Modification of cement-bound mixtures with sodium formate additives for the construction of pavement bases at low air temperatures

E A Vdovin* and V F Stroganov

Kazan State University of Architecture and Engineering, 420043, Kazan, Zelenaya str., 1, Russia
*E-mail: vdivin007@mail.ru

Abstract. The paper considers the influence of an antifrosty additive of sodium formate (SF) on the kinetics of hardening of cement-bound mixes (CBM) in the bases of road pavements at air temperatures from 0°C to (-15) °C with a cement content of 7.0% and 10.0%. The authors establish that the highest intensity of CBM hardening was noted in the first 7 days of hardening, at which the strength was 50-60% of the strength of the material at the age of 28 days. The SF modifier provides an increase in compressive strength (Rcs) of the material depending on the amount of additive and air temperature. The study makes it possible to establish the optimal consumption of SF for different temperature regimes of hardening of mixtures and at the indicated cement contents. The use of SF provides a 30% set of strength at a temperature not lower than (-5) °C. Modification of CBM with additives of SF provides the opportunity to increase the volume of construction of pavement foundations by performing work during periods of the year with lower air temperatures.

1. Introduction
The development of the state’s transport system is determined by many factors, including volumes of road construction [1-4]. The increase in volumes is possible with the use of materials ensuring work in adverse conditions, especially at low air temperatures (below 0°C) [5-10]. Another direction in the development of the country’s transport strategy is the use of stone materials and soils modified with functional additives, reinforced with cement [11-33]. The use of anti-frost additives represented by a wide range of chemical compounds: chlorides, nitrates, nitrites, carbonates, sulfates and formates, etc., is known as functional additives for work at low air temperatures [34-42]. Taking into account chemical and environmental safety, compounds based on low molecular weight, low basic carboxylic acids have become very popular [42-45]. The most popular compound is sodium formate (SF) - the sodium salt of formic acid. Its widespread use as an antifrosty additive to cement concrete is well-known [46-47]. This substance has a relatively low freezing temperature, up to (-17) °C, which attracted the attention of specialists in the field of winter concreting. However, data on the use of SF in the road industry in literary sources are very scarce [48, 51].
Basing on the properties of SF and the relevance of its application to increase the volume of road construction, the following goal of the work is formulated: to study the dependences of the influence of antifrosty SF additives on the kinetics of CBM hardening in road surfaces at air temperatures from 0°C to (-15) °C with a cement content of 7.0% , 10.0% and determination of the feasibility of using a functional additive of SF when arranging CBM pavement layers at low temperatures.

2. Materials and methods
Studies were carried out on crushed stone mixtures of limestone and dolomite rocks, including substandard crushed stone of stone quarries of fractions (0-40) mm. The particle size distribution and physico-mechanical properties of the mixtures are shown in Tables 1 and 2.

| Table 1. Granulometric composition of crushed stone mixture. |
|-------------------------------------------------------------|
| Maximum grain size, (mm) | The total residue on the sieve size of the holes, (mm) |
| 40 | 20 | 10 | 5 | 2,5 | 1,25 | 0,63 | 0,315 | 0,14 |
| 40 | 5 | 37 | 56 | 70 | 80 | 85 | 86 | 88,5 | 91 |

| Table 2. Physico-mechanical properties of crushed stone mixtures. |
|---------------------------------------------------------------|
| Fraction Size (mm) | Bulk density (kg / m3) | Water absorption (%) | Abrasion Grade | Strength grade | Frost resistance indicator |
| 0-40 | 1600 | 9,1 | IV | 200 | 10 |

To strengthen the mixtures we used the most recommended for road construction Portland cement brand CEM I 42.5N. The mineral and chemical compositions of cement clinker are shown in Tables 3 and 4.

| Table 3. Mineral composition of cement clinker. |
|-----------------------------------------------|
| Name | C_3 S | C_2 S | C_3 A | C_4 AF |
| Content, (%) | 58 | 17 | 8 | 13 |

| Table 4. The chemical composition of cement clinker. |
|---------------------------------------------------|
| Name | SiO_2 | Al_2O_3 | Fe_2O_3 | a) CaO | b) MgO | SO_3 | R_2O (Na_2O+ +0,65 K_2O) | CaO_t |
| Content, (%) | 21,1 | 5,85 | 4,2 | 65,4 | 1,13 | 1,03 | 1,07 | 0,16 |

As an antifrosty additive we used sodium formate acid (HCOONa). When selecting CBM formulations, the cement content was adopted taking into account the brand strength established for road pavement. The tests were carried out on mixtures with 7% and 10% cement by weight of the crushed stone mixture.

The temperature regime of CBM hardening was changed from 0 °C to (-15) °C. As a criterion for evaluating the effectiveness of antifrosty additives, we took an indicator of the set of compressive strength during 28-day hardening at a negative temperature. In accordance with the requirements of consumers, at least 30% of the brand strength should be provided at a temperature of (-15) °C (± 5) °C at 28 days of age. To compare the test results, the process of hardening of control mixtures was studied under normal conditions (+ 20 °C).

To manufacture the samples with dimensions of 15 * 15 * 15cm, we used metal molds lubricated with a release agent. The cement-bound mixture was compacted on a laboratory vibratory platform of
type S-I35-A, which provided vertical vibrations of the filled form with a frequency of 2900 ± 100 vibrations per minute and an amplitude of 0.5 ± 0.05 mm. After preliminary aging for 2-2.5 hours, the samples were placed in chambers with different temperature and humidity conditions: in a normal storage chamber (temperature 200°C, with a relative humidity of 95%), in refrigeration chambers with constant temperatures 0°C, (-5) 0°C, (-10) 0°C, (-15) 0°C.

The compressive strength of CBM samples was determined on an MS-500 press. The kinetic dependences of the compressive strength are constructed from the averaged values of the index in points for various amounts of the SF additive (Figure 1-2).

3. Results and discussion
Similarly to cement concrete, the highest rate of curing during compression of CBM was determined in the first 7 days of hardening (Figure 1-2). We found that mixtures, regardless of the content of the physical density and temperature, have a strength in the range of 50-60% of the strength of the material at the age of 28 days.

Figure 1. Hardening kinetics of CBM with the addition of SF and cement content of 7% at different temperatures.

The research revealed that the SF contributes to an increase in the strength of the material depending on the amount of added additive and the temperature of the outside air (Figure 3.4). In these figures, in addition to the curves of the dependences of the strength of the mixtures, lines of the levels of vintage strengths and the strength of the control mixtures are plotted, and the dotted lines indicate the minimum strengths at the age of 28 days, which should be provided with the introduction of an anti-frost additive.
Figure 2. Hardening kinetics of CBM with the addition of SF and cement content of 10% at different temperatures.

We determined that the use of SF provides a 30% set of strength at a temperature not lower than -5 °C (Figure 3.4). With a 7% cement content, the level of material strength is not lower than 40 MPa (grade M40) with SF 2.5–3.0% by weight of cement. For mixtures with a high cement consumption (10%), a lower addition of SF is required: 2–2.5% to achieve the M40 grade.

Figure 3. The dependence of the compressive strength of CBM on the amount of SF additives and temperature of hardening with a cement content in the mixture of 7%.

A further increase in SF of 3.5–4.0% in the mixture provides brand strength above 60 MPa (grade M60). Modification of CBM with additives of SF provides the ability to set the required strength for layers of pavement and increase the volume of road construction by performing work during periods of...
the year with lower air temperatures. Investigations (Figs. 3, 4) made it possible to establish the optimal SF consumption for temperature hardening mixtures from 0 °C to (-15) °C with a cement content of 7% and 10%.

![Graph](image)

**Figure 4.** The dependence of the compressive strength of CBM on the amount of SF additives and temperature of hardening with a cement content in the mixture of 10%.

Analyzing the data of kinetic and strong dependences (Figure 1-4), we should note that the addition of SF provides a greater increase in strength compared to cement, although the amount of functional modifier is much smaller in absolute value. An increase in cement content by almost 1.5 times (from 7% to 10%) practically does not change the level of material strength at low temperatures, while the strength of control samples CBM (hardening at 20 °C for 28 days) increased by 1.5 times.

Lowering the hardening temperature from 0 °C to (-15) °C provides a multiple (8-10 times) decrease in the strength of the material by 28 days. In the interval (-10) - (-15) °C, the used amount of SF 4.0-4.5% does not provide a noticeable increase in strength. The question of studying the effect of increased amounts of SF (more than 4.5%) in CBM compositions for pavement requires further study. Moreover, the modification of mixtures with the introduction of additional components of additives that can increase the hardening efficiency at temperatures below (-10) - (-15) 15° C and provide the specified construction and technical properties of pavement materials is of a great interest. The subsequent hardening of CBM at positive temperatures will provide further hardening, which is known from the theory and practice of winter concreting [36–38, 42], but requires research for CBM.

4. **Conclusion**

1. In accordance with the purpose of the work, the dependences of the effect of the antifreeze additive SF on the kinetics of hardening CBM in pavement bases at air temperatures from 0°C to (-15) °C with a cement content of 7.0%, 10.0% were studied. The highest rate of hardening of CBM is
determined in the first 7 days. It was found that mixtures, regardless of the content of the physical density and temperature, have a strength in the range of 50-60% of the strength of the material at the age of 28 days. It is determined that the use of SF provides a 30% set of strength at a temperature not lower than (-5) °C. At a 7% cement content, the level of material strength is not lower than 40 MPa (grade M40) with a pressure factor of 2.5-3.0% by weight of cement. For mixtures with a high cement consumption (10%), a lower addition is required: 2-2.5% to achieve the M40 grade. A further increase in the SF of 3.5-4.0% in the mixture provides brand strength above 60 MPa (grade M60). Investigations made it possible to establish the optimal consumption of SF for temperature hardening mixtures from 0 °C to (-15) °C and with a cement content of 7% and 10%.

2. We should note that it is advisable to use a functional SF additive when arranging CBM pavement layers at low temperatures, which under these conditions provides the opportunity to set the required strength for pavement layers and increase the volume of road construction by performing work during periods of the year with adverse conditions.

3. Attention should be paid to the prospects of the development of research on the use of antifreeze additives based on SF in CBM compositions for road pavements in the direction of study:
   - modification of the material with an increased amount of antifrosty additives;
   - the possibility of increasing the hardening efficiency at temperatures below (-10) - (-15) °C by adding additional components to the modifier;
   - the processes of subsequent hardening of the material in pavements at positive temperatures.

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