Use of “Lean” Concrete Mixes for Road Construction in the Arctic Regions

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Abstract. The article presents experimental data on the study of the physical-mechanical properties of modified “lean” concrete. Magnesium nanospinel with mechanically activated cement and sand were used as modifiers. The prospect of modifying “lean” concrete by introducing mechanically activated parts of cement binder and fine aggregate has been established. Optimal formulations and technological conditions for manufacturing modified “lean” concrete were developed for the construction of the pavement base course in the Arctic regions.

1. Introduction
The development of the natural resources of the Far North is one of the priority directions of the state policy of Russia in the 21st century. It requires the creation of modern transport infrastructure in the regions of the North [1, 2]. The economic activities and life sustaining of the indigenous peoples of the North, as well as the operation of industrial, military and research facilities, require regular supplies of food and fuel. Transportation expenses on commodity prices in the Arctic regions are up to 60% instead of 10%, typical for mid-latitudes. Therefore, special attention should be paid to the quality of roads [3].

2. Relevance
Road construction in the Arctic is performed under extreme climatic conditions. The construction of the subgrade must be arranged based on the principle of the minimum allowance of permafrost thawing, according to the Law of the Republic of Sakha (Yakutia) “On the Protection of Permafrost in the Republic of Sakha (Yakutia)” dated May 22, 2018, N 2006-3 N 1571-V, the main principles of which are scientific validity, systematic and a comprehensive approach to permafrost protection.

Hence, road pavement combined with asphalt concrete surfacing and a base of hard mixes, “lean” concrete, has a promising outlook. Compared to heavy concrete, “lean” concrete is a building material, in which the amount of cement and water is significantly reduced, and the content of aggregate (crushed stone, sand) is increased [4].
The existing experience of using such structures in Russia and abroad has shown a number of advantages over a traditional pavement:
- low shrinkage and stability of deformation properties under temperature influences;
- increased evenness and rigidity of the road pavement, which allows reducing the number of asphalt concrete layers laid above;
- long service life and, as a result, low road maintenance costs;
- simplified construction technology with the use of available tools and mechanisms [5].

Strict requirements for manufacturability and strength of concrete mix for road construction in modern conditions lead to the need to use modifying additives to produce composite materials with increased operational properties [6, 7].

Modern scientific research on improving the efficiency of building materials is aimed not only at obtaining new ones but also at improving the properties of already known materials, for example, by using nanodispersed components. The introduction of nanoparticles as modifiers can significantly increase the strength characteristics of various materials, their service life, resistance to external influences, such as temperature and humidity fluctuations, and air pollution [8-10]. They are also designed to affect the formation of concrete microstructure, optimization correlation of amorphous and crystalline components of hardening cement stone, regulation of chemical-mineralogical, dispersed and morphological composition and state of newly formed newgrowths [11]. All this influences on the processes that occur at various stages of structure formation, which also affects the features of nanomodified mixtures [12].

The purpose of this work is to study the physical-mechanical properties of lean concrete with various modifiers for the construction of pavement base course in the Arctic regions.

3. Methodology

Portland cement PC 400 D0, which complies with the requirements of GOST 10178-85, crushed limestone produced by OAO Yakutcement, as well as river sand from the Lena floodplain, were used as the initial raw material. The fineness modulus of the sand was Mk=1.1-1.3 and related to the “extra fine” group. Its bulk density was 1395 kg/m³, the content of flour and clay particles varied from 0.9 to 1.3%, and the content of harmful impurities was 0%. The grain-size distribution of crushed limestone conformed the standards of GOST 26633 and included 40% of 5-10 mm fractions and 60% of 10-20 mm fractions. The content of flour and clay particles in the crushed limestone did not exceed 2 wt.%. The content of thin flattish (flaky) and needle-shaped grains in large aggregate did not exceed 35 wt.%. Modifying additives were the following:
- magnesium nanospinel powder, characterized by high dispersion of particles (50-70 nm), a developed specific surface (40-170 m² / g) and equal ratio of the oxide phases of magnesium and aluminum;
- mechanically activated Portland cement;
- mechanically activated sand.

The proportion of the mix was selected according to GOST 27006. The final composition of the concrete mixture consisted of 53 wt.% of crushed stone, 30 wt.% of sand, and 10 wt.% of cement. In the modified concrete mix, the content of activated cement varied from 5 to 15 wt.% of the weight of the initial binder, activated sand varied from 10 to 30 wt.% of the weight of inactive sand, and magnesium nanospinel was from 0.01 to 1.0 wt. %.

For a uniform distribution of nanoparticles over the concrete volume, a stable weakly concentrated water suspension was obtained from them, which was introduced into the concrete mix together with mixing water. The water-cement ratio was 0.6 for all formulations.

Mechanical activation of cement and sand was performed using AGO-2 laboratory ball mill, which implements the free-blow method. The activation time of the components was 1, 3 and 5 minutes. Mechanical activation of materials will increase their specific surface area and capacity of reaction, which will have a significant impact on the formation of concrete structure, its hardening rate and physical-mechanical properties [13].
For research, cylindrical samples with a diameter of 102 ± 2 mm and square section prism-samples with a size of 100x100x40 mm were manufactured. There were 5 samples for each type and period of the test. The compaction load was 10 MPa, and the load application time was 3 minutes. Self-drying of the finished concrete samples lasted for 28 days at an air temperature of 20 ± 2 °C and air humidity of 50 ± 5%.

The physical-mechanical properties of the samples were determined according to standard methods: the compressive and tensile strength under bending — according to GOST 10180 on an IP-1A-1000 press at a loading speed of 3.5 kN/s, water absorption — according to GOST 12730.3, frost resistance — according to the accelerated method with repeated freezing and thawing by GOST 10060.2.

4. Discussion of results
To optimize the compositions, the dependence of the compressive strength of the samples on the content of magnesium nanospinel and mechanically activated cement and sand additives was studied. The results are presented in Figure 1, 2 and 3.

![Figure 1](image)

**Figure 1.** Dependence of compressive strength of samples on the content of magnesium nanospinel.

It was found that nanomodification of the concrete mix allows increasing the strength of the samples to only 15%, while the greatest effect was recorded with the introduction of 0.01 wt.% magnesium nanospinel. Its decrease was established with an increase in the amount of introduced additive (Fig. 1).

The low efficiency of using magnesium nanospinel to increase the strength properties of concrete in our case is probably due to the chemical composition of the latter, which contains oxide phases of magnesium and aluminum. It is known that an additional amount of CSH(1) is formed in cement systems with hydraulically active mineral fillers during hardening due to the interaction of Ca(OH)₂ with active silica or silica-alumina filler. The consequence of these processes is the formation of additional phase contacts (integrowth between crystalline hydrates) and an increase in the density of cement stone, which determines the high strength of the cement system [14, 15]. In the case of using an inert nanofiller (magnesium nanospinel), a slight increase in compressive strength of the samples is possible due to filling of the corresponding voids and some densification of the structure, which is consistent with experimental data [16]. According to these data, with an increased volume content of the inert nanofiller, the effect of filling voids and densification of the structure cannot compensate the negative effect of the filler on the contacts of the integrowth. Therefore, the strength decreases.
Fig. 2. Dependence of compressive strength of samples on the duration of mechanical activation of sand.

Samples, which were modified with mechanically activated sand, provide other results (Fig. 2). It was found that mechanical activation of part of the sand increases the compressive strength of modified samples up to 60%, and the maximum effect is achieved with the content of 10 wt.% sand activated for 1 min. As a result of mechanical activation of sand, its dispersion and amount in the composition increase due to an increase of newly formed surfaces, which intensifies the formation and growth of Ca(OH)$_2$ crystals.

Fig. 3. Dependence of compressive strength of samples on the duration of mechanical activation of cement.

Activation of a part of the binder is a promising method for improving the physical-mechanical properties of cement concrete along with the introduction of various additives to the concrete mix [17]. Due to the fine grinding of cement powder, the strength of concrete and the activity of the binder increase, and the hydration process accelerates [18-20]. The presented data correlate with the results presented in Figure 3. It has been established that the compressive strength of the samples increases to 62% when the composite contains 10 wt.% cement activated for 3 minutes.

The studies made it possible to recommend optimal formulations of composite materials characterized by improved strength properties (Table 1), for which tensile strength under bending, water
absorption, and frost resistance were studied. Samples modified with magnesium nanospinel were excluded from further studies due to the low efficiency of nanoadditives.

It has been established that the tensile strength of modified samples under bending increases up to 30% relative to the strength of the initial samples and up to 2 times higher than the minimum regulatory requirements of SP 34.13330.2012 (Table 1). Studies of the effect of modifying additives on the water absorption of the samples revealed that the water absorption values of these samples are reduced to 25% compared with the original samples. Besides, there is an increase in compressive strength to 47% compared to 11% for the original samples. The increase in strength of the samples after water absorption is, probably, due to the continuation of hydration processes in the cement system and further hardening of the samples.

| Composition, wt.% | σ\text{compr.}, MPa | σ\text{fizr.}, MPa | W, % | σ\text{oct. after water absorption tests}, MPa | Concrete grades on frost resistance, F | σ\text{oct. after testing on frost resistance}, MPa |
|------------------|---------------------|-------------------|------|---------------------------------------------|-----------------------------------------|-----------------------------------------------|
| Initial: Crushed stones – 53 | 9,3/7,5 | 1,9/1,2 | 4,9 | 10,4 | 75/50 | 7,6 |
| Sand – 30 Cement -10 | | | | | | |
| Crushed stones – 53 | 15/7,5 | 2,3/1,2 | 4,6 | 19,3 | 300/50 | 14,6 |
| Sand – 30 Cement -10, Activated sand - 10 (by weight of sand) | | | | | | |
| Crushed stones – 53 | 15,2/7,5 | 2,5/1,2 | 3,9 | 22,3 | 200/50 | 14,9 |
| Sand – 30 Cement -10 Activated cement - 15 (by weight of cement) | | | | | | |

*the minimum values regulated by SP 34.13330.2012 are under the bar

After frost resistance tests, the modified samples endured 5 (F200) and 8 (F300) cycles of alternate freezing and thawing with no visible signs of damage and cracking on the surface. Besides, their compressive strength decreased by only 2.7%, while the compressive strength of the initial samples decreased by 22% after 2 cycles (F100) (Table 1).

5. Conclusion

Thus, it has been established that it is possible to modify lean concrete mixtures with mechanically activated cement and sand additives to improve the basic physical-mechanical properties of road construction materials for various purposes that can be used in the climatic and soil conditions of the Arctic. Therefore, the resource and reliability of their operation in such conditions increase. Implementation of the results will improve the technical and operational quality of constructions and structures, prolong the intermaintenance period and reduce the cost of their implementation, improve the operation quality of passenger and freight vehicles, on which the competitiveness and efficiency of all economic sectors depend.
6. References

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