High-early strength concretes modified with polycarboxylate admixture on different cement types

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Abstract. Early and grade strength of modified concrete on different cement types (CEM II/A-S 42,5 and pozzolanic cement CEM IV/A(P) 42,5 R-SR) for concrete pavements repair was explored. Application range of the polycarboxylate modifier was 0.8-1.4% by weight of cement. All concrete compositions had equal workability (slump 5…9 cm). The aim of the investigation was to determine the optimal volume of the polycarboxylate modifier to achieve high strength indicators for repair material at the early and grade age.

High-strength concrete of grades C 50/60 and C 40/50 were obtained, with early strength at the 3 days age above 35 MPa, which allows them to be used as a repair concrete material for rigid road pavements.

X-ray phase analysis confirmed the positive effect of the polycarboxylate admixture in the structure formation of concrete. With an increase in the dosage of the BASF MasterGlenium SKY 608 admixture to 1.2…1.4%, the intensity of the diffractogram lines, which corresponds to the metastable hydration phase in the cement-sand matrix, decreased for concretes on both cement types.

1. Introduction
Growth of the transport and air flows traffic demands an enhancement in the road pavement features. The global trend in the transport industry provides for the development of cement concrete pavements technology for highways and airfield pavements. The annual increase in passenger and freight traffic leads to the destruction of existing hard road surfaces. It will be necessary to rehabilitate and repair these pavements with fast opening of traffic [1-3]. Full-depth repair technology with high-early strength concrete compositions are increasingly used as the major repair strategy [4-8].

Our research is aimed at choosing the optimal binder type and rational amount of polycarboxylate type admixture for high-early strength repair concrete mixtures.

2. Analysis of recent researches and problem statement
Flexible road pavements predominate in Ukraine [9]. However, it is necessary to note the vector of road network development in favour of concrete pavement technology [10]. The lifespan of rigid pavement is 3-6 times longer than flexible asphalt concrete pavement, and the crude oil reserves for bitumen production are limited compared to the raw materials for cement production [2].

According to the 21st World Road Congress [2] and data [1,3,9], the length of highways with rigid pavement is as follows: USA – 60%, Austria – 46%, Belgium – 41%, Germany – 31%, France – 20%, Netherlands – 15%, Portugal – 10%, Spain, Italy, Canada, Switzerland, Great Britain <5 %, Ukraine – 1,92%. Most of them were built over 40 years ago and need major repairs or reconstruction.

Repair concrete mixtures must have high early compressive and flexural strength (1-3 days), which is regulated depending on the place of work [1,3,4,6]. The technology of high-early concrete is actively used, that is specified by national and other specifications [4-6]. According to [11], strength of repair concrete at 28 days of age must be no less than design strength of existing concrete pavement, for a road of the 1st category - this is concrete grade C30/35. Based on the world experience of concrete pavements,
the strength characteristics of the repair concrete must be changed taking into account the necessary conditions for opening the road section for traffic and the region where the repair is being carried out.

Early-strength concrete is based on the following principles [12-15]: reduction W/C due to the use of admixtures-superplasticizers affecting on the hydration processes and structure formation; use of rapid-hardening binders and an optimal selection of grain size using high-quality aggregates is also required. Today, the most effective are polycarboxylate-type superplasticizers, which have a steric mechanism of action. Having a long chain of molecules, cement particles are dispersed at a greater distance from each other, therefore, more surfaces of contact with water are formed [16,17].

In Ukraine, rigid pavement repair technology is underdeveloped and there is practically no standards base. Our research will make it possible to formulate technical requirements and recommendations for the use of high-early strength concrete compositions as the main repair material for rigid road pavements.

3. Research objective
Selection the optimal volume of polycarboxylate type modifier for concrete mixture repairing on different cement types. Consideration of the admixture effect on the early and grade compressive strength of repair concrete for rigid road pavements.

4. Materials and research methods
Two cement types were used in the research: CEM II/A-S 42,5 and pozzolanic cement CEM IV/A(P) 42,5 R-SR. Polycarboxylate type modifier was used in volume of 0,8-1,4% by weight of cement. Granite crushed stone with nominal maximum size 20 mm and quartz sand were used as aggregates. Sieve analysis of aggregates is presented in figure 1. Conventional concrete compositions were also investigated.

![Figure 1. Coarse and fine aggregates gradation](image)

5. Research results
10 batches of concrete samples were fabricated (in each batch 6 cubes 10x10x10 cm). Slump of concrete mixtures was (5…9 cm), that corresponds to the most common flowability of concrete mixtures for the rigid pavements repair. The compositions of the investigated concrete mixtures and W/C are shown in table 1.
Table 1. Concrete mixtures and W/C ratio

| №  | Cement type     | Cement, kg/m³ | Breakstone, kg/m³ | Sand, kg/m³ | Admixture MasterGlenium SKY 608, % | Water, l/m³ | W/C  |
|----|----------------|---------------|-------------------|-------------|------------------------------------|-------------|------|
| 1  | CEM IV/A(P) 42,5 R-SR | 400           | 1140              | -           |                                    | 216,8       | 0,542 |
| 2  |                | 705           |                   | 735         | 0,8                                | 188,4       | 0,471 |
| 3  |                | 740           | 1,0               | 755         | 1,2                                | 148,4       | 0,371 |
| 4  |                | 750           | 1,4               | 750         |                                    | 160,8       | 0,402 |
| 5  |                | 720           |                   | 765         | 0,8                                | 148,4       | 0,371 |
| 6  | CEM II/A-S 42,5 | 400           | 1140              | 785         | 1,0                                | 125,2       | 0,313 |
| 7  |                | 765           | 0,8               | 800         | 1,2                                | 116,8       | 0,292 |
| 8  |                | 795           | 1,4               | 795         |                                    | 119,2       | 0,298 |

The use of the plasticizer significantly reduced the W/C of concrete mixtures in comparison with unmodified mixtures № 1 and 6 and retained their flowability. Effect of the volume admixture and the cement type on mixtures W/C ratio are shown in figure 2.

The greatest decrease in the W/C ratio is observed with the 1,2% volume of the admixture by weight of cement. In this case, the W/C of concrete mixtures based on pozzolanic Portland cement CEM IV/A(P) 42,5 R-SR was significantly higher than the W/C of similar flowability mixtures based on Portland cement CEM II/A-S 42,5.

The average density of the investigated concretes ranged from 2430 to 2510 kg/m³. Strength characteristics of the obtained concrete are shown in figure 3. Compression strength tests were carried out for each batch at the age 3 and 28 days.
As can be seen from figure 3, early and grade strength of conventional concrete based on CEM II/A-S 42.5 are higher than that of similar concrete based on pozzolanic cement CEM IV/A(P) 42.5 R-SR. For mixtures № 2-5 and № 7-10 there is also a tendency towards greater concrete strength based on the Portland cement CEM II/A-S 42.5. This is due to the increased water demand of pozzolanic cement and, consequently, concrete mixtures based on it.

Concretes on different cement types with the admixture in amount of 0.8% by weight of cement increased the compressive strength by almost 2 grades. With the addition of 1% modifier, the strength increased by another 1 grade, and with 1.2% - by 3 grades for concrete based on Portland cement CEM IV/A(P) 42.5 R-SR and by 2 grades with Portland cement CEM II/A-S 42.5. With a further increase in the admixture to 1.4%, an increase in the W/C of concrete mixtures is observed, respectively, strength of the investigated concrete decreases.

Thus, the rational amount of admixture for concrete on both cement types is 1.2% of the binder mass, which provides maximum compressive strength by minimizing W/C.

High-strength concrete was obtained based on Portland cement CEM II/A-S 42.5 with compressive strength 85.6 MPa (grade no less than С 50/60). Concrete based on Portland cement CEM IV/A(P) 42.5 R-SR had compressive strength 64.1 MPa (grade no less than С 40/50).

Strength of modified concrete at 3 days age on Portland cement CEM II/AS 42.5 - 68...75%, and concrete based on pozzolanic cement CEM IV/A (P) 42.5 R-SR was 45...53% depending on the amount of admixture. Compressive strength required for most concrete for rigid pavements is achieved at the 3 days age, which is especially important for repair materials.

According to the data of X-ray phase analysis, it was found that on the diffraction patterns (Fig. 4. a, b) samples № 1-4 of the cement matrix of concrete based on Portland cement CEM IV/A (P) 42.5 R-SR and CEM II/AS 42.5, the lines of natural quartz are recorded (d/n = 0.424; 0.334; 0.245; 0.228 nm) and minor reflections of portlandite (d/n = 0.493; 0.263 nm).
Figure 4. Diffraction patterns of the concrete cement matrix: a – based on Portland Cement CEM IV/A (P) 42.5 R-SR; b – based on Portland Cement CEM II/AS 42.5

a - 1 - CEM II/AS 42.5 (1,4% polycarboxylate admixture); 2 - CEM II/AS 42.5 (1,2% polycarboxylate admixture); 3 - CEM II/AS 42.5 (1,0% polycarboxylate admixture); 4 - CEM II/AS 42.5 (0,8% polycarboxylate admixture)

b - 1 - CEM IV/A (P) 42.5 R-SR (1,4% polycarboxylate admixture); 2 - CEM IV/A (P) 42.5 R-SR (1,2% polycarboxylate admixture); 3 - CEM IV/A (P) 42.5 R-SR (1,0% polycarboxylate admixture); 4 - CEM IV/A (P) 42.5 R-SR (0,8% polycarboxylate admixture)
The d/n = 1,000 nm line also appears, which corresponds to the metastable hydration phase in the cement-sand matrix - sodium containing calcium hydroxysulfoaluminate 4CaO ∙ 0.9Al₂O₃ ∙ 1.1SO₃ ∙ 0.5Na₂O ∙ 16H₂O. (according to Larionov Z. M.). It is important to note that the line intensity d/n = 1,000 nm at high dosages of the MasterGlenium SKY 608 polycarboxylate admixture (1.2% and 1.4% of the cement mass) both for concretes based on CEM II/AS 42.5 and for concretes based on CEM IV/A (P) 42.5 R-SR is less than the intensity of this line at a lower dosage of the admixture (0.8% and 1%). This testifies to the positive effect of the polycarboxylate admixture in the structure formation of concrete.

6. Conclusions and further researches
Using the optimal amount of BASF MasterGlenium SKY 608 admixture based on polycarboxylate ethers makes it possible to obtain high-strength and high-early-strength concrete. The use of such concrete for the rigid highway and airfield pavements repair contributes to the early start traffic. The rational amount of MasterGlenium SKY 608 admixture is 1.2% of the binder mass for concrete on both cement types - CEM II/AS 42.5 and CEM IV/A (P) 42.5 R-SR. The use of the obtained concrete as repair material will extend the service life of the pavement by 5-10 years.

Further research will be aimed at determining the flexural strength of such concrete and fiber concrete, as the main characteristic for road pavements. Also, the indicators of wear resistance and frost resistance of these concrete will be determined, as the main ones in assessing the durability of rigid road pavements.

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