THE USE OF CEMENT CONCRETE PAVEMENTS FOR ROADS, DEPENDING ON CLIMATIC CONDITIONS

Iryna SOLONENKO

Abstract: The development of road network infrastructure is an important component of the economic development of the European Union. Updating of the road network contributes to the integration of the economies of countries into a coherent whole. The road network provides the free movement of citizens, the movement of goods and the effective implementation of various services. The increase in the length of the road network leads to an increase in the financial and material costs necessary to ensure its maintenance and repair. One of the ways to reduce costs is by strengthening the physico-mechanical and operational characteristics of the pavement due to the widespread use of cement concrete. The quality of the pavement of cement concrete depends largely on the rational selection of its composition. This allows a significant increase in the durability of road pavement. The purpose of the research was: the development of recommendations for the rational selection of the composition of the road pavement material of cement concrete, aimed at upgrading longevity, and taking into account its frost resistance grade. According to the goal, the following tasks were developed: the analyses of the climatic zones in which the road network of the European Union is located; the development of a research plan, a selection of the response function and influence factors; the study of physico-mechanical and operational characteristics of the researched material of road pavement; on the basis of the obtained data, the calculation of the complex of experimental-statistical models, which describe the physico-mechanical and operational characteristics of the road pavement material; on the basis of experimental statistical models, a method was proposed for selecting the rational compositions of the cement concrete pavement road material depending on the conditions of its application. The results presented in the article can be used in engineering and scientific practice for the selection of road pavement from cement concrete for highways.

Keywords: cement concrete; experimental statistical models; highway; road pavement; transport corridor; weather conditions

1 INTRODUCTION

The network of European roads has a considerable length. They ensure the stable development of the European Union (EU) countries. European roads are combined in a number of transport corridors. The main direction of traffic in these corridors: from north to south and from west to east. They enable the free movement of citizens and various goods and the performance of necessary services [1]. EU roads are directly adjacent to the road network of Belarus, Ukraine, Moldova and Russia. The distinctiveness of the roads of Ukraine and Moldova is the low quality of the road pavement, which is caused by the insufficient allocation of funds for their maintenance and repair.

As the analysis of the works [2, 3] shows, the condition of the roads mainly depends on the condition of the road pavement. The defects of road pavement (Fig. 1) significantly complicate the effective operation of vehicles, they reduce their speed and endanger traffic safety.

An analysis of scientific publications [5, 6, 7] showed that a decrease in the operational costs of maintaining and repairing roads can be achieved by using cement concrete as a pavement material (Fig. 2).

The large length of EU roads (Tab. 1) requires significant funds for their maintenance and repair [4].

Table 1 The length of main roads, highways and specific sections of roads in the EU countries [4]

| No. | Country | Main-line highway | Hard road pavement | Ground road pavement | General |
|-----|---------|-------------------|--------------------|----------------------|---------|
| 1   | Austria | 2 223             | 200 000            | 33 498               | 155 775 |
| 2   | Belgium | 1 763             | 120 541            | 440                  | 448 980 |
| 3   | Bulgaria| 801               | 43 649             | 440                  | 448 980 |
| 4   | Great Britain | 3 557   | 344 000            | 54 350               | 401 907 |
| 5   | Hungary | 1 481             | 76 075             | 123 492              | 201 048 |
| 6   | Germany | 12 917           | 644 480            | 0                    | 657 397 |
| 7   | Greece | 2 311             | 107 406            | 9 594                | 119 311 |
| 8   | Denmark | 1 205            | 74 558             | 0                    | 757 63 |
| 9   | Ireland | 1 224            | 91 145             | 5 457                | 978 25 |
| 10  | Spain  | 16 583            | 683 175            | 0                    | 699 758 |
| 11  | Italy  | 6 758             | 487 700            | 0                    | 485 458 |
| 12  | Cyprus | 254               | 8 564              | 4 442                | 13 260 |
| 13  | Latvia | 0                 | 14 707             | 75 737               | 72 444 |
| 14  | Lithuania | 0              | 13 584             | 8 242                | 21 826 |
| 15  | Luxembourg | 152            | 2 899              | 0                    | 3 051 |
| 16  | Malta  | 0                 | 2 704              | 392                  | 3 096 |
| 17  | Netherlands | 2 808    | 139 295            | 0                    | 142 103 |
| 18  | Poland | 1 566             | 292 134            | 131 863              | 425 563 |
| 19  | Portugal | 2 992         | 71 294             | 11 606               | 858 92 |
| 20  | Romania | 806             | 49 873             | 34 312               | 84 991 |
| 21  | Slovakia | 432            | 38 085             | 5 676                | 44 193 |
| 22  | Slovenia | 618            | 38 985             | 0                    | 39 603 |
| 23  | Finland | 386              | 51 016             | 27 146               | 79 025 |
| 24  | France | 11 882           | 1 028 446          | 0                    | 1 040 328 |
| 25  | Croatia | 1 318           | 26 958             | 0                    | 28 276 |
| 26  | Czech  | 1 250            | 130 671            | 0                    | 131 921 |
| 27  | Sweden | 2 050            | 579 564            | 0                    | 581 164 |
| 28  | Estonia | 115             | 10 427             | 47 985               | 58 527 |
As it can be seen from Fig. 3, the total cost of construction and maintenance of highways made from cement concrete (c), after 10 years of operation, is lower than for the roads with asphalt concrete (a). Thus, the use of cement concrete coatings for the European Union countries reduces the cost of their maintenance and repair.

2 RESULTS AND DISCUSSION

An analysis of literary sources [7, 8, 9] showed that meeting the requirements on the durability of the cement concrete pavement for a highway can be achieved by a rational selection of its composition. The pavement is significantly affected by loads caused by traffic and climatic conditions.

The existing normative document EN 206-1 [10] (Tab. 2) does not take into account the frost resistance of the cement concrete pavement.

![Figure 2](image_url)  
**Figure 2** Relative construction cost ($P_2$), maintenance and repair of roads bituminous with asphalt concrete and cement concrete (a - asphalt concrete, c - cement concrete, $P_1$ - construction, $P_2$ - content, $P_3$ - repair, $T_n$ - road operation in time (in years), $P_{stc} = 1.8 P_{sta}$)

| Characteristics                        | Demands                                      |
|----------------------------------------|----------------------------------------------|
| Water/cement (W/C)                     | 0.45 ± 0.65                                  |
| Class for compressive strength (MPa)   | C 35/45 (45) ÷ C 40/50 (50)                  |
| Absorption of water, %                 | ≥ 5                                          |
| Frost resistance                       |                                              |
| Abrasion, mm                           | ≥ 4                                          |
| Air entrainment, %                     | 4-7                                          |

With the purpose of studying the effect of the freeze-thaw temperature on the compressive strength and abrasion of the pavement material of cement concrete, researches have been conducted.

**The purpose of the research** was: the development of recommendations for a rational selection of the composition of the road pavement material of cement concrete, aimed at upgrading longevity, taking into account its frost resistance grade.

According to the goal, the following tasks were developed:
- the analyses of the climatic zones in which the road network of the European Union is located;
- the development of a research plan;
- the study of physico-mechanical and operational characteristics of the researched material of the road pavement;
- on the basis of the obtained data, the calculation of the complex of experimental-statistical models, which describe the physico-mechanical and operational characteristics of the road pavement material;
- on the basis of experimental statistical models, a method was proposed for selecting the rational compositions of the cement concrete pavement road material depending on the conditions of its application.

An analysis of the works [8, 9, 11] showed that the durability of the coating for highways made of cement concrete is significantly affected by the frost resistance of the material. The resistance of the pavement material to the effects of alternating temperatures is important for climatic zones with unstable negative temperatures (Fig. 2, Tab. 3). In these zones, throughout the entire winter period, repetitive cyclical freeze-thawing of the road pavement is happening.

![Figure 3](image_url)  
**Figure 3** The location of the main roads of the EU countries in climatic zones

As it can be seen from Fig. 2, the roads of the European Union lie in different climatic zones. Therefore, different requirements for frost resistance should be imposed to the pavement material, depending on the climatic zones.

According to the works [7, 8, 9], an improvement in the frost resistance of cement concrete can be achieved by introducing an air-entraining additive into its composition, as well as a microsilica suspension filler. An increased resistance to the abrasion of the material is provided by the introduction of fibre material in the concrete. This composition allows the factors that influence the frost resistance of the pavement material to be determined (Tab. 4). The range of changes in the number of added components was determined on the basis of the recommendations of the MAPEI firm [12], an analysis of literature [11] and the personal experience of the author [9].
The main characteristics of the additives and fillers used:
- air entraining agent additive Mapeplast PT-1 ("MAPEI"), its inclusion into the concrete mix provides an increase in the amount of the entrapped air (designed to increase the frost resistance of concrete);
- microsilica suspension, particle size 0.1-0.2 microns, specific surface area ~ 20,000 m²/kg (designed to increase the strength of concrete and frost resistance, reduces abrasion and the permeability of concrete, etc.);
- polypropylene fibre - Mapefibre NS 12/NS 18 ("MAPEI"), diameter ~ 0.34 mm, fibre length 12-18 mm, density ~ 9.1×10-4 kg/m³, tensile strength ~ 700 MPa, (increases the crack resistance of concrete and makes it resistant to abrasion).

The basic composition of the concrete mix for the manufacture of prototypes was determined by the method described in the article [9]:
- portland cement PC I-H 500 - 470 kg/m³;
- granite chippings (fractions 5÷20) - 1055 kg/m³;
- sand (fineness modulus = 2.5) - 578 kg/m³;
- superplasticizing admix Dynamon Easy 11 firms of "MAPEI" firms – 8.55 l/m³;
- for adding water to the mix, distilled water was used.

The experiment plan is presented in Tab. 5.
At each point of the experiment plan, at least three experiments were conducted with the subsequent determination of the average value of the measurement result. To eliminate the influence of systematic errors caused by external conditions, the order of the experiments was randomized.

The experiments were conducted in the following sequence:
- the necessary amount of additives and fillers were added into the basic composition of the concrete mixture (Tab. 4);
- for each point of the experiment plan, the required number of samples was formed in the sizes of 0.1×0.1×0.1 meters and 0.07×0.07×0.07 meters [13];
- the obtained samples (Fig. 4a) were maintained under the standard curing of a normal set for 28 days (t = 20 °C, W = 80%) [13];
- on the 28th day, samples of 0.07×0.07×0.07 meters were tested for an abrasion test (LKI-3 device) [14];
- the samples of 0.1×0.1×0.1 meters were tested for compressive strength [13];
- the part of the samples of 0.07×0.07×0.07 and 0.1×0.1×0.1 meters were tested for frost resistance in the freezer (in the freezing room temperature of ~50 °C [15]);
- after testing for frost resistance (F50, F100, F150, F200), the samples (Fig. 4b)) were tested for the abrasion test and compressive strength [13, 14].

The results of the experiments are presented in Tab. 6. The convenience of the analysis for Tab. 6 is shown in a graphical form in the Figs. 5 and 6.

As it can be seen from the presented data (Fig. 5), the compositions used for the manufacture of the samples No. 1, 2, 3, 4 can be used as road pavement on the sections of roads that are not affected by the freeze-thaw.

Under the influence of the freeze-thaw temperature, the compressive strength of these samples decreases:
- for the sample No. 1 at: F50 – 3.1%, F100 – 8.1%, F150 – 9.5%, F200 – 14.2%;
- for the sample No. 2 at: F50 – 4.6%, F100 – 8.4%, F150 – 11.8%, F200 – 15.6%;
The specimens at abrasion under the influence of freeze-thaw
- for the sample No. 3 at: F50 – 3.2%, F100 – 6.4%, F150
- for the sample No. 4 it comes down to: F50 – 1.9%, F100
- 5.4%, F150 – 8%, F200 – 9.3%.

The compressive strength of the remaining samples subjected to frost resistance tests, even after F200, was more
than 50 MPa, which allows its use in all climatic zones.

| No  | f<sub>a</sub> (MPa) | f<sub>ck.cube</sub> (MPa) | f<sub>ck.cube50</sub> (MPa) | f<sub>ck.cube100</sub> (MPa) | G<sub>1</sub> (kg/m²) | G<sub>2</sub> (kg/m²) | G<sub>3</sub> (kg/m²) | G<sub>4</sub> (kg/m²) | G<sub>5</sub> (kg/m²) |
|-----|-------------------|--------------------------|---------------------------|---------------------------|------------------|------------------|------------------|------------------|------------------|
| 1   | 50.25             | 48.70                    | 46.20                     | 45.50                     | 43.15            | 0.062            | 0.065            | 0.067            | 0.068            |
| 2   | 52.60             | 50.30                    | 48.40                     | 46.70                     | 44.80            | 0.030            | 0.033            | 0.036            | 0.038            |
| 3   | 51.80             | 50.20                    | 48.60                     | 47.20                     | 45.20            | 0.048            | 0.050            | 0.052            | 0.054            |
| 4   | 50.10             | 49.15                    | 47.40                     | 46.10                     | 45.45            | 0.067            | 0.069            | 0.072            | 0.074            |
| 5   | 53.40             | 52.90                    | 52.00                     | 51.10                     | 50.35            | 0.033            | 0.036            | 0.039            | 0.042            |
| 6   | 54.60             | 53.90                    | 52.70                     | 52.00                     | 51.45            | 0.037            | 0.040            | 0.043            | 0.045            |
| 7   | 54.20             | 53.80                    | 52.40                     | 51.20                     | 50.35            | 0.048            | 0.053            | 0.057            | 0.059            |
| 8   | 55.20             | 54.70                    | 53.90                     | 52.00                     | 51.45            | 0.038            | 0.040            | 0.042            | 0.044            |
| 9   | 54.70             | 53.15                    | 52.50                     | 51.70                     | 50.75            | 0.029            | 0.032            | 0.035            | 0.036            |
| 10  | 53.75             | 53.00                    | 52.10                     | 51.40                     | 50.50            | 0.037            | 0.039            | 0.041            | 0.043            |
| 11  | 56.50             | 56.10                    | 55.40                     | 54.90                     | 53.90            | 0.058            | 0.060            | 0.063            | 0.066            |
| 12  | 57.80             | 57.00                    | 56.10                     | 55.20                     | 54.30            | 0.025            | 0.028            | 0.033            | 0.036            |
| 13  | 55.45             | 55.00                    | 54.10                     | 53.25                     | 52.80            | 0.037            | 0.039            | 0.043            | 0.045            |
| 14  | 54.90             | 54.00                    | 53.25                     | 52.30                     | 51.80            | 0.045            | 0.048            | 0.054            | 0.057            |
| 15  | 55.00             | 54.50                    | 54.00                     | 53.85                     | 53.20            | 0.029            | 0.031            | 0.034            | 0.036            |

Figure 5 The results of the testing samples for abrasion before and after freezing and the thawing test (F0, F50, F 100, F150, F 200)

As it can be seen from Fig. 6, the abrasion of road pavement depends on the number of freeze-thaw cycles. An analysis of the data shown in (Fig. 6) proved that the samples of the material in which the loss of mass G was the following were the best in frost resistance:
- for the sample No. 2 at: F50 – 0.033 kg/m², F100 – 0.036
- for the sample No. 5 it comes down to: F50 – 0.036 kg/m², F100
- 0.039 kg/m², F150 – 0.042 kg/m², F200 – 0.045 kg/m²;
- for the sample No. 9 at: F50 – 0.032 kg/m², F100 – 0.035
- for the sample No. 15 at: F50 – 0.031 kg/m², F100
- 0.034 kg/m², F150 – 0.036 kg/m², F200 – 0.038 kg/m².

The worst indicators have the following samples: No. 1,
No. 4, No. 7, No. 11 and No. 14.

As it can be seen from Figs. 5 and 6, the dependence of the change in compressive strength and the loss of mass of the specimens at abrasion under the influence of freeze-thaw

\[ y = b_0 + \sum_{i=1}^{n} b_i x_i + \sum_{i=1}^{n} \sum_{k=i+1}^{n} b_{ik} x_i x_k + \sum_{i=1}^{n} \sum_{k=i+1}^{n} \sum_{l=k+1}^{n} b_{ikl} x_i x_k x_l + \ldots \]

(1)

Where: y – the response function, \( b_0, b_i, b_{ikl} \) – coefficients of the multiple regression equation, \( x_i \) – normalized value of the influence factor.

For the convenience of calculating mathematical models, the scale of the factors of influence was chosen so that the
value of the upper level was equal to +1, and the lower to –1. The origin of the coordinates of the influence factors was transformed and the transition to the normalized value of each factor was made:

\[ x_i = \frac{\bar{x}_i - \bar{x}_{i0}}{I} \]  

(2)

Where: \( x_i \) – normalized value; \( \bar{x}_i \) – natural value; \( \bar{x}_{i0} \) – main level; \( I \) – variability interval.

The description of the methods for calculating the coefficients of regression models is beyond the scope of this article, but if necessary, you can refer to the works [16, 17]. The calculated mathematical models describing the change in the compressive strength \( (f_{ck,cube}) \) and abrasion \( (G) \) of the pavement material before and after the freezing thawing resistance test of the test samples \( (F, 200) \) are presented in Tab. 7.

Table 7 Mathematical models describing the change in the compressive strength \( (f_{ck,cube}, f_{ck,cube200}) \) and abrasion \( (G, G200) \) of the pavement material before and after the freezing thawing resistance test

| No | Response function | ES-models |
|----|-------------------|-----------|
| 1  | \( f_{ck,cube} \) (MPa) = 54.49 - 0.46x_1 - 0.63x_2x_3 + 0.75x_4 - 0.53x_5x_6 + 2.15x_7 - 0.71x_8^2 \) | (4) |
| 2  | \( G \) (g/m²) = 0.04 + 0.002x_1x_2 - 0.002x_1x_3 - 0.01x_2 + 0.002x_3x_4 - 0.04x_5 + 0.004x_6^2 \) | (5) |
| 3  | \( f_{ck,cube200} \) (MPa) = 51.29 + 0.28x_1 - 0.85x_2x_3 + 0.24x_4 - 0.31x_5x_6 + 2.69x_7 \) | (6) |
| 4  | \( G200 \) (g/m²) = 0.05 + 0.001x_1x_2 - 0.002x_1x_3 - 0.01x_2 + 0.003x_3^2 + 0.001x_4x_5 - 0.003x_5 + 0.006x_6 \) | (7) |

3 CONCLUSIONS

The obtained mathematical models allow us to determine the indicators of compressive strength and the abrasion of the road pavement material with a different combination of influence factors lying in predetermined intervals (Tab. 7).

To convert the results of the calculations using mathematical models into real physical quantities, a reverse transition from a standardized scale to a natural scale was made, using Eq. (2). The illustration of the use of mathematical models (for the sample No. 5) is presented in the Figs. 7 and 8.

The calculations of the compressive strength and abrasion with consideration of the freeze-thaw resistance for cement concrete pavements are made in the following sequence:

- the substituting formulas 4 ÷ 7 (Figs. 7 and 8) and the data of the influence factors (Tabs. 4 and 5) will determine the values - compressive strength \( (f_{ck,cube}) \) and abrasion \( (G) \), when exposed to the freeze-thaw temperature (at \( F = 0 \) and \( F = 200 \) cycles);
- through the obtained values, linear interpolation is performed and if necessary, extrapolation of the results is performed (Figs. 7 and 8);
The study of changes in the properties of the pavement material depending on the number of freeze-thaw cycles has been carried out.

The recommendations for a rational selection of the composition of the pavement material of the cement concrete depending on the requirements for the freeze-thaw resistance were developed.

On the basis of the experimental statistical models obtained, a method is proposed for selecting the rational compositions of cement concrete road pavement materials, depending on the required freeze-thaw resistance.

When conducting research, additives and fillers from the MAPEI firm were used, which were kindly provided to the author by a representative of the company. If necessary, similar results can be obtained for the components from other manufacturer firms.

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