly ash [12] and metakaolin (Fig. 1) in reducing the expansion of concrete for sleepers due to alkaline corrosion is the interaction between active aluminosilicate and water-soluble alkali (Na^+/K^+) and the formation of amorphous alkaline hydroaluminosilicates that act constructively, promoting the system's compaction.

In the same way, it is possible to explain the effectiveness of metakaolin (Fig. 3) and fly ash (Fig. 4) to prevent expansion as a result of crystallization of delayed and secondary ettringite. Binding the ions of Na^+/K^+ by an active aluminosilicate

licate from the porous solution predetermines an increase in the temperature of ettringite stability to temperatures above 60–70 °C, which reduces the potential number of recrystallization cycles of secondary ettringite and the probability of formation of delayed ettringite.

The alternative mechanism of action of active Al_2O_3 pozzolan implies the binding of SO_4^{2-} and Ca^{2+} ions from a porous solution into low-sulfate forms of calcium hydro-sulfoaluminates, which excludes the crystallization of delayed and secondary ettringite. However, in the presence of an external source of sulfates, the amount of newly-formed ettringite (expansion) in the systems with aluminosilicate pozzolans can exceed the amount of ettringite (expansion) in systems without admixtures (Fig. 3).

The use of admixtures from a plasticizing group makes it possible to increase the electrical resistance of the modified concrete for sleepers by reducing the consumption of cement and water (Fig. 8, 9), which can be explained by the decrease in the volume of capillaries containing the electrolyte. The positive effect in terms of an increase in electrical resistance when introducing 5 % of metakaolin is due to binding, by active aluminosilicates, the ions from a porous solution – the electrolyte.

The SVA method is typically used to determine the sulfate resistance of binders under the influence of an external source of sulfates. The combined effect exerted on the examined samples by sulfate and temperature cycles can be considered to be the most favorable for recrystallization of secondary ettringite (Fig. 4). Thus, the proposed methodology makes it possible to reliably assess the effectiveness of pozzolan to prevent the crystallization of secondary ettringite.

Although our study enables revealing general patterns and mechanisms of action of various types of pozzolans as regards the examined types of corrosion, however the effects of action and dosage of other manufacturers' admixtures could differ significantly from the above. Thus, the use of more reactive aggregates may require a greater consumption of pozzolan admixtures to ensure the stability of concrete to alkaline corrosion.

The present study into effectiveness of the pozzolanic admixtures in preventing internal corrosion as a result of crystallization of delayed and secondary ettringite in line with the SVA method implied testing the samples from cement-sand mortars in the presence of an external influence of sulfates. Extending the obtained results to the concrete for sleepers requires additional (industrial) tests.

We determined electrical resistance of the modified concrete using samples-cubes not taking into account reinforcement and macrostructural imperfection of reinforced-concrete sleepers, which can significantly affect the

electrical resistance of the article. This predetermines the appropriateness of additional control this parameter during industrial tests of reinforced-concrete sleepers. It should also be noted that at the same electric resistance of concretes with varying compositions, their resistance to electric corrosion may differ.

Our research may continue through industrial implementation and subsequent observation of concrete for sleepers under operating conditions. However, it should be noted that an analysis of damaged concretes typically does not make it possible to draw an unambiguous conclusion about the cause of their destruction. For example, ettringite in concrete is formed in such minor quantities, which are often even impossible to detect.

9. Conclusions

1. The effectiveness of silica fume and metakaolin to improving the resistance of concrete for sleepers against alkaline corrosion has been examined. Taking into account almost the same effect of 5 and 10 % of metakaolin, one can assume that 5 % of metakaolin is sufficient to block the «alkali-silica reaction». The examined silica fume is less effective in eliminating the threat of a reaction between aggregates' silica and alkali, both at concentrations of 5 % and 10 %.

2. We have investigated the efficacy of pozzolanic admixtures, containing active Al_2O_3 , to preventing corrosion due to the crystallization of delayed and secondary ettringite. It has been established that 6 % of metakaolin and the aluminosilicate modifier Centrilit NCII make it possible to reduce the expansion of samples over early periods of the influence of a sodium sulfate solution, which meets the conditions for delayed ettringite formation. Over longer periods of testing, in the presence of an external source of sulfate, the expansion of samples with these pozzolans exceeds the expansion of the control sample without admixtures. The content of fly ash exceeding 17 % results in a decrease in sample expansion at the initial periods of a cyclic effect of a hot sodium sulfate solution (>60 °C), which corresponds to the conditions of recrystallization of secondary ettringite. However, the stabilization of sample expansion under such conditions is achieved only at the content of fly ash exceeding 28 %.

3. We have investigated the influence of modifier admixtures on electrical resistance of concrete for sleepers. An increase in electrical resistance of the modified concrete has been established with a decrease in the consumption of cement and water in the composition of a concrete mix. A weak positive effect in terms of improving electrical resistance is observed when introducing 5 % of metakaolin.

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