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Application of Fibrous Fillers in Cement Concrete for Road Construction

[1]**BAIDZHANOV Dzhumageldi,** *Dr. of Tech. Sci., Professor, bdo3@yandex.kz,*
[1]***AISANOVA Madina,** *doctoral student, madinochka222@mail.ru,*
[1]**TOIMBAYEVA Bakyt,** *Master, Senior Lecturer, toimbayeva@mail.ru,*
[2]**ILINA Liliya,** *Dr. of Tech. Sci., Professor, l.ilina@sibstrin.ru,*
[1]**DIVAK Lyudmila,** *Master, Senior Lecturer, lesikdi@mail.ru,*
[1]*NPJSC «Abylkas Saginov Karaganda Technical University», Kazakhstan, Karaganda, N. Nazarbayev Avenue, 56,*
[2]*Novosibirsk State University of Architecture and Civil Engineering (Sibstrin), Russia, Novosibirsk, Leningradskaya Street, 113,*
**corresponding author.*

Abstract. *Nowadays the road surfaces of motorways (autobahns) are experiencing a significant increase in cargo traffic and traffic intensity, in this regard, one of the ways to increase the durability of road structures is the use of cement concrete coatings. Cement concrete coating has a number of advantages: high strength and frost resistance, longer service life, stability of the coefficient of adhesion of the coating to the wheels of cars. Fillers are used to increase the durability of cement concrete coatings and to obtain high-strength concretes. Fillers improve the grain composition, microstructure and reduce the porosity of concrete. One of these fillers is wollastonite and its fibers. The purpose of this work is to study the use of fibrous materials in the production of cement concrete road surfaces, to determine the basic mechanical properties of cement beams, in particular concrete based on fibers (fibers). Scientific research methods used in the work – analysis, observation, experiment, modeling.*

Keywords: *road concrete, pavement, cement concrete, fiber concrete, fiberglass, asbestos fiber, basalt fiber, wollastonite.*

Introduction. In the Message of the President of the Republic of Kazakhstan Kassym-Jomart Tokayev (September 2, 2019), the task was set to reconstruct and provide 24 thousand kilometers of roads (all republican roads) with road service by 2025. The President also emphasized that for the development of tourism it is crucial to ensure the construction of the necessary infrastructure, primarily roads [1].

The constant and rapid growth in the turnover of motor vehicles necessitates the construction of the most durable and durable highways in the country. In this regard, it is advisable to use road clothes made of cement concrete during heavy traffic of heavy vehicles and on high-speed autobahns [2]. In comparison with asphalt concrete coatings, such coatings have better transport and operational qualities.

The main advantages of cement concrete coatings are:

1. High coefficient of adhesion.
2. High bearing capacity of cement concrete in comparison with asphalt concrete.
3. A lighter coating that provides greater safety in the dark and less need for lighting.
4. On concrete roads, fuel costs are less than on asphalt concrete surfaces, due to the lower coefficient of rolling friction when the wheels come into contact with the coating.
5. When laying pavement made of cement concrete, there are fewer emissions of harmful substances in comparison with asphalt concrete coatings where bitumen is used. And also the cost of bitumen is rapidly becoming more expensive, which leads to an increase in prices for road construction.
6. Cement concrete coatings are characterized by a long repair period in comparison with asphalt concrete coatings.

At the moment, the length of highways with cement-concrete pavement in the USA is 60%, in Belgium – 40-50%, in Germany it is 30-35%, in Russia only 2%. Several cement-concrete roads have been implemented in Kazakhstan: «Astana-Shchuchinsk» and «Astana-Karaganda-Balkhash-Almaty». According to world practice, the average service life of cement-concrete roads is 26 years.

One of the main reasons of road surfaces' destruction is their low durability. The specific operating conditions of road surfaces associated with the simultaneous impact of mechanical loads, as well as physical and chemical environmental factors, adversely affect the operation of road surfaces [3]. Road surfaces made of cement concrete must be strong, durable, withstand cyclical effects of environmental factors, dynamic and statistical loads from moving vehicles.

To ensure the required characteristics, it is proposed to use fiber concrete. World experience demonstrates that dispersed reinforcement of concrete with various fibers is the most optimal and is increasingly widely used in many areas of construction. At the moment, multilevel reinforcement is effective, where the reinforcing elements at the macro–scale level are fibers, and at the micro-scale level are highly dispersed mineral fillers introduced into the molding mixture together with cement [4]. Steel wire, glass, basalt, polypropylene fibers, etc. are usually used as fibers.

Steel fiber increases the strength of concrete to tensile and tear forces, reduces shrinkage of the material and cracking. In concrete with steel fiber, the grade of frost resistance, heat resistance and water resistance increases. Due to the use of steel fiber in concrete structures instead of a full-fledged metal frame, the cost of products decreases. Materials with steel fiber are used for the construction of railway sleepers, building bases, road surfaces, monolithic frames. One of the disadvantages of using steel fiber in concrete structures is the increased wear of concrete mixing equipment.

Glass fiber has a high modulus of elasticity, which allows concrete to be more plastic, but at the same time glass fibers are not adapted to the alkaline environment of the concrete mixture. In this regard, concrete is impregnated with polymers and substances are used to bind with alkalis. The result is a material with unique properties, such as: high impact resistance, resistance to temperatures, moisture and chemicals, abrasion. The use of fiberglass has found itself in the creation of noise-proof structures, waterproofing and finishing materials.

Basalt fiber contributes to the improvement of impact resistance, crack resistance and resistance to deformation. It is used in such structures as the foundations of parking lots of motor transport, road surfaces, hydraulic structures, railway structures.

Synthetic fibers (polypropylene, polyethylene, etc.) increase the resistance of concrete to stretching, the action of various chemicals, elevated temperatures and leads to a decrease in such properties as electrical conductivity. The main advantage of synthetic fiber is the low weight of structures. In this regard, synthetic fiber is used in the production of foam block products, porous concrete composites and small-sized structures.

Scientific studies represent that it is more effective to use basalt and asbestos fibers as fibers. Asbestos has a number of advantages, such as:

1) High tensile strength;
2) Heat resistance, fireproof, low heat conductivity;
3) Weather resistance;
4) Alkali resistance and resistance to seawater;
5) Cheapness and accessibility.

However, the use of asbestos fibers is treated differently. In some countries, an anti-asbestos campaign is underway. In this regard, an analogue was selected, such as wollastonite.

According to the patent search, invention No. 20697 was analyzed, where road concrete for coatings and bases of highways and airfields, including stone aggregates from crushed stone, cement and water, additionally contains wollastonite fractions of 0-20 mm. The authors of the invention are Chernoglazova T.V., Iskandarov T.R., Bekbosynov [5].

In turn, wollastonite is a mineral from the silicate class, a natural calcium silicate of the pyroxenoid subclass of the chain silicate group with the formula $Ca[SiO_2]$. The color of wollastonite is white with a grayish or brownish tinge. Wollastonite is an alternative to asbestos, unlike it is not a carcinogen. Wollastonite, depending on the length of the fibers, is divided into: long- and short-fiber. Figure 1 shows a photo of wollastonite.

The main deposits of this mineral are countries such as China, India, Finland. Mineral reserves have also been found in Serbia, Russia, Australia and Greece. Synthetic wollastonite is also isolated, but its production is limited and is carried out in countries such as the USA, Denmark, Italy, Germany, Russia. The artificial production of wollastonite differs significantly in that it lacks various impurities. Synthetic wollastonite can be obtained using industrial waste, such as aerated concrete, silicate bricks.

According to the structure, wollastonite is a repeating tetrahedron of silica, where they are connected along the edges through oxygen and calcium, forming 8-facets. This needle-like structure contributes to the absence of splitting.

There are large deposits of wollastonite ores in the Republic of Kazakhstan, such as:

1) Akkul-Kara;
2) Aktasty;
3) Alaigyr;
4) Aksoran;
5) Bosaginskoe;
6) Khairuzovskoe.

Chemical composition of wollastonite ores of the Alaigyr deposit,%: SiO_2 – 40,4, TiO_2 – 0,08, Al_2O_3 – 2,8, Fe_2O_3 – 0,25, FeO – 0,65, CaO – 40,0, MgO – 0,95, MnO – 0,09. The chemical composition of the wollastonite ores of the Bosaginsky deposit is slightly different: SiO_2 – 46,09-49,6 (47,5), TiO_2 – 0,033-0,27 (0,13), Al_2O_3 – 0,5-2,97 (1,4), Fe_2O_3 + FeO – 2,15-6,82 (4,5), CaO –

Figure 1 – Photo of wollastonite

33,53-41,23 (38,29), MgO – 1,31-3,27 (1,95), MnO – 0,47-0,88 (0,7). These deposits were discovered in the early 60-70s of the XX century and are prospective for use as additives in building materials.

At the Altai State Technical University named after I.I. Polzunov (Barnaul) under the leadership of Sadrasheva A.O., the possibility of using local wollastonite (Sinyukhinskoye deposit) as a mineral additive to cement was considered. The wollastonite additive was introduced into the mixture in an amount of 5-20% by weight of cement. Then the samples were molded and subjected to heat and humidity treatment. The results of testing the cement stone for compressive strength showed high results with the addition of wollastonite up to 20%. The author associates this reinforcing effect with the rough surface of wollastonite, which has chemisorption properties. The efficiency of fiber reinforcement is calculated by the ratio of the crystal length L to its diameter d, the greater this ratio (L/d), the higher the strength characteristics of the material properties [6].

Employees Panina A.A., Gubaidullina A.M., Kornilov A.V. of Tsniigeolnerud also considered the possibility of using wollastonite as a filler additive of portland cement. Natural wollastonite of 2 samples was used in the studies: long-fiber No. 1 and short-fiber No. 2, where the content of SiO2 is 51.5%, CaO is 43.5%. Wollastonite was introduced into M400 grade portland cement in an amount of 5-25% by weight of cement [7].

Based on the results obtained, it is clearly seen that when using short-fiber wollastonite in an amount of 15%, a significant increase in compressive and bending strength is observed. At the same time, the cement grade increases from M400 to M500. In comparison with long-fiber wollastonite, the increase in strength is insignificant and is achieved at 5% of the cement weight.

Further, the authors found that the addition of wollastonite into the composition increases the water demand of cement dough. At 15% of wollastonite, the normal density increased from 28 to 34%. The setting time has changed: the beginning of setting of the initial cement is 2 hours 10 minutes, the beginning of setting with a wollastonite content of 15% is 4 hours 10 minutes; the end of setting of the initial cement is 4 hours 50 minutes, the end of setting with a wollastonite content of 15% is 5 hours 50 minutes.

Also in the journal «Building Materials» Panina A.A. and Lygina T.Z. considered such additives to portland cement as zeolite-containing siliceous rock formation (ZCSF) and enriched wollastonite. According to its composition, ZCSF consists of: SiO_2 – 59,09%, Al_2O_3 – 6,91%, Fe_2O_3 – 2,11%, CaO – 12,64%, MgO – 1,18%, Na_2O – 0,12%, K_2O – 1,31%, ППП – 6,21%. In turn, wollastonite consists of 51% of SiO_2, Al_2O_3 – 0,6%, CaO – 4%, Fe_2O_3 – 1,2%, MgO – 0,14%. [8].

The addition of 10 and 15% activated wollastonite increases the compressive strength of portland cement by 19 and 21%, respectively. The optimal amount of natural inactivated wollastonite is 7-9%, while the compressive strength increases by 15-20%.

We have conducted research on the use of wollastonite as an additive to portland cement. TREMIN 939 was chosen as a filler, for the production of which pretreated wollastonite is used, which is then ground without iron. The surface of the filler is covered with organosilicon compounds. This wollastonite has a pronounced needle-like structure, shown in Figure 2.

Table 1 shows a typical chemical analysis in percentage.

To begin with, there was considered the ability of interaction of wollastonite in cement beams. That is why wollastonite was added to Portland cement M400 in an amount of 5, 10, 15% by weight of cement.

On the 28th day, the beams were tested for compressive strength. The tests were carried out on certified equipment and presses. Figures 3 and 4 show photographs of cement beams with and without additives, as well as the tests carried out.

Scientific results. The results of the study showed that the addition of wollastonite increases the grade of cement from M400 to M500. Compressive strength on the 28th day showed an increase of 10% with the amount of wollastonite 10% by weight of cement. When wollastonite is added in an amount of 5%, there is no significant increase in strength.

Conclusions. Thereby, in the conditions of progressive motorization, increased cargo traffic, intensive destruction of the existing transport network, the fragility of the current coating, there

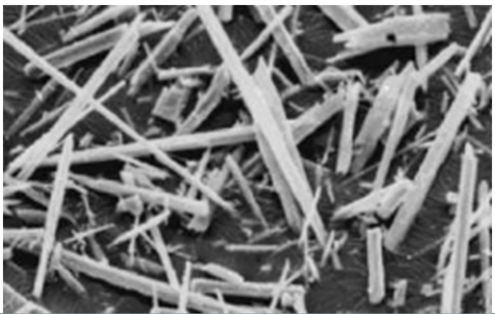

Figure 2 – Microstructure of wollastonite TREMIN 939

Typical chemical analysis of TREMIN 939

№	Chemical compounds	Percentage, %
1	SiO_2	50
2	Al_2O_3	1
3	Fe_2O_3	0,3
4	CaO	45
5	MgO	0,8
6	Na_2O+ K_2O	0,2
7	Losses during calcination of 1000 deg. under Celsius	3

Figure 3 – Cement beams with and without wollastonite

Figure 4 – The process of testing cement beams on a hydraulic measuring press PGN-500

is an alternative to the construction of highways with cement concrete coating. This will lead to minimizing the costs of road construction in the long term, increasing the transport and operational characteristics and high-quality roads.

Due to the fact that road concrete works in difficult operating conditions, there are special requirements for the materials used. This article suggests options for using wollastonite fibers as concrete fillers that contribute to improving the physical and mechanical properties of road surfaces. The introduction of a filler-wollastonite into the composition of portland cement proves an improvement in the strength characteristics of cement and concrete in general.

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Жол құрылысы үшін цемент-бетондағы талшықты толтырғыштарды қолдану

[1]***БАЙДЖАНОВ Джумагельды Омарович,*** *т.ғ.д., профессор, bdo3@yandex.kz,*
[1]****АЙСАНОВА Мадина Акпановна,*** *докторант, madinochka222@mail.ru,*
[1]***ТОИМБАЕВА Бакыт Мухамедиевна,*** *магистр, аға оқытушы, toimbayeva@mail.ru,*
[2]***ИЛЬИНА Лилия Владимировна,*** *т.ғ.д., профессор, l.ilina@sibstrin.ru,*
[1]***ДИВАК Людмила Анатольевна,*** *магистр, аға оқытушы, lesikdi@mail.ru,*
[1]*«Әбілқас Сағынов атындағы Қарағанды техникалық университеті» КеАҚ, Қазақстан, Қарағанды, Н. Назарбаев даңғылы, 56,*

[2]Жаңасібір мемлекеттік сәулет-құрылыс университеті (Сибстрин), Ресей, Жаңасібір, Ленинградская көшесі, 113,

*автор-корреспондент.

Аңдатпа. *Бүгінгі таңда автомагистральдардың (автобандардың) жол төсемдері жүк ағыны мен қозғалыс қарқындылығының едәуір артуын сезінуде, осыған байланысты жол конструкцияларының беріктігін арттыру тәсілдерінің бірі цемент-бетон жабындарын пайдалану болып табылады. Цемент-бетон жабынының бірқатар артықшылықтары бар: жоғары беріктік пен аязға төзімділік, ұзақ қызмет ету мерзімі, автомобиль дөңгелектерімен жабынның адгезия коэффициентінің тұрақтылығы. Цемент-бетон жабындарының беріктігін арттыру және жоғары берік бетон алу үшін толтырғыштар қолданылады. Толтырғыштар астық құрамын, микроқұрылымды жақсартады және бетонның кеуектілігін азайтады. Осындай толтырғыштардың бірі-волластонит және оның талшықтары. Бұл жұмыстың мақсаты цемент-бетоннан жол жабындарын өндіруде талшықты материалдарды пайдалануды зерттеу, цемент арқалықтарының, атап айтқанда талшық (талшық) негізіндегі бетонның негізгі механикалық қасиеттерін анықтау болып табылады. Жұмыста қолданылатын ғылыми зерттеу әдістері-талдау, бақылау, эксперимент, модельдеу.*

Кілт сөздер: *жол бетоны, жол жамылғысы, цемент-бетон, фибробетон, шыны талшық, асбест талшығы, базальт талшығы, волластонит.*

Применение волокнистых наполнителей в цементобетоне для дорожного строительства

[1]***БАЙДЖАНОВ Джумагельды Омарович,*** *д.т.н., профессор, bdo3@yandex.kz,*
[1]****АЙСАНОВА Мадина Акпановна,*** *докторант, madinochka222@mail.ru,*
[1]***ТОИМБАЕВА Бакыт Мухамедиевна,*** *магистр, старший преподаватель, toimbayeva@mail.ru,*
[2]***ИЛЬИНА Лилия Владимировна,*** *д.т.н., профессор, l.ilina@sibstrin.ru,*
[1]***ДИВАК Людмила Анатольевна,*** *магистр, старший преподаватель, lesikdi@mail.ru,*
[1]*НАО «Карагандинский технический университет имени Абылкаса Сагинова», Казахстан, Караганда, пр. Н. Назарбаева, 56,*
[2]*Новосибирский государственный архитектурно-строительный университет (Сибстрин), Россия, Новосибирск, ул. Ленинградская, 113,*

**автор-корреспондент.*

Аннотация. *На сегодняшний день дорожные покрытия автомагистралей (автобанов) испытывают существенное увеличение грузопотока и интенсивности движения, в связи с этим одним из способов повышения долговечности дорожных конструкций является применение цементобетонных покрытий. Цементобетонное покрытие обладает рядом преимуществ: высокая прочность и морозостойкость, более длительный срок службы эксплуатации, стабильность коэффициента сцепления покрытия с колесами автомобилей. Для повышения долговечности цементобетонных покрытий и получения высокопрочных бетонов используют наполнители. Наполнители улучшают зерновой состав, микроструктуру и уменьшают пористость бетонов. Одним из таких наполнителей является волластонит и его волокна. Целью данной работы является использование волокнистых материалов в производстве дорожных покрытий из цементобетона, определение основных механических свойств цементных балок, в частности бетона на основе фибр (волокон). Научные методы исследования, использованные в работе, – анализ, наблюдение, эксперимент, моделирование.*

Ключевые слова: *дорожный бетон, дорожное покрытие, цементобетон, фибробетон, стекловолокно, асбестовое волокно, базальтовая фибра, волластонит.*

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