Cement concrete modified by fine-dispersed anionactive bitumen emulsion for road construction

Aidar Garipov\textsuperscript{1}, Dmitry Makarov\textsuperscript{1}[0000-0001-6879-0369], Vadim Khozin\textsuperscript{1}[0000-0003-0874-316X], Sergei Stepanov\textsuperscript{1}[0000-0003-4926-8537] and Damir Ayupov\textsuperscript{1}[0000-0002-4145-5250]

\textsuperscript{1}Kazan State University of Architecture and Engineering, Kazan, Russia
E-mail: makarov@kgasu.ru

Abstract. Cement concretes are strong and able to resist external adverse environmental factors, have an increased water absorption and, as a result, insufficient frost resistance and deformability. Therefore, wide use of cement concrete in road construction is limited. Modification of road cement concrete with anionactive bitumen emulsions is a current and promising solution. By introducing small concentrations of bitumen emulsions into cement concrete, one gets a material with the basic properties of cement concrete and the properties of asphalt concrete. Rigid crystallization bonds formed as a result of cement hydration are dominantly present in cement systems, while coagulation type bonds with adhesive properties bitumen prevail in asphalt systems. Depending on the quantitative relationship between these bonds, the deformability of concrete tends to change. The main technological and operational properties of the resulting road cement concrete were investigated. Cement concrete was bituminized by introducing the anionic bitumen emulsions into the concrete mixture (from 0.5\% to 8.0\% of cement weight), which allowed increasing technological properties of concrete mixture and the performance properties of hardened concrete. This increases mobility, improves deformability of hardened concrete, increases its abrasion resistance, water resistance, frost resistance, reduces shrinkage without reducing the strength properties of road concrete.

Key words: road construction, cement concrete, bitumen emulsion, anionactive emulsifier, concrete mixture, deformability, frost resistance.

1 Introduction
Road construction is one of the most material intensive industries in Russia. Every year, a large amount of construction materials is consumed for the construction of new and the repair of existing road pavements. The most promising material to be used in road construction is cement concrete [1-3]. Cement concrete has a number of valuable attributes, namely: high strength and durability.

However, road concrete bases have a number of disadvantages, such as: low impact strength, high fragility, inability to compensate for the resulting thermal stresses. This necessitates producing and installing special temperature joints inside the roadbed.

These downsides can be reduced by introducing anionactive bitumen emulsions (hereinafter BE) into cement concrete [4]. Based on comparative analysis of available technologies [5, 6] used in making bitumen emulsions it was revealed that combined emulsification is the most effective way of producing anionactive emulsions. This allows achieving fine-dispersed emulsions even using low-active bitumen. When small amounts of BE are introduced into cement concrete, organo-mineral composite material is produced, which combines all the positive properties of traditional concrete like high durability, low fragility and increased deformability [7]. It is known from literature that rigid
crystallization bonds formed as a result of cement hydration are dominantly presented in cement systems, while coagulation type bonds with adhesive properties bitumen prevail in asphalt systems [8]. We can assume that cement concrete added with bitumen will contain the two bonds.

Depending on the quantitative relationship between these bonds, the deformability of such concrete tends to change.

The bituminous additive can be considered as a lubricant that reduces friction between two different bodies [9, 10]. Such property of emulsified bitumen can also be useful in terms of increasing the remoldability of bituminized cement concrete mix. Increasing the remoldability will reduce the amount of gauged water, i.e. will reduce the water solid ratio, which is important from the point of view of improving the operational and technical characteristics of the road cement concrete [11], including its durability [12].

The possible use of anionactive bitumen emulsions on floto tar (FG) for modification of cement concrete in different dosages [13-15], has been studied as part of the work. The anionactive bitumen emulsions are more effective than bitumen emulsions used in industrial emulsifiers [16]. The results of the research are consistent with other works [17-20].

Based on the above mentioned, the aim of the study is to assess the impact of anionic bitumen emulsions in cement systems for the production of road cement concretes with high operational and technical characteristics.

2 Materials and methods

The emulsifier of anionic floto tar type is a mixture of secondary tars obtained by distillation of fatty acids isolated from primary tars of various vegetable oils.

The general molecular formula of higher fatty acids:

\[ R - C = O \]

where R is a hydrocarbyl.

Visually the floto tar is a paste of dark brown color, which passes into a liquid state when heated up to 50-60°C. Judging by their main characteristics, they are an excellent starting product for the production of effective anionic emulsifiers (table 1).

| item number | Properties                                      | FG     |
|-------------|------------------------------------------------|--------|
| 1           | Monomeric acid content, % weight.               | 29     |
| 2           | Monomeric oligomeric content, % weight.         | 71     |
| 3           | Acid number, mg KOH/g                          | 60-80  |
| 4           | Saponification value, mg KOH/g                 | 140-150|
| 5           | Hydrogen indicator, pH                         | 10-11,4|
| 6           | Number-average molecular weight                | 920    |
| 7           | Weight-average molecular weight;               | 1120   |
| 8           | Chilling point, °C                             | 20-25  |
| 9           | Flash point, °C                                | 250    |

Based on comparative analysis of available technologies [5, 6] used in making bitumen emulsions it was revealed that combined emulsification is the most effective way of producing anionactive emulsions. This allows achieving fine-dispersed emulsions even using low-active bitumen. The traditional way of emulsifying bitumen uses ready-made soaps, whilst performing the combined
emulsification, the first half of the floto tar is introduced into bitumen, and the second is saponified in water solution. And then the both compositions are mixed in dispersant, which emulsify the bitumen.

The most important operational and technical properties of the obtained anionactive bitumen emulsion were studied. It was established that bitumen emulsion's main properties on floto tar are more effective than of bitumen emulsion on industrial emulsifiers “AMDOR” (Russia) and “Redicote” (Sweden) (table 2) [16]. As a result of research a new anionactive bitumen emulsion was developed, which is currently patented [21].

Optical microscopy is one of the main ways of studying the structure and properties of bitumen emulsions. It was used to determine the effect of developed emulsifiers on various characteristics of bitumen emulsions. The microstructure of the bitumen emulsion was studied and photographed using the Axioskop 40 microscope.

![Bitumen emulsion with 2% FG emulsifier](image)

**Figure 1.** Bitumen emulsion with 2% FG emulsifier.

The BE images (figure 1) are taken in the transmitted light at an increase of 400X, and also processed using the software product “Computer image processing system”. The program allows you to calculate

### Table 2. Comparative characteristics of bitumen emulsions.

| Properties                        | BE on the FG emulsifier | BE on the “AMDOR” emulsifier | BE on the Redicote emulsifier |
|-----------------------------------|-------------------------|-------------------------------|-------------------------------|
| 1. Mass fraction of bitumen,%     | 55                      | 55                            | 55                            |
| 2. Relative viscosity of the emulsion at 20°C, c | 20                      | 19                            | 14                            |
| 3. Sieve uniformity No. 0.14,%   | 0.3                     | 0.48                          | 0.43                          |
| 4. Storage stability ,%           | 0.35                    | 0.5                           | 0.45                          |
| - after 7 days                    | 0.5                     | 0.75                          | 0.65                          |
| - after 30 days                   |                         |                               |                               |
| 5. Transportation stability,%     | stable                  | stable                        | stable                        |
| 6. Binding film's adhesion to mineral material, score | 4                      | 4                             | 4                             |

The BE images (figure 1) are taken in the transmitted light at an increase of 400X, and also processed using the software product “Computer image processing system”. The program allows you to calculate
the plane and spatial characteristics of the structure as quickly and accurately as possible for the dark or light phases of the bitumen emulsion determining the following parameters:
- average particle size;
- coefficient of variation;
- dispersion;
- the number of particles at 10 equal intervals with their size determined.

To study these parameters, we propose to use diluted bitumen emulsion using emulsifier fivefold water solution, as it does not have a significant effect on emulsion particle size. A water solution of the emulsifier is introduced into the precooked bitumen emulsion, after which the disperse phase of the emulsion will amount to 10%. This allows a clear image of bitumen particles without overlapping and analyzing them. An emulsion with 2% floto tar content was chosen for the study (table 3, 4).

| Table 3. Characteristic of the structure for the dark phase. |
|-------------------------------------------------------------|
| Parameters       | Plane characteristics |
| Average particle size: | 1.817287475            |
| Variation factor:    | 0.452728948            |
| Dispersion:        | 0.676898882            |
| Magnification ratio:| 0.018691588            |

| Table 4. Histogram for the dark phase. |
|----------------------------------------|
| No. Pos. | Fraction (µm) | QTY of particles | Particle percentage |
|----------|---------------|------------------|---------------------|
| 1        | 0 – 0.872     | 9666             | 79                  |
| 2        | 0.872 – 1.745 | 1555             | 12.7                |
| 3        | 1.745 – 2.618 | 723              | 5.9                 |
| 4        | 2.618 – 3.491 | 179              | 1.5                 |
| 5        | 3.491 – 4.364 | 58               | 0.47                |
| 6        | 4.364 – 5.237 | 17               | 0.14                |
| 7        | 5.237 – 6.11  | 28               | 0.23                |
| 8        | 6.11 – 6.983  | 1                | 0.008               |
| 9        | 6.983 – 7.856 | 1                | 0.008               |
| 10       | 7.856 – 8.728 | 2                | 0.016               |

Figure 2. Curve of bitumen particles distribution over fractions.
As can be seen, the emulsion is a monodisperse system, so it consists of droplets of virtually the same size. It was established that with the optimal concentration of the emulsifier (FG 2%), a higher degree structuring of the studied emulsion, expressed in uniform particle distribution over the total volume in a smaller particle size from 0.1 to 1.7 microns is observed. This indicates that emulsion (figure 2) has sedimentative and aggregative stability.

3 Results and discussions

Earlier, the authors tested out the most important operational characteristics of bitumen emulsions produced based on floto tar. The usefulness of the developed anionactive bitumen emulsion for modification of cement concrete is shown [22].

This paper studies the main technological and operational properties of road cement concrete modified by fine-dispersed anionactive bitumen emulsion. Cement concrete was bituminized by introducing the anionic bitumen emulsions into the concrete mixture (from 0.5% to 8.0% of cement mass), which allowed increasing performance properties of hardened concrete. BE concentration was chosen in compliance with other works [13-15].

The introduction of bitumen emulsion into the concrete mixture allows reducing the water solid ratio of the concrete mixture, which should lead to decreased porosity and water absorbability of concrete, increased strength and frost resistance. Figure 3 shows the dependence of the concrete mixture water-solid ratio on the bitumen emulsion concentration. The curve has a clear downward trend. The significant effect of modification (decrease in the ratio from 0.535 to 0.495) is explained by the active effect of bitumen emulsion on the cement-aggregate boundary.

![Figure 3](image.png)

**Figure 3.** Dependence of the concrete mixture's water-solid ratio on the BE concentration.

The strength relation of cement concrete compressing on the concentration of bitumen emulsion was traced on day 7 and day 28 following the hardening in normal humid conditions (figure 4).

As can be seen in figure 4, on day 7 (curve 1) and day 28 (curve 2) there is a sharp increase in the concrete strength at 0.5% concentration of anionactive bitumen emulsion followed by a decrease in strength at 8% of BE concentration. This can be explained as follows: concrete modified with bitumen emulsion tends to develop strength faster over time due to the accumulation of clinker stock, decreased water-solid ratio, especially at low concentrations of bitumen emulsions (0.5 per cent). With the increase of concrete bitumen emulsion concentration there is a decrease in mechanical strength of concrete when compressed. This can be attributed to the bitumen slowing down the cement hydration process. As the modified concrete ages, the compressive strength will increase relative to the unmodified concrete. The results are consistent with other studies [17-18].
Figure 4. The strength relation of cement concrete compressing on BE concentration:
   Curve 1 — concrete strength on day 7;
   Curve 2 — concrete strength on day 28.

Figure 5. Water absorption relation of cement concrete on the BE concentration:
   Curve 1 — concrete with 0% BE;
   Curve 2 — concrete with 0.5% BE;
   Curve 3 — concrete with 8% BE.

Figure 5 shows the water absorption relation of cement concrete on the concentration of bitumen emulsion. Unmodified concrete (curve 1) has greater water absorption relative to modified concrete (curves 2, 3). Moreover, the effect of modification is most pronounced in the highest concentration of bitumen emulsion (8%, curve 3). Reduced water absorption leads to increased frost resistance of cement concrete and, therefore, its durability.

The effect of bitumen emulsion concentration on the abrasion capacity of cement concrete was also studied (figure 6).
Figure 6. The effect of bitumen emulsion concentration on the abrasion capacity of cement concrete.

Figure 6 shows that the abrasion capacity index was significantly decreased with the increased concentration of bitumen emulsion (from 0.51 g/cm in unmodified cement concrete to 0.35 g/cm in concrete containing 8% BE), that being the case the modification effect was more than 30%.

Testing out concrete tension strength is a matter of great importance for the road construction sector. In this regard, we studied the tensile strength relation of cement concrete when cracking was caused by the concentration of bitumen emulsion (figure 7).

Figure 7. Tensile strength relation of cement concrete when cracked by the BE concentration.

With a lower content of bitumen emulsion (0.5%), the strength of the modified concrete increased to 17.6 kg/cm, while unmodified concrete strength is lower and equal to 16.8 kg/cm. Further increase in the bitumen emulsion concentration in concrete leads to a slight decrease in strength, but does not reach its initial level even at 8% of BE concentration. These indicators point to increased deformability of the resulting concrete.

Figure 8 shows that the nature of the curves is identical in normal hardening condition regardless of the strength development period (3, 14, 28 days). The introduction of bitumen emulsion into concrete
reduces shrinkage (from 4.3% to 2.3% of shrinkage at 8% of BE concentration), thus reducing shrinking deformation in cement concrete by 46.5%, which is an indirect evidence of increased crack resistance and deformability by almost 2 times.

One of the main indicators of road concrete is shrinkage, which occurs in hardened material. Shrinkage can cause concrete to crack, which degrades quality and durability of the road decreases (figure 8).

![Figure 8](image)

**Figure 8.** Effect of bitumen emulsion on the shrinkage of cement concrete:
- Curve 1 — shrinkage of concrete on day 3;
- Curve 2 — shrinkage of concrete on day 14;
- Curve 3 — shrinkage of concrete on day 28.

The results of the research are consistent with other works [19-20].

4 Conclusions
1. The possibility of cement concrete bituminizing by introduction of finely dispersed anionactive bitumen emulsion into the concrete mixture is shown.
2. The introduction of bitumen emulsion (from 0.5 to 8% of the cement weight) increases the technological properties of the concrete mixture and operational and technical characteristics of concrete. Water-solid ratio reduces by 9%; water absorption reduces by 46%; abrasion capacity reduces by 30%; shrinkage reduces by 45%.
3. The introduction of more than 1% of BE significantly reduces the cement concrete strength characteristics. To increase concrete strength it is necessary to use compositions modified with a small concentration of BE (from 0.5 to 1.0% of the cement weight).
4. It is possible to produce cement concrete with a wide range of properties depending on the conditions of operation and the purpose of the road surface by variating the concentration of anionic bitumen emulsion.

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