Doi: 10.33644/01008

УДК 620.193.4:691.32

SHEINICH L.A.
Dr, Prof., Dept. Head, State enterprise "The State Research Institute of Building Constructions",
Kyiv, Ukraine,
e-mail: schein@ndibk.gov.ua,
tel. +38 (044) 248-88-73
ORCID: 0000-0002-7684-9495

MYKOLAIETS M. G.
PhD, Head of laboratory, State enterprise "The State Research Institute of Building Constructions",
Kyiv, Ukraine,
e-mail: mykolayets@ndibk.gov.ua
tel. +38 (044) 224-78-79
ORCID: 0000-0002-8823-3401

KRYLOV E.A.
Lead Engineer, State Enterprise "The State Research Institute of Building Constructions",
Kyiv, Ukraine,
e-mail: krylov@ndibk.gov.ua
tel.: +38 (044) 249-38-41,
ORCID: 0000–0001–7944–2132

THE PROBLEMS OF CHEMICAL CORROSION OF CONCRETE ON RAILWAYS OF UKRAINE

ABSTRACT

The types of defects arising in the concrete sleepers on the railway tracks of Ukraine are investigated. It is established that the causes of cracks can be both permanent dynamic loads and the destruction of concrete due to alkali corrosion. The most common cases are the combined action of loads (occurrence of force cracks), corrosion (development of cracks) and freezing of water under the action of low temperatures. It is known that gel is generated during the chemical interaction between the various forms of silicic acid, which is differently contained in the fillers of different types, solutions of alkali metal hydroxides, which fill the pores of the matured concrete and alkali penetrating from the outside. Such a newly formed structure is able to absorb water and increase in volume, and thus leads to the formation of microcracks in the concrete and, eventually, the destruction of the concrete. Chemical microscopic examinations of aggregates and cement were carried out for the concrete aimed for sleepers. Studies showed that cements of Ukrainian production had an excessive content of alkaline component. Based on the obtained results, recommendations are given to reduce the content of alkaline component in concrete. Microscopic studies of concrete showed that alkaline corrosion occurred more intensively in the sleepers made before 2010 than in the sleepers made after 2010. This is due to the fact that manufacturers of sleepers began to monitor constantly the content of alkaline component and amorphous silica in aggregates and cement. In this case, the amount of gel is already insufficient for destruction of concrete in its pure form as a result of alkaline corrosion, but still sufficient to accelerate the opening of force cracks due to corrosion of concrete. This again leads to the formation of a complex effect of various harmful factors on the concrete, which destroy sleepers.

To reduce the alkaline corrosion of concrete, certain steps must be taken such as to introduce plasticizing additives that reduce the amount of cement and, accordingly, the number of soluble alkalis, to use additives that bind alkalis - slag, ash, etc., or to apply III PC / A-W cement with the content of granulated slag up to 20% and to carry out an input control of each batch of aggregate in order to determine harmful substances and availability of alkalis.

KEYWORDS: concrete, aggregate, corrosion, alkali, silicate, crack, sleepers

ПРОБЛЕМИ ВИНИКНЕННЯ ХІМІЧНОЇ КОРОЗІЇ БЕТОНУ НА ЗАЛІЗНИЧНИХ ШЛЯХАХ УКРАЇНИ

АННОТАЦІЯ

Досліджено види дефектів, що виникають в залізобетонних шпалах на залізничних шляхах України. Встановлено, що причинами виникнення тріщин можуть бути як постійні динамічні навантаження, так і руйнування бетону внаслідок протікання лужної корозії. Найпоширенішими випадками є комбінована дія навантажень (виникнення силових тріщин), корозії (розвиток тріщин) та замерзання води під дією низьких температур. Відомо, що під час хімічної взаємодії між різними формами силікатної кислоти, яка в різній мірі міститься в заповнювачах різних видів, та розчинами гідрооксидів лужних металів, якими заповнені пори бетону, що затверднув, а також із лугами, що проникають ззовні, утворюється гель. Таке новоутворення здатне поглинати воду і збільшуватись в об'ємі і таким чином призводить до утворення мікротріщин в бетоні та, з часом, до руйнування бетону. Проведено хімічні, мікроскопічні дослідження заповнювачів та цементу для бетону шпал. Дослідження показали, що цементи українського виробництва мають завищений вміст лужної складової. На основі отриманих результатів надано рекомендації по зменшенню вмісту лужного компоненту в бетоні. Мікроскопічні дослідження бетону показали, що у шпалах, виготовлених у 2010 році, лужна корозія протікає інтенсивніше, ніж у шпалах, що виготовлені після 2010 року. Це пов'язано з тим, що заводи-виробники шпал почали постійно контролювати вміст лужного компоненту та аморфного кремнезему в заповнювачах та цементах. В цьому випадку кількості гелю вже недостатньо для руйнування бетону в «чистому вигляді» як результат лужної корозії, але достатньо щоб прискорювати розкриття силових тріщин за рахунок корозії бетону. Це в свою чергу призводить до утворення комплексного впливу різних шкідливих чинників на бетон, які руйнують шпали.

Для зниження масштабів лужної корозії бетону необхідно виконати певні заходи: вводити пластифікуючі добавки, що зменшують кількість цементу, і відповідно – кількість розчинних лугів, застосовувати добавки, що зв'язують луги – шлаки, золи і т.п, або застосовувати цемент марки ПЦ II/А-Ш з вмістом гранульованого шлаку до 20%, проводити вхідний контроль кожної партії заповнювача по визначенню шкідливих речовин, наявності лугів в цементі.

КЛЮЧОВІ СЛОВА:бетон, заповнювач, корозія, луг, силікат, тріщина, шпала

INTRODUCTION

As a result of the work of special commission in 2018-2019, it was found that the railways of Ukraine showed an unsatisfactory condition of concrete sleepers. Inspections of sleepers of various production years revealed defects in the form of cracks, which eventually led to the destruction of the product. The cracks were of various types from transverse to longitudinal ones and cracking.

This condition of concrete sleepers has lead to the need in special physical and chemical studies of concrete to determine the causes of cracks and corrosion of concrete.

ANALYSIS OF RECENT RESEARCH AND PUBLICATIONS

It is known [1] that in case if reactive aggregate and alkali are available in the composition of concrete, alkaline corrosion occurs in the concrete and it is demonstrated by destruction of concrete after 1-2 years of operation in wet conditions.

Reaction between alkalis and silicic acid refers to chemical reaction between the various forms of silicic acid (SiO2 nH2O) which is contained in the aggregates and the solutions of alkali metal hydroxides (NaOH, KOH) that fill pores of the matured concrete and alkali penetrating from the outside. The gel resulting from these reactions is able to increase in volume due to water absorption and leads to the destruction of concrete [1].

The reaction between alkalis and silicic acid contained in certain types of rocks is described in the works of Stanton [2], God [3], Kyul [4]. Such reactions are accompanied by the formation of gel-like products that are able to increase in volume and that is a sign of alkaline corrosion. This type of corrosion refers to the corrosion of the second type i.e. chemical.

PROBLEM DEFINITION

The actual task is to conduct a survey of concrete sleepers produced by Ukrainian manufacturers, to conduct physical and chemical studies of concrete and aggregates, to determine the cause of destruction of sleepers.

MAIN PART

In 2012, in Research Institute for Building Constructions (NIISK), L. Sheinich and I.Ignatova conducted research on raw materials that had been used thus far and suggested measures on how to prevent alkaline corrosion, which occurred in the products of this manufacture. In particular, it was proposed to use aggregate with a lower content of alkali in terms of Na2O equivalent as well as amorphous silica, it was suggested to set a limit of alkali content of 0.6% for cement, to introduce additives that bind alkali and to reduce the amount of cement.

Today the manufacturers use cement in which the minimum content of the alkaline component is about 0.8% in terms of Na2O equivalent.

In studies of small aggregate it was established that the content of amorphous silica varied depending on the batch and the supplier and did not exceed the requirements set in DSTU B B.2.7-32 [6].

The alkali content does not exceed the requirements specified in [6]. Compounds of amorphous silica in large aggregate were not found.

In 2010, a number of studies was carried out by the sleeper fabrication plants in order to define the reactivity of large aggregate with alkali contained in cement. According to these studies, crushed stone was considered not reactive with alkali. This has been also confirmed by testing aggregate with the method used to measure linear deformations.

The research with electron microscope has covered the microstructure of the cement stone of 3 samples of concrete that were taken from concrete sleepers manufactured by the same plant in 2010, 2017, and 2019. The newly formed structures were identified according to the data [1, 7-10].

Analysis of the micrograph of the material of sleepers 2019, shown in Figure 1 shows that cement stone has mainly the amorphous hydrate structure formed as a result of the cement hydration.

In Figure 2, there are minor spherical formations which according to [1] can be identified as alkaline-silicate gel, which proves alkaline corrosion of concrete. The presence of alkaline corrosion can reduce bear capacity of sleepers and accordingly contribute to transverse force cracks. A small amount of alkaline gel in concrete indicates that raw materials (aggregate) contain trace of amorphous silica and cement with extended amount of soluble alkalis.

Figures 3 and 4 show micrographs of cement stone taken from a sleeper produced in 2017.

Analyzing the microstructure of cement stone taken from concrete of sleepers produced in 2017, it can be noted that the number of granules of alkali-silicate gel has increased compared to that in concrete sleepers produced in 2019 (Figure 3). This indicates that the alkaline corrosion of concrete evolves over time.

Figure 4 shows that the microstructure of the

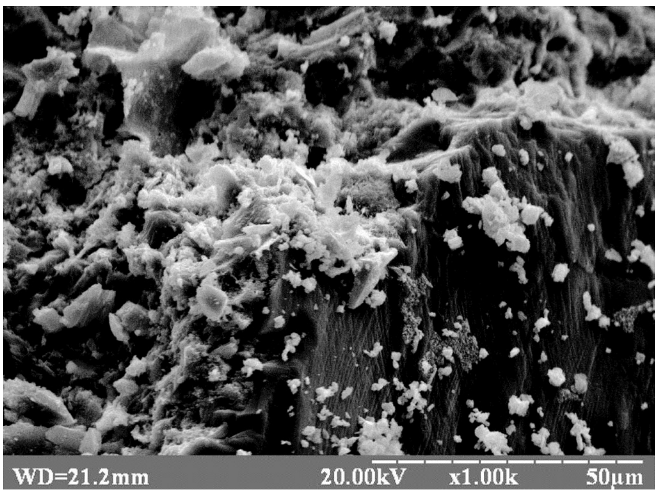

Figure 1 – Amorphized hydrated cement stone

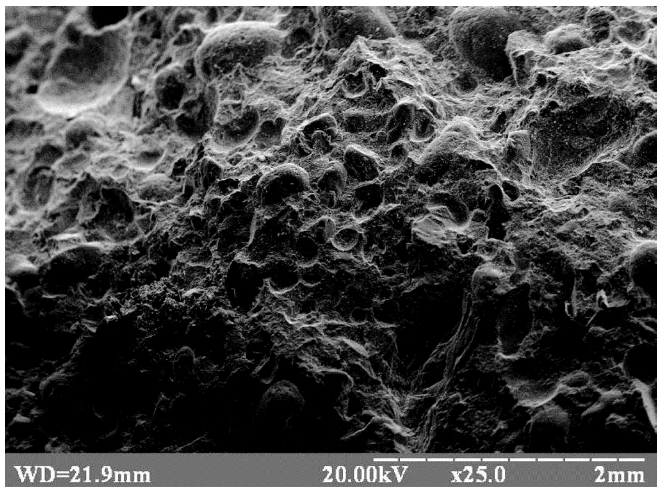

Figure 3 – Micrograph of cement stone taken from a sleeper produced in 2017

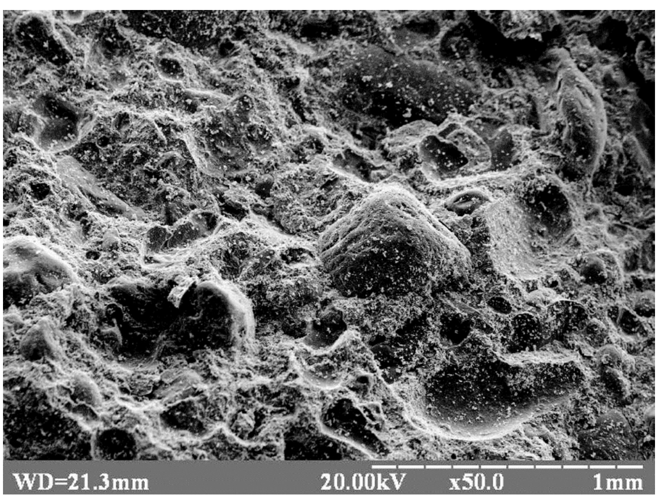

Figure 2 – Cement stone with speckles of alkali-silicate gel

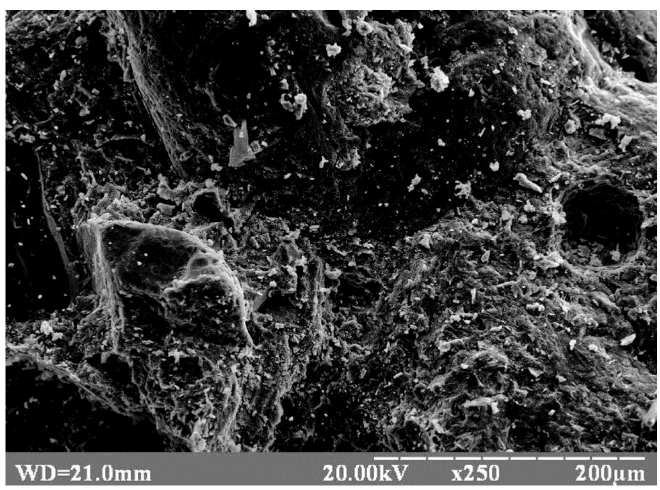

Figure 4 – Micrograph of cement stone with microcracks taken from the sleeper produced in 2017

cement stone is represented by the hydrated cement and has microcracks which have to reduce the durability of concrete.

Looking at the photo of a sleeper produced in 2017 (Figure 5), it can be noted that there are transverse cracks of the sleeper concrete which occur in high power load. This means that the significant cracks in sleepers, which could be attributed to the cracks resulting from alkaline corrosion are not found. The amount of gel is already insufficient for the destruction of concrete in its pure form as a result of alkaline corrosion, but still enough to initiate force cracks due to corrosion of concrete. This in turn leads to the formation of a comprehensive effect of various harmful factors on the concrete which destroy sleepers.

Figures 6 and 7 are micrographs of cement stone taken from sleepers produced in 2010. This sleeper was manufactured at the plant prior to the optimization of production process aiming at prevention of alkaline corrosion [5, 11].

Analyzing the microstructure of the cement stone given on Figure 6, one can observe that the number and size of granules of alkaline-silicate gel has increased in comparison to the the amount of gel in the sleepers produced in 2017. The microstructure of cement stone given in Figure 7 is presented by hydrated cement and provides microcracks which are expected to ruin the concrete. The size of the gel granules have increased even more. The amount of alkaline-silicate gel is enough to bring to the deterioration of concrete attributed to alkaline corrosion (Fig. 8).

Thus, the research has found that alkaline corrosion occurs in the concrete of sleepers. Its intensity is less than it was before due to the optimization of technology in 2010-2011. [5, 11].

The content of alkali in Ukrainian cement of I

Figure 5 – Cracks within concrete sleeper

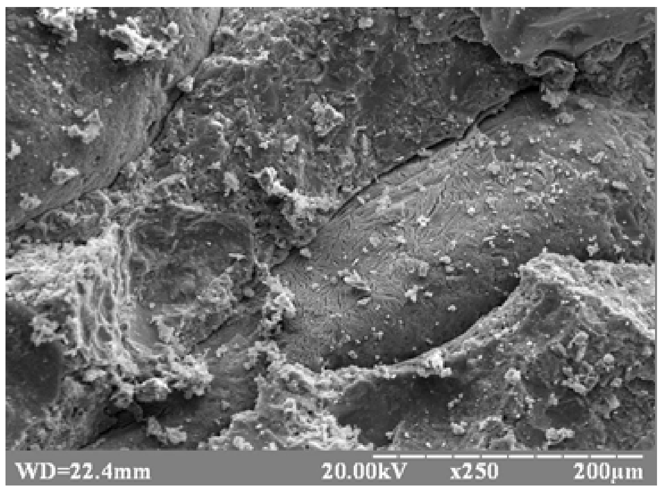

Figure 7 – Micrograph of cement stone with concrete microcracks taken from the sleeper produced in 2010

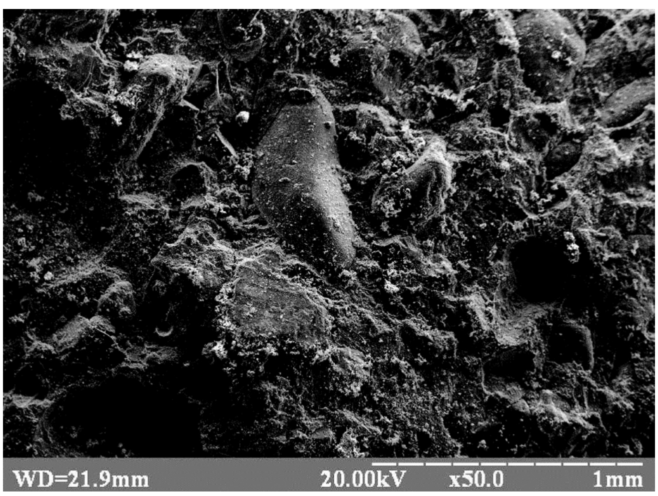

Figure 6 – Micrograph of cement stone taken from a sleeper produced in 2010

Figure 8 – Crackingon the sleeper produced in 2010

type, M500, normalized composition exceeds the allowable value of 0.6% [12] according to the data of Association of Ukrainian Cement in 2019 and this is the reason why it is necessary to introduce mineral admixtures in concrete and to fix alkali into insoluble how it is recommended in [5,11]. These admixtures can be aluminosilicate substances, for example slag, ash. This technological solution is confirmed by the content of paragraph 5.11 [12].

Slag admixture can be introduced in cement willing and this will simplify the technology of concrete, this means the application of cement of grade PC II / A-W with a content of granular slag up to 20% while maintaining the quality of concrete according to [13]. Such a positive solution will not only reduce the alkaline corrosion of concrete due to the interaction of cement slag with alkali and the formation of insoluble [1] but also contribute to lowering of prime costs.

CONCLUSIONS

1. It is established that all concrete sleepers produced within the period from 2004 to 2012 showed intensive alkaline corrosion of concrete. In sleepers manufactured from 2017 to 2019 defects are associated with force loads and transverse cracking. The crack width increase with time. As water gets into cracks and freezes in winter, it breaks the concrete. The crack width grows and the process of concrete deterioration promotes. In due time, cracks occur and it is already characteristic to corrosion of concrete. Thus, the prevention of the destruction of sleepers is associated with the solution of a comprehensive problem, which covers the following issues: load applied to sleepers, their operation conditions, design of sleepers and their manufacturing technology (including the prevention of alkaline corrosion).
2. As a result of the research work, a number of measures to prevent alkaline corrosion of concrete was suggested. Concrete-making facilities have taken some measures to reduce alkaline corrosion of concrete, but not in full. The steps have been mainly taken towards the control of input raw materials. If the amount of harmful substances in the aggregates does not exceed the allowable values, then the amount of soluble alkali in the cement made in Ukraine varies considerably and can be within the permissible limits [12] and exceed those reaching more than 1%.
3. Electron microscope studies have shown that the presence of soluble alkali in cement and amorphous silica in aggregates bring to the formation of alkali-silicate gel, which provokes alkaline corrosion of concrete. It should be noted that the control and selection of good aggregates reduces the size and intensity of alkaline corrosion.
4. To reduce the size of alkaline corrosion of concrete, some certain steps should be taken such as introduction of plasticizing additives that reduce the amount of cement and, accordingly, the number of soluble alkali, use of additives that bind alkali like slag, ash, etc., or application of cement of grade PC II / A-W containing granular slag up to 20% according to [13]. Applying crushed stone of several fractions will also help reduce the consumption of cement with excess reactive alkali. It is necessary to carry out an input control of each batch of aggregate to determine the harmful substances and alkali in cement.

БІБЛІОГРАФІЧНИЙ СПИСОК

1. Штарк, Й., Тулаганов, А. (Пер.), & Кривенко, П. (Ред.). Щелочная коррозия бетона: Монография. (2010). Киев.
2. Stanton, T.E. (1940). Expansion of concrete through reaction between cement and aggregate. Proceedings of the American Society of Civil Engineers, 66 (10), 1781-1811.
3. Bogue, R.H. (1952). The chemistry of Portland cement. New York: Reinhold Publishing Co.
4. Kühl, H. (1951). Die Erhärtung und die Verarbeitung der hydraulischen Bindemittel. Zement-Chemie (Bd. 3). Berlin: Verlag Technik.
5. Висновок щодо встановлення впливу оптимізованої технології виготовлення шпал на їх довговічність: Висновок за результатами випробувань. Київ: ДП НДІБК, 2012. 81 с.
6. ДСТУ Б В.2.7-32-95 Пісок щільний природний для будівельних матеріалів, виробів, конструкцій і робіт. Технічні умови. [Чинний від 01.01.1996] Вид. офіц. Київ, 1996. 17 с.
7. Штарк Й., Вихт Б. Цемент и известь, Ин-т строительных материалов им. Ф.А. Фингера. Баухаус-Университета, Ваймар. Киев, 2008, 480 с.
8. Горшков В.С., Тимашев В.В., Савельев В.Г. Методы физико-химического анализа вяжущих веществ, М: «Высшая школа», 1981. 335 с.
9. Минералогические таблицы. Справочник / под ред. Е.И. Семенова. М: «Недра», 1981. 399 с.
10. ДСТУ Б В.2.7-75-98 Щебінь та гравій щільні природні для будівельних матеріалів, виробів, конструкцій і робіт. Технічні умови. [Чинний від 01.01.1999] Вид. офіц. Київ, 1999. 15 с.
11. Проведення досліджень по встановленню причин руйнування залізобетонних

шпал та розробка рекомендацій по підвищенню міцності бетону: Звіт про науково-дослідну роботу. Дніпропетровськ: Дніпропетровський національний університет залізничного транспорту ім. академіка В. Лазаряна, 2011.
12. ДСТУ Б В.2.6-209:2016 Шпали залізобетонні попередньо напружені для залізниць колії 1520 і 1435 мм. Технічні умови. [Чинний від 01.01.2017] Вид. офіц. К., 2017.
13. ДСТУ Б В.2.7-46:2010 Будівельні матеріали. Цементи загальнобудівельного призначення. Технічні умови. [Чинний від 01.09.2011] Вид. офіц. К., 2011. 14 с.

REFERENCES

1. Stark, J., Tuluhanov, A. (Tr.), & Krivenko P. (Ed.). (2010). Alkali-Kieselsaure-Reaktion. Kyiv.
2. Stanton, T.E. (1940). Expansion of concrete through reaction between cement and aggregate. Proceedings of the American Society of Civil Engineers, 66 (10), 1781-1811.
3. Bogue, R.H. (1952). The chemistry of Portland cement. New York: Reinhold Publishing Co.
4. Kühl, H. (1951). Die Erhärtung und die Verarbeitung der hydraulischen Bindemittel. Zement-Chemie (Bd. 3). Berlin: Verlag Technik.
5. Conclusions on determining the optimized sleeper manufacturing technology influence on their durability: Conclusions based on the test results. (2012). Kyiv: SE NDIBK.
6. Building materials. Dense natural sand for building materials, products, structures and construction works. Specifications: DSTU B V.2.7-32-95. (1996).
7. Stark, J., Wicht, B., & Krivenko, P. (Ed.). (2008). Zement und Kalk. Kyiv.
8. Gorshkov, V.S., Timashev, V.V., & Saveliev, V.G. (1981). Methods of physical and chemical analysis of binding materials. Moscow: «Vysshaia shkola».
9. Semenov, E.I. (Ed.). (1981). Mineralogical tables. Directory. Moscow: Nedra.
10. Building materials. Solid natural crushed stone and gravel for building materials, products, structures and construction works. Specifications: DSTU B.V.2.7-75-98 (1999). Kyiv.
11. Carrying out studies on the determination of the reinforced concrete sleepers destruction causes and development of the recommendations for the concrete strength increasing: Research Report. (2011). Dnipropetrovsk: Dnipro National University of Railway Transport named after Academician V. Lazaryan.
12. Prestressed reinforced concrete sleepers for 1520 and 1435 mm gauge railways. Specifications: DSTU B.V.2.6-209:2016 (2017).
13. Building materials. Common cements. Specifications. Specifications: DSTU B.V.2.7-46:2010. (2011).

The paper was received by Editorial office on 16 December 2019