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Research Article

Assessment of the Quality of Cement Concrete Roads by X-ray Diffractometric and Chemical Analysis

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ABSTRACT

This article discusses the issue of the quality of cement concrete roads, which is important in ensuring the durability and reliability of road surfaces. The main attention is paid to the analysis of common defects, such as cracks and peeling, using the example of the Almaty-Khorgos road section. These defects can significantly impair the performance of the coating, reduce traffic safety and increase road maintenance costs. The article describes the application of X-ray diffractometric and chemical analysis for a detailed study of the mineral composition and chemical characteristics of cement-concrete mixtures. According to the results of X-ray diffractometric and chemical analysis, free lime was found in all samples taken at the studied sites. This indicates an accelerated process of concrete hydration, which can lead to a number of negative consequences. The research presented in the article confirms the hypothesis about the effect of portlandide on increasing the strength of concrete by increasing internal stress. The presence of many microcracks on the surface of the concrete coating confirms this assumption. The data obtained make it possible to identify the main factors affecting the durability of the coating and propose effective measures to prevent the formation of cement concrete defects during installation and operation.

Keywords: Cement concrete roads, X-ray diffraction analysis, chemical analysis, pavement durability, concrete defects.

INTRODUCTION

The quality of cement concrete roads is a key factor determining the durability and reliability of road surfaces. During operation, such roads are subject to various types of damage, among which cracks and peeling are the most common. Concrete quality issues have been investigated by domestic scientists based on various research works [1–4]. Figure 1 shows these defects of the section of the Almaty-Khorgos cement concrete road. These defects can significantly worsen the performance characteristics of the coating, reduce traffic safety and increase the cost of repair and maintenance of roads. Therefore, timely examination and analysis of the causes of cracks and peeling are important tasks to maintain the high quality of the road network. The formation of cracks and peeling of the surface of cement concrete roads can be caused by many factors, including mechanical loads from vehicles, climatic conditions, the composition and quality of materials used in construction, as well as technologies for laying and surface care [5-6]. Understanding the nature and mechanism of these defects makes it possible to develop effective measures to prevent and eliminate them, which helps to extend the service life of roads and reduce the cost of their operation.

a)

b)

Figure 1. Road defects: a) hairline cracks and b) peeling.

In conditions of constantly increasing traffic intensity and climatic changes, it is especially important to ensure the stability of roads to various types of impacts, including mechanical loads, temperature fluctuations and chemical aggression. One of the critical aspects affecting the durability of cement concrete coatings is the composition and structure of the materials used. Given the accumulated years of experience of scientists, the use of different approaches and qualitative research method allows researchers to get the most accurate result [7-8]. Therefore, accurate assessment and quality control are key aspects in the construction and operation of road infrastructure. This article presents part of a comprehensive study of the condition of cement concrete roads during operation, including an assessment of their quality using X-ray diffractometric and chemical analysis of cement concrete. This research was carried out on the section of the Almaty-Khorgos highway, where core samples were taken for analysis.

Modern methods of analysis, such as X-ray diffractometric and chemical analysis, make it possible to study in detail the mineral composition and chemical characteristics of cement-concrete mixtures. X-ray diffractometric analysis provides information about the crystal structure of materials, allowing the identification of phases and the estimation of their quantity. Chemical analysis, in turn, makes it possible to determine the content of basic oxides and other chemical components that affect the properties of concrete.

This article presents a study aimed at assessing the quality of cement concrete roads using X-ray diffractometric and chemical analysis methods. The purpose of the work is to identify the main factors affecting the durability and performance properties of the pavement, and to develop recommendations to prevent the occurrence of defects in cement concrete. The results of the study will improve the quality and reliability of road infrastructure, which is important for ensuring safe and sustainable traffic on highways.

1 METHODOLOGY

Cement concrete studies were carried out on the section of the Almaty-Khorgos highway in operation (108 and 305 km). To assess the quality of road construction, a core sample was taken at different locations of the road section under study. The location of the road section locations are shown in Figure 2.

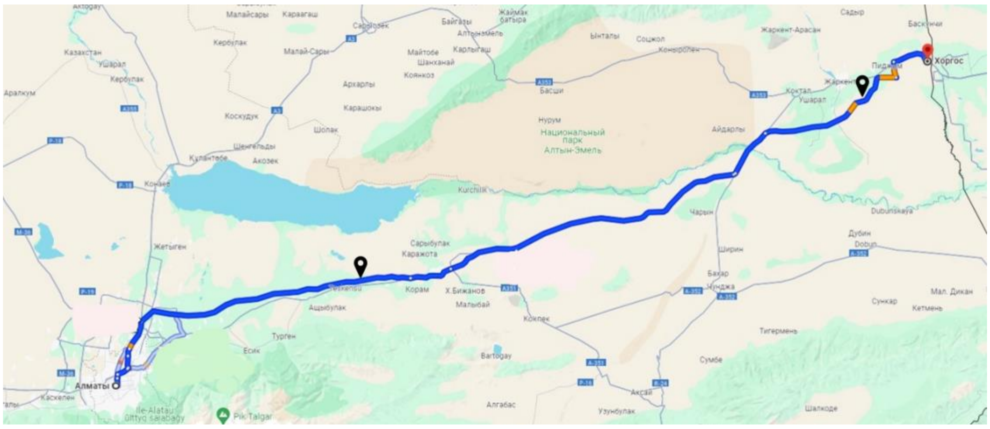


Figure 2. Location of core sampling locations.

The mineralogical and chemical composition of cement concrete were the control indicators characterizing the quality of performance and condition of the highway.

The sequence of studies:

- drilling of cores on the road section under study;
- X-ray diffractometric analysis of cement concrete;
- chemical analysis of cement concrete;
- processing and analysis of the results.

Core drilling was carried out using a core collector with a diamond crown with an inner diameter of 100 mm (Figure 3).

a) b)

Figure 3. Core sampling: a) K1 – core 108 km and b) K2 – core 305 km.

X-ray diffractometric analysis of cement concrete samples was performed in order to determine its mineralogical composition, as well as the phase composition and crystal structure of the material. X–ray diffraction analysis was performed on an automated DRON-3 diffractometer using CuKa radiation and a β filter. Diffractogram shooting conditions: voltage U = 35 kV; current I = 20 mA; shooting method θ-2θ; detector rotation speed — 2 degrees/min. Semi-quantitative X-ray phase analysis was performed on the basis of diffractograms of powder samples using the equal investment method and artificial mixtures. The interpretation of diffractograms was carried out using data from the ICDD card file: the PDF 2 Powder Diffraction analysis database (Powder Diffraction File) of 2022 and the HighScorePlus software.

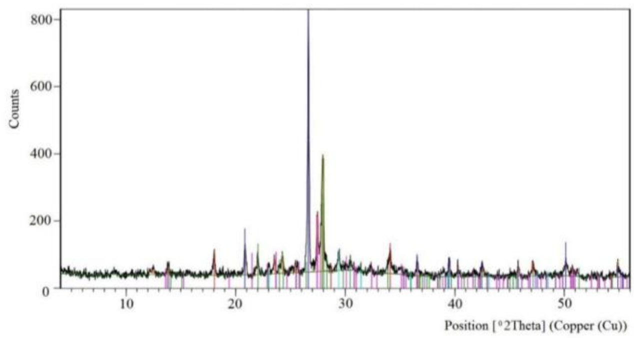
Chemical analysis was performed to determine the chemical composition of cement concrete and the concentration of all components. Chemical analysis is a rather laborious process, which was carried out with the help of special equipment. The interpretation of the obtained chemical analysis results will allow us to assess the quality of the cement used and various aggregates of cement concrete, as well as an assessment of compliance with the technological process of construction.

2 TEST RESULTS

Table 1 shows possible impurities, the identification of which is difficult due to their low content, the presence of only 1-2 diffraction peaks or weak crystallization. Figure 4, Figure 5 shows a diffractogram of a cement concrete sample K1, K2. The results of the semi-quantitative analysis of the crystalline phases are also shown in Table 2.

Table 1. Interplane distances and phase composition of samples

Pos. [2Th.]	d-spacing [A]	Rel. Int. [%]	Matched by
12.3755	7.15251	1.75	
13.8156	6.41003	2.58	00-041-1480; 01-077-0982
18.0506	4.91456	9.08	01-078-0315
20.8626	4.25805	11.78	01-070-7344
22.0245	4.03599	7.22	00-041-1480
23.5481	3.77819	6.22	00-041-1480; 01-077-0982
24.2584	3.66914	7.40	00-041-1480
25.4115	3.50520	2.56	00-041-1480; 01-077-0982
26.6386	3.34645	100.00	01-070-7344; 00-041-1480
27.4953	3.24410	22.59	01-077-0982
27.9583	3.19142	44.20	00-041-1480; 01-077-0982
29.4228	3.03583	6.76	01-071-3699
34.0988	2.62946	9.30	01-078-0315; 00-041-1480
36.5778	2.45675	5.30	01-070-7344; 01-078-0315; 00-041-1480; 01-077-0982
39.4863	2.28223	5.84	01-070-7344; 00-041-1480; 01-077-0982; 01-071-3699
40.3198	2.23696	3.49	01-070-7344; 01-077-0982
42.5440	2.12502	3.44	01-070-7344; 00-041-1480
45.8102	1.98083	3.36	01-070-7344; 00-041-1480
47.1230	1.92866	4.89	01-078-0315; 01-071-3699
50.1556	1.81893	5.10	01-070-7344
54.8632	1.67347	6.00	01-070-7344



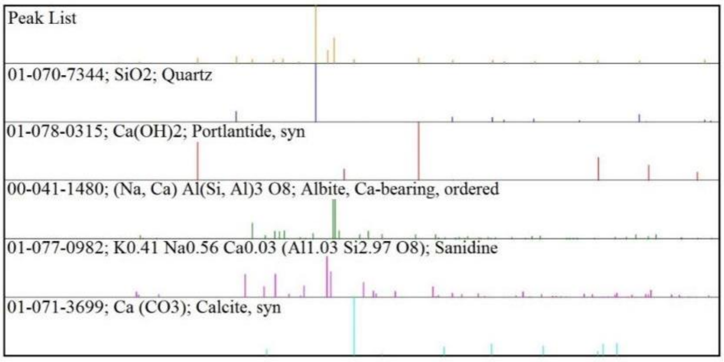


Figure 4. Diffractogram of a sample of cement concrete K1

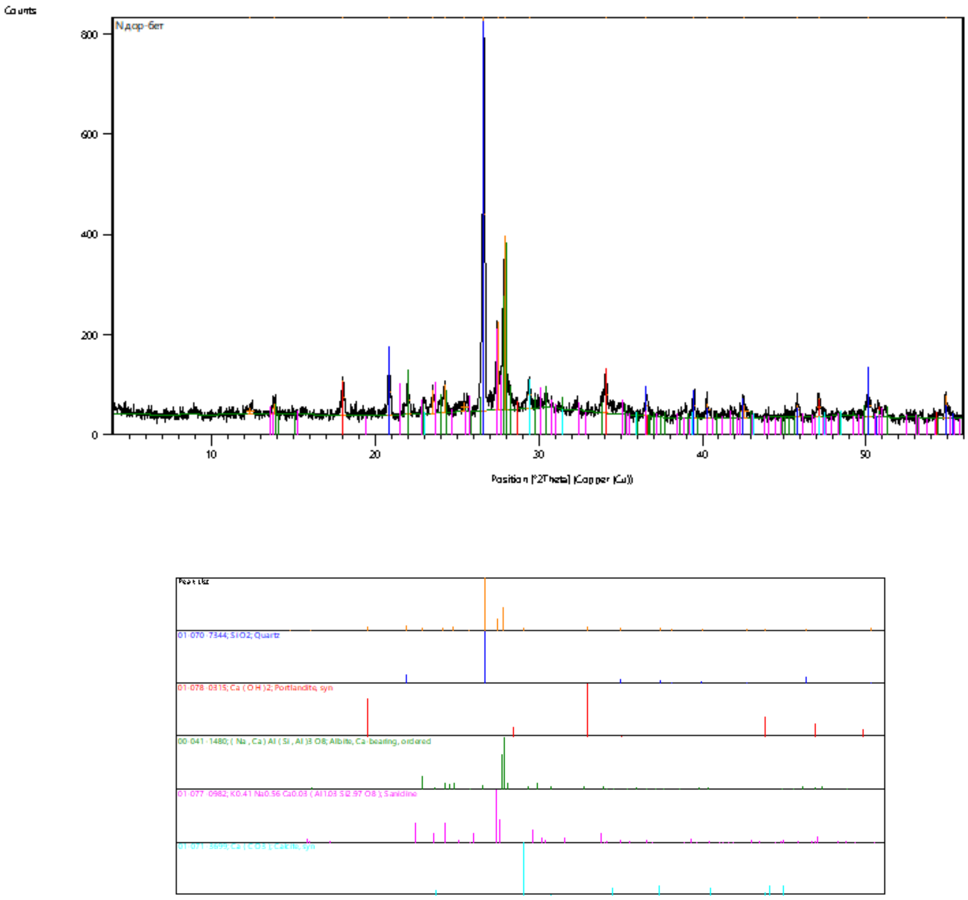


Figure 5. Diffractogram of a sample of cement concrete K2

Table 2. Results of semi-quantitative analysis of crystalline phases

Ref. Code	Compound Name	Chemical Formula	Mineral Name	RIR	Semi Quant [%]
01-070-7344	Silicon Oxide	SiO_2	Quartz	3.050	29
01-078-0315	Calcium Hydroxide	$Ca(OH)_2$	Portlandite, syn	3.460	3

00-041-1480	Sodium Calcium Aluminum Silicate	(Na , Ca) Al (Si , Al)$_3$ O8	Albite, Ca-bearing, ordered	1.060	36
01-077-0982	Potassium Sodium Calcium Aluminum Silicate	K0.41 Na0.56 Ca0.03 (Al1.03 Si2.97 O8)	Sanidine	0.600	31
01-071-3699	Calcium Carbonate	Ca (CO$_3$)	Calcite, syn	3.230	2

The results of X-ray diffractometric analysis show that free lime is present in all samples taken at the studied sites. Its presence indicates an acceleration of the concrete hydration process, which entails a number of negative consequences.

The cement hydration process takes place according to the following steps. The primary strength of concrete is achieved due to the interaction of an alkaline medium with aluminum oxide Al_2O_3, after which free lime $Ca(OH)_2$ (alkali) passes from a chemical reaction to another mineralogical state. The subsequent strength is achieved due to the work of SiO_2, calcium oxide and gypsum, and the interaction of these elements. If, after hardening for 28 days, the pH of the water in which the sample is placed shows an alkaline environment, there is a risk of migration of free lime, the formation of flakes. If the Al_2O_3 in the cement composition is in the range from 3 to 8%, there will be an increase in strength and internal tension (brittleness). As a result, we can observe the following negative consequences: cracks, chips, peeling and warping; internal peeling and destruction of concrete will occur after complete hydration of Al_2O_3. These effects depend on the influence of water and the amount of Al_2O_3 in the cement. The internal destruction occurs from the effect of free lime on SiO_2, the thermal expansion increases from the internal tension of concrete.

Table 3, Table 4 present the results of the chemical composition of the elements and oxides of cement concrete samples.

Table 3. Chemical composition by elements

Spectrum	O	Na	Mg	Al	Si	S	K	Ca	Ti	Fe	Result
Average	53.63	1.95	0.81	4.64	19.00	0.73	1.69	14.70	0.21	2.64	100.00

Table 4. Chemical composition by oxides

Spectrum	Na_2O	MgO	Al_2O_3	SiO_2	SO_3	K_2O	CaO	TiO_2	FeO	Na_2O	Result
Average	3.05	1.60	10.49	49.67	2.33	2.52	25.68	0.44	4.21	3.05	100.00

According to the regulatory document of the Republic of Kazakhstan 218-127-2016 "Recommendations on rational compositions for cement-concrete road coverings taking into account the climatic conditions of Kazakhstan" paragraph 4.1, Portland cement aluminium oxide should be from 4% to 8%, while laboratory experiments on chemical composition according to the diagram amount to more than 10%.

CONCLUSION

The conducted studies presented in the article confirm the hypothesis of the influence of portlantide ($Ca(OH)_2$) to increase the strength achieved by increasing the internal tension of concrete, which leads to both an increase in strength and high brittleness of concrete. These results are confirmed by a multitude of micro cracks on the surface of the concrete coating.

1) According to X-ray phase analysis, the content of portlandite in various sites varies from 3 to 5%, which indicates its activity. The article discusses the influence of aluminum oxides in the structure of concrete on the condition of

highways. In areas with a high content of portlantide and aluminium oxide, the surface of the cement concrete coating has a large number of filamentous cracks caused by high internal tension of the cement concrete coating, thus, under systematic dynamic loads, the cement concrete coating will gradually collapse, increasing its strength.

2) The presented results of samples with a relatively low content of aluminium oxide and a high content of portlantide lead to corrosion of the surface of the cement concrete coating, this process is caused by the fact that when exposed to rainwater, portlantides migrate through the concrete body, and since aluminium oxides are completely hydrated, portlantide binds salts into compounds and rushes to the surface of the concrete coating, which causes peeling of the surface. Peeling of the surface is formed in places where there is a large accumulation of water or its constant impact.

According to the results obtained, it is necessary to change the attitude to the composition of concrete, identifying the main aspects that allow to increase the service life of the pavement:

1) It is recommended to establish requirements for the bending strength of the cement binder.

2) Define strict requirements for the content of aluminium oxides in cement binder for cement concrete roads

3) It is necessary to ensure control over the hydrogen index of the tested samples measuring the pH of the water in which the samples are placed. increased alkalinity indicates the presence of caustic substances, which will subsequently increase the internal tension, and after peeling of the coating surface.

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