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MODIFICATION OF CONCRETE RAILWAY SLEEPERS AND ASSESSMENT OF ITS BEARING CAPACITY

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ABSTRACT: The issue of concrete modification of railway sleepers remains relevant in connection with the growing demand for this product and increased requirements for the operational characteristics of one of the basic materials of the track superstructure. The problem is a partial early failure of sleepers, loss of load-bearing capacity in the early periods of operation (in the first years or after ten years). A lot of work has been done in this direction, most of them are aimed at concrete modification, but it is also worth considering the design features of the sleepers, and in order to increase the bearing capacity it is necessary to consider other ways to solve the problem. The aim of the researching was to modify the properties of concrete by polycarboxylate-based superplasticizers as concrete modifiers, determines their optimal dosages (from 0.8 to 1.1% by weight of cement) in accordance with the physical and mechanical properties of the raw materials and the required concrete workability. The sleepers considered in this article are reinforced with a wire with a diameter of 7 mm (one of the options for enlarged reinforcement). An option for additional reinforcement of sleepers in the area of the rail seat is proposed. Tests were carried out to determine the physical and mechanical properties of raw materials, the strength of concrete, and full-scale tests of the spars for crack resistance in bending were also carried out. The tests were carried out on certified equipment. According to the research results, it was concluded that for the production of sleepers that meet the requirements, it is necessary to use high-quality cements, polycarboxylate-based superplasticizers and additional reinforcement.

Key words: Sleepers, Additional reinforcement, Crack resistance, Strength, Superplasticizers.

1. INTRODUCTION

Railway transport is a dynamically developing mode of transport around the world, since the transportation of various types of cargo using this mode of transport significantly increases the sales turnover between countries, which positively affects the economy [1].

For Kazakhstan, rank 9th in the world for territory size, not only transportation of goods, but also the development of regions, the solution of many social problems, such as employment, reducing inflationary pressure on prices, improving the quality and standard of living of people are associated with transport [1].

Internationally, the solution of these issues is also in demand due to the fact that the development of transit and logistics between the East and the West is a very important issue, since Kazakhstan is located on the route of all land routes from Asia to Europe, which will remove barriers to the international transport of goods [1].

Reinforced concrete sleepers are one of the important components among the materials of the track superstructure. Their role is to distribute the loads from the base of the rail to the underlying ballast layer. The main functions of sleepers are: (1) transfer and distribution of load from the rail base to the ballast layer; (2) holding the rails on the correct gage through the rail fastening system; (3) maintenance of the inclination of the rail; and (4) restrain the longitudinal, transverse and vertical movements of the rails (Fig. 1) [2].

The use of concrete for the manufacture of railway sleepers began in 1884.The development of the first project of reinforced concrete sleepers

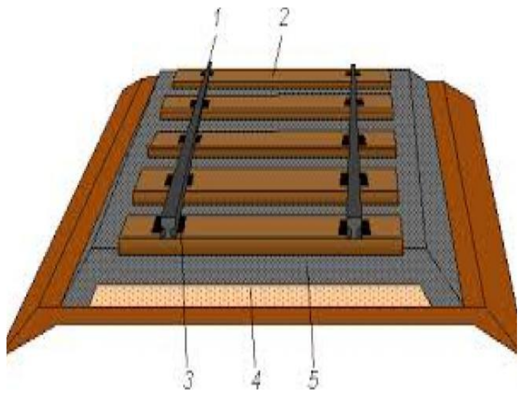


Fig. 1 The construction of tracks.
1 - rail; 2- sleepers; 3- intermediate rail fastening;
4 - crushed stone ballast; 5 - sand cushion

belongs to the French Mounier. Nevertheless, the first experiments were generally unsuccessful, since the shape of the reinforced concrete sleepers completely repeated the shape of the wooden sleepers (concrete beams of uniform section). However, the development of prestressed concrete allowed creating a new stage in the design of reinforced concrete sleepers. Through numerous experiments and studies on several railways, the world managed to come to modern models: safe, sustainable and economical [3,4].

During operation, the sleepers experience the strongest dynamic loads from the wheelsets during the movement of the train, which determines the increased requirements for the quality of concrete sleepers and their structural features. The main defect of the sleepers is the formation of cracks or fracture in the area of the rail seats during operation (fig. 2). According to the scientists S. Kaewunruen, A. Remennikov, Gustavson R. [5-9] the cause of cracking is short-term, but significant dynamic loads (the magnitude of the loads can reach more than 400 kN depending on the speed of trains) on the ballast layer.

Fig.2Defects in sleepers that occur as a result of operation.

In 2021, on the territory of the Republic of Kazakhstan, amendment No. 1 to GOST 33320-2015 “Concrete sleepers for railways” is introduced. The main change is the introduction of a new concept of “fulfillment” (1 and 2) of sleepers and an increase of the requirements for the assigned resource of sleepers. It is important to pay careful attention to the fact that concrete sleepers of 2 fulfillment increase the requirements to concrete (concrete class B 50) and increase the load on crack resistance during bending (up to 142 kN instead of 123 kN for version 1). In connection with the introduction of these changes, the urgent issue is the modification of concrete sleepers and the search for solutions of increasing of the bearing capacity, durability of the structure. The study of this issue requires work in the direction of not only the modification of concrete, but also making changes to the design of the sleepers.

Concerning the history of the development of high-speed railways, it is worth noting that in Japan the first high-speed railways were built in 1964 (speed - 210 km / h), in France 1981 (speed - 280 km / h), in Germany in 1991 (speed - 250 km / h).

Compared to Kazakhstan, European countries have extensive experience in using railway sleepers with high performance characteristics designed for high-speed railways (train speeds of 200 km / h and above). From the beginning of the use of sleepers (beginning of the 20th century), researchers have always been worried about the cases of relatively early failure of reinforced concrete sleepers as a result of premature destruction, since this meant earlier dates for the beginning of the overhaul of the track and as a consequence the material damage. In this regard, the issue of increasing the durability of the structure has always remained relevant. It is also necessary not to forget about the different climatic conditions for the operation of sleepers and other important features of each country.

The scientists S. Kaewunruen, A. Remennikov [5] in their work investigated the endurance of sleepers to buffing loading by drop tests (weight of the guided mass was 600 kg, drop height 0.2 m) and impact analyzes at various drop heights. In the course of the work, the predictions of numerical methods and experimental work were compared, the difference in performance was 10%. According to the results of their research, it was found that the extended model proposed by the scientists can be used to predict shock reactions of prestressed concrete sleepers.

Author Olga Smirnova in her work studied the issue of modifying concrete sleepers by using superplasticizers on a polycarboxylate basis. In particular, the effect of additives Stachement2280 and Stachement2060 was studied. When using these additives, the water-cement ratio was reduced from 0.34 to 0.3, and the temperature of isothermal heating with a heat-moisture structure was also reduced, which also has a positive effect on the microstructure of concrete [10].

Scientists [11] in their work noted that superplasticizers based on naphthalene lignosulfonate do not have a selective property with respect to cement in comparison with polycarboxylates.

In terms of concrete modifying for sleepers, the scientists Sakdirat Kaewunruen, Dan Li, Yu Chen and Zhechun Xiang and others [12-16] propose adding crumb rubber to the concrete mix. They refer to the fact that many literary sources indicated that the compressive strength of concrete would decrease if the fine aggregate was partially replaced with rubber crumb.

Japanese researchers from the Railway Technical Research Institute Shintaro Minoura, Tsutomu Watanabe, Masamichi Sogabe, Keiichi Goto in their work [17] studied the main causes of premature failure of prestressed concrete sleepers and identified a number of reasons: loss of prestressing force, corrosion of steel wire starting from the sole sleepers, concrete fatigue due to repeated exposure to dynamic loads.

2. MATERIALS AND RESEARCH METHODS

The compatibility of superplasticizers with various types of Portland cement was investigated in the authors' article [18-20]. As a result, it was concluded that the mineralogical composition of Portland cement clinker is important, namely, with an increase in the content of tricalcium aluminate (C_3A) (about 9.9%), the water-reducing ability of superplasticizers decreases. Recommended C_3A content is up to 7%. Also, the possibility of lowering of the temperature of isothermal heating of concrete, that is, the transition to a gentle mode (from 70^0C to 40^0C) is indicated.

The water/cement ratio ranged from 0.28 to 0.37, depending on the type of additive used. The cement consumption was 500 kg / m3 when using Poliplast SP 1, and in other compositions - 480 kg / m3.

In the work we used the following materials:

No	Name of materials	Type and characteristics	Factory-manufacturer
1	Portland cement	CEM I 42,5	"Central Asia Cement" Limited liability partnership (LLP)
2	Sand	Particle size module 2.5, 2.9	"Nur-Adil" LLP "KKK Beton" LLP
3	Crushed stone	fraction 5-20 mm	"Story Kam" LLP, "Tekhnoindustriya" LLP, "Stroitelnoe upravlenie NTS-24" LLP, "Karaganda Nerud" LLP.
4	Superplasticizers	PoliplastSP-1, Sika Visco CreteT 100KZ, EzkonKH-5, Master Glenium Sky 504, Master Glenium 51, Master Glenium 511, MasterGlenium977, Master Glenium 430.	Polyplast Kazakhstan LLP Sika Kazakhstan LLP Basf

Physical characteristics of raw sand-gravel mixture and crushed stone are given in Tables 1 and 2

Table 1. Results of physical tests of sand

No	Name of the characteristic	Requirements of GOST 8736	KH "Nur-Adil"	"KKK Beton" LLP
1	Particle size module	Not rated	2,5	2,9
2	Bulk density, kg/m^3	Not rated	1520	1550
3	Content of dust and clay particles, %	No more than 2.0	1,8	1,2
4	Grain size above 10 mm, %	No more than 5,0	4,2	5,0
5	Grain size above 5 mm, %	No more than 15,0	12,9	10,2
6	True density, kg/m^3	Not rated	2,65	2,62
7	Clay in lumps, %	No more than 0,25	0,19	Not detected

In connection with the above-mentioned increase in the load on the crack resistance of sleepers, it is also worth studying the reinforcement schemes used in the Republic of Kazakhstan. At present, 2 reinforcement options are used: wire with a diameter of 3 mm in an amount of 44 pieces, high-strength wire with a diameter of 7 mm in an amount of 8 pieces (meeting the requirements of European standards). The second option of enlarged reinforcement (with rod reinforcement from 4 to 8 rods) is increasingly popular in Europe and is also used in factories in Russia and Belarus.

Table 2. Results of physical tests of crushed stone

No	Name of the characteristics	Requirements	"Story Kam" LLP	"Tekhnoindustriya" LLP	"Stroitelnoe upravlenie NTS-24" LLP	"Karaganda Nerud" LLP
1	Grain composition	Table 1 GOST 8267-93	Meet the requirements			
2	Dust and clay particles, % by weight, no more	1	1,7	1,1	0,8	1,2
3	Lamellar (bream) and needle-like grains, % by weight, no more for group I	10	8,2	9,1	15,1	7,5
4	Bulk density, kg / m3	Not rated	1482	1340	1410	1450
5	Mark for divisibility in the dry state	Not rated	M 1200	M1200	M 1200	M 1200
6	Brand for frost resistance	at least F200	F200	F300	F200	F200

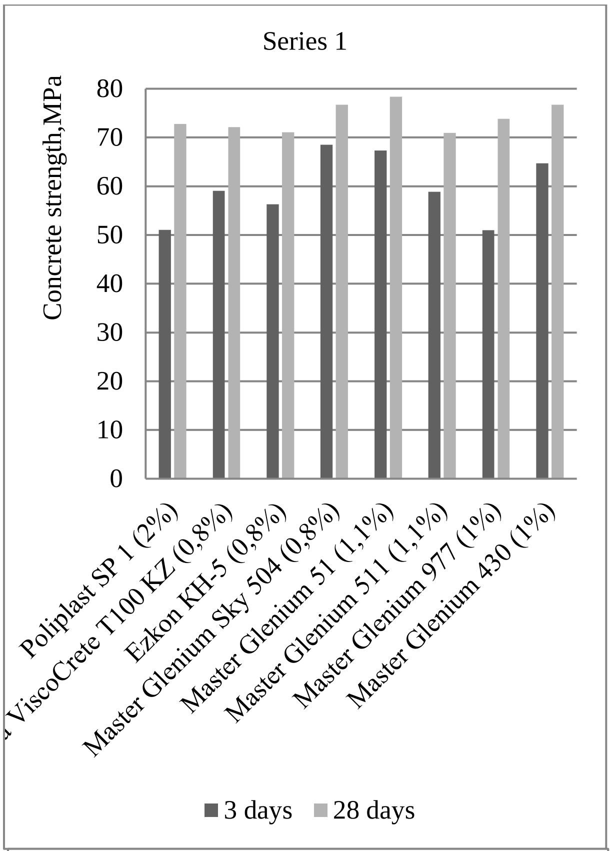
3. RESULTS AND DISCUSSIONS

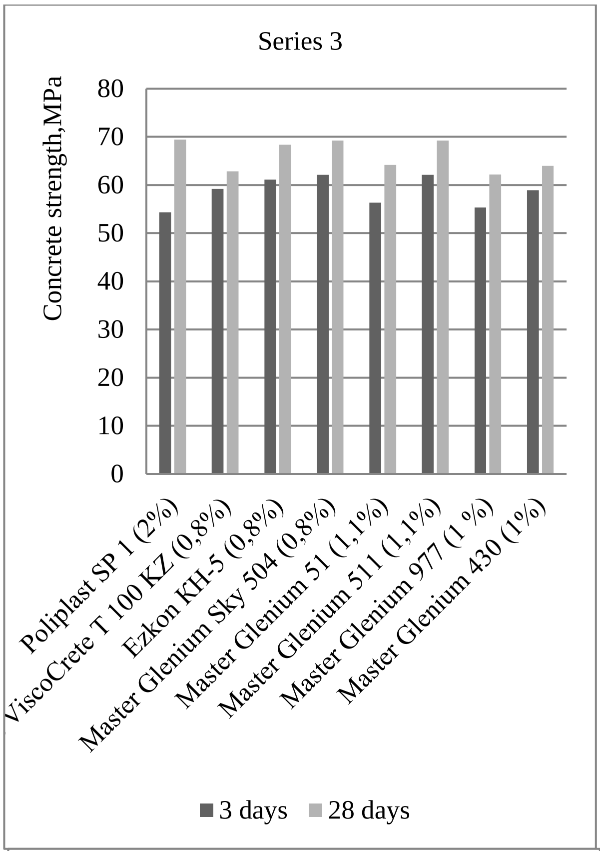
Concrete cubes patterns were made in 8 series of compositions (concrete class B 50); each series of concrete was distinguished by the use of sand and crushed stone of different deposits (table 3). Each series of compositions was made using 8 types of the above additives. In the series of compositions numbered 1,3,5,7were used KH«Nur-Adil» sand, and in the series 2,4,6,8 were used «KKK Beton» LLP sand in combination with crushed stone from the four quarries indicated in table 2. Each series of samples used 8 types of additives mentioned above. In polycarboxylate-based superplasticizers, the dosage ranged from 0,6 to 1,1 %, in Poliplast SP 1 - 1,8-2%.

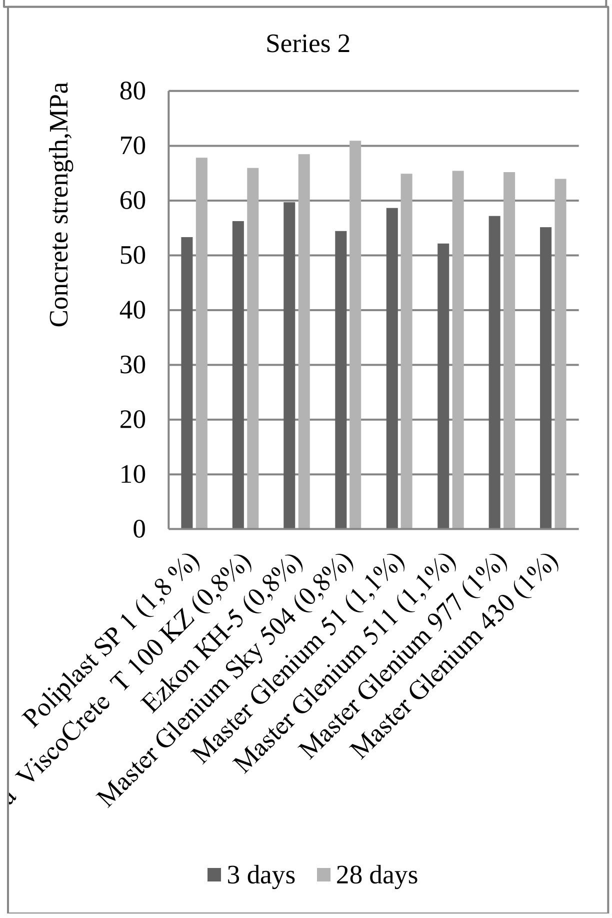
The tests for determining the strength of concrete-cube patterns were carried out on a hydraulic press RS with a maximum working load of up to 800 kN. According to the test results (Fig. 2), we can conclude that all the considered additives allow to obtain concrete of the required strength with a low water/cement ratio (from 0.28 to 0.37) and the required workability (grade for mobility P2), when using sand- gravel mix produced by "KKK Beton" LLP, a decrease in water demand of concrete mix by 5% was noted. This is due to the low content of dusty and clay particles in the sand-gravel mix of "KKK Beton" LLP as compared to the sand-gravel mix of KH “Nur-Adil”; these materials also have different particle sizes (2.9 and 2.5, respectively).

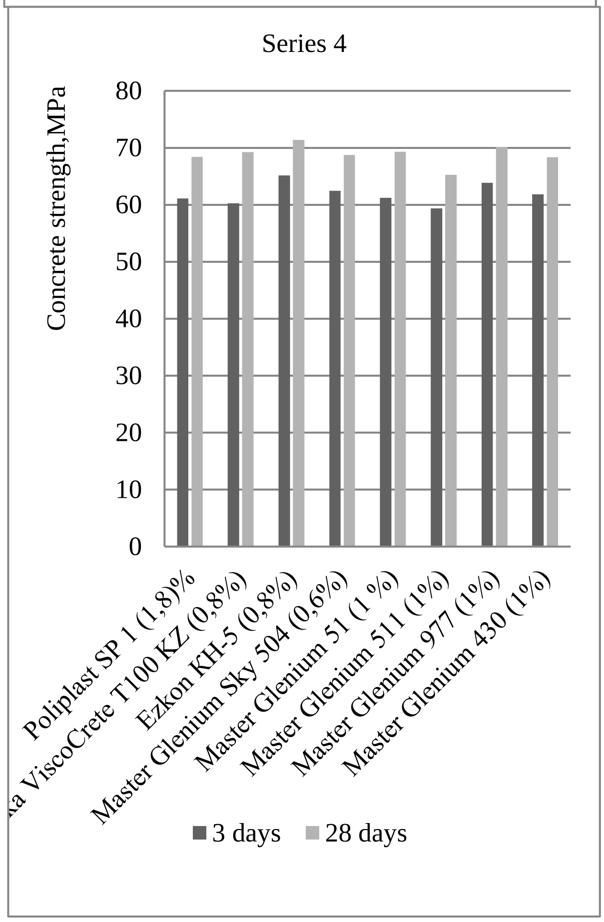
Table 3. Series of concrete compositions for sleepers

Composition series number	Cement consumption, kg / m^3	Sand KH "Nur-Adil"	Sand "KKK Beton" LLP	Crushed stone" Story Kam" LLP	Crushed stone "Tekhnoindustriya" LLP	Crushed stone "Stroitelnoe upravlenie NTS-24"	Crushed stone "Karaganda Nerud" LLP.
1	500	+		+			
2	480		+	+			
3	480	+			+		
4	480		+		+		
5	480	+				+	
6	480		+			+	
7	480	+					+
8	480		+				+


Series 1
Concrete strength,MPa
80
70
60
50
40
30
20
10
0
Poliplast SP 1 (2%)
ViscoCrete T100 KZ (0,8%)
Ezkon KH-5 (0,8%)
Master Glenium Sky 504 (0,8%)
Master Glenium 51 (1,1%)
Master Glenium 511 (1,1%)
Master Glenium 977 (1%)
Master Glenium 430 (1%)
3 days
28 days


Series 3
Concrete strength,MPa
80
70
60
50
40
30
20
10
0
Poliplast SP 1 (2%)
ViscoCrete T 100 KZ (0,8%)
Ezkon KH-5 (0,8%)
Master Glenium Sky 504 (0,8%)
Master Glenium 51 (1,1%)
Master Glenium 511 (1,1%)
Master Glenium 977 (1 %)
Master Glenium 430 (1%)
3 days
28 days


Series 2
Concrete strength,MPa
80
70
60
50
40
30
20
10
0
Poliplast SP 1 (1,8 %)
ViscoCrete T 100 KZ (0,8%)
Ezkon KH-5 (0,8%)
Master Glenium Sky 504 (0,8%)
Master Glenium 51 (1,1%)
Master Glenium 511 (1,1%)
Master Glenium 977 (1%)
Master Glenium 430 (1%)
3 days
28 days


Series 4
Concrete strength,MPa
80
70
60
50
40
30
20
10
0
Poliplast SP 1 (1,8)%
ViscoCrete T100 KZ (0,8%)
Ezkon KH-5 (0,8%)
Master Glenium Sky 504 (0,6%)
Master Glenium 51 (1 %)
Master Glenium 511 (1%)
Master Glenium 977 (1%)
Master Glenium 430 (1%)
3 days
28 days

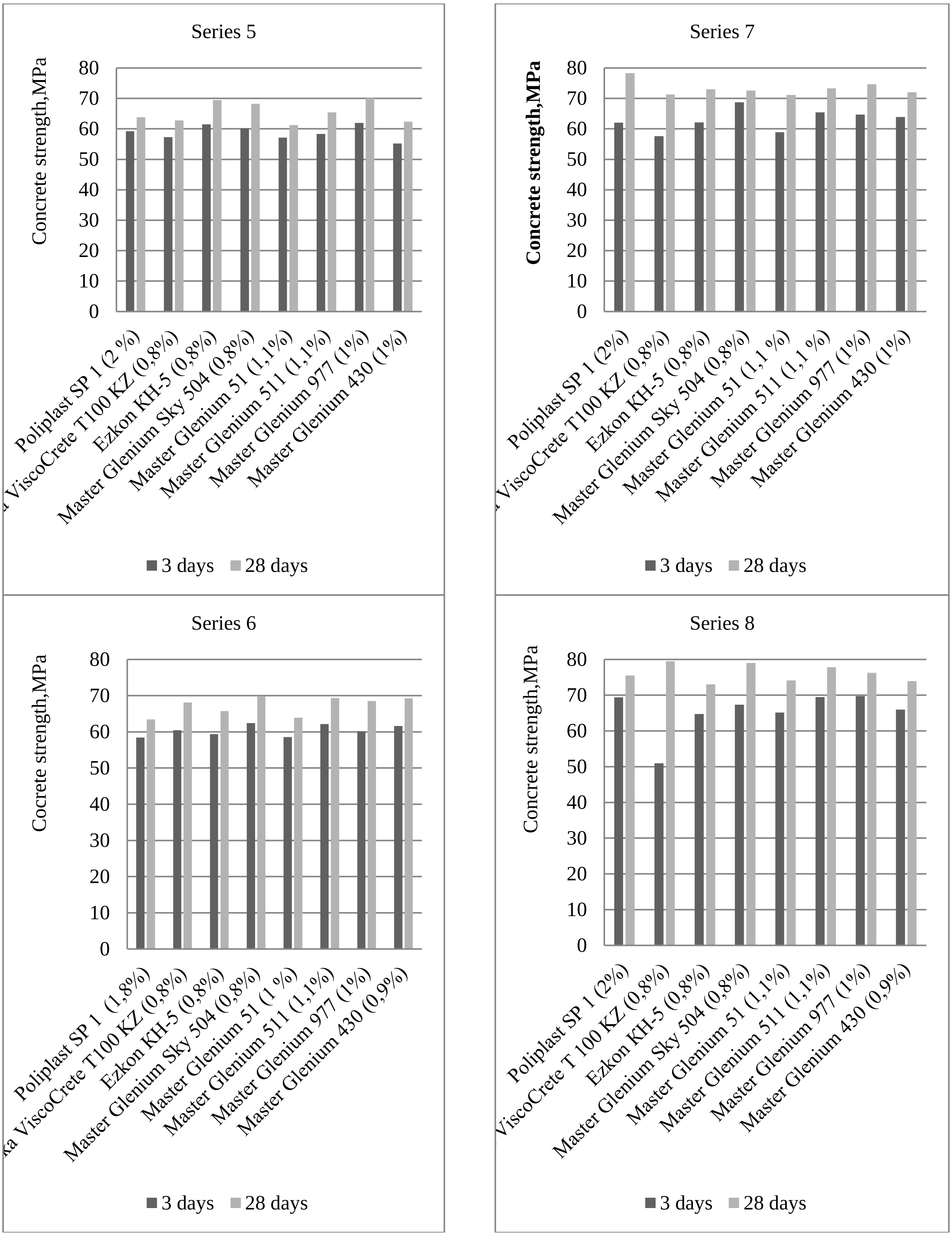


Fig. 3 The effectiveness of superplasticizers influence on the strength of concrete sleepers (B 50)

The authors' article [22] shows the difference between European standards and GOST, which consists in demanding action to dynamic and shock loads. For this, the authors compared the options for reinforcing sleepers with high-strength reinforcement of 9.6 mm and 10.5 mm. As a result of their work, it was found that when using reinforcement of 10.5 mm and additional reinforcement in the area under the rail seat, it is possible to achieve compliance with shock loads.

In our work, reinforcement of sleepers with high-strength wire with a diameter of 7 mm in the amount of 8 pieces in accordance with Italian technology (conveyor technology, carousel method) and the option of additional reinforcement in the area of the rail seat area are considered (Fig.3). For additional reinforcement, a wire of 3 mm BPI diameter was used. The metal frame consisted of three rows of wire with a distance between the rods of 30 mm, was installed outside around the plastic dowels. The thickness of the protective layer of concrete to the top of the rail seat level was 35 mm. At the same time, anchor heads are planted on eight rods, which are held by steel anchor plates remaining in the concrete body. Reinforcement with high-strength wire with a diameter of 7 mm in an amount of 8 pieces is mentioned by G.S. Ivanov [23], where it is indicated that it began to be used in the FRG factories from the 70s of the last century. Throughout a half-century history of application, this reinforcement has proven its reliability in providing crack resistance and bearing capacity of sleepers.

Fig. 3. A variant for additional reinforcement of the rail seat area.
1 - main reinforcement;
2- additional reinforcement.

The authors propose additional helical reinforcing separately around each dowel for a sleeper of type III (for screw-expansion dowel fastening) according to GOST 33320-2015. According to the authors, reinforcing of dowel helically allows better distribution of loads and damping vibrations arising during time dynamic loads, preventing the premature destruction of sleepers. Unfortunately, in the report to the useful model, the type of reinforcement of the sleepers (3 mm wire in the amount of 44 pieces or the variant of the enlarged reinforcement with wires of 7 or 9.6 mm) is not indicated.

In the article by Omarova G.A. [25] the results of studies on the resistance to tearing dowels from reinforced concrete sleepers are reflected. The paper describes the nature of concrete deterioration between the rows of the reinforcing cage at the moment of dowel tearing. The option of additional reinforcement of the dowel area is proposed to increase the resistance to tearing and the possibility of maintaining the sleepers in good condition. A variant of reinforcing sleepers was tested in the author's work [25] - 3 mm wire in the amount of 44 pieces.

According to the authors [23], crack resistance is an important qualitative characteristic of sleepers. under the action of concentrated train loads in the sleeper, there are positive bending moments in the rail seat and a negative moment in the middle part. Therefore, the stretched zones are located on the side of the sole in the rail seat sections and on top in the middle part [22].

Sleepers (type III as per GOST 33320-2015) were manufactured at the "NORD Prom NS" LLP plant using conveyor technology of a carousel type. The prestressed force was 46.5 kN, concrete class was B50. The calculations have shown that with the planned crack resistance of 142 kN, the positive moment of the first crack formation in the rail seat is 24.353 kN·m.

Static tests of rail seats were carried out on a machine for bending tests (Fig.4) according to the beam scheme with a distance between supports of 800 mm.

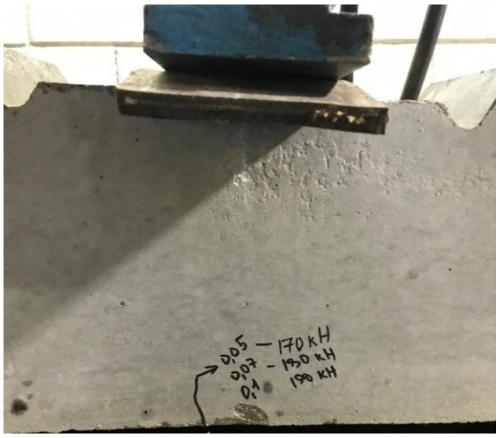
Fig. 4 External appearance of the test of the rail seat for crack resistance.

The load was applied in the form of a concentrated force at the level of the center of the rail seat. The technical standard document for testing is GOST 33320-2015 “Concrete sleepers for railways”. During the tests, the Metrocom program is used, in which the values of dead-weight loads, the rate of their rise and the exposure time at a certain load are set. The exposure time under load was 3 minutes, during the time the test section was examined in the tensile area at the moment of determining of crack initiation and measuring of crack width. The initial load during the test was 130 kN, and the final load was 190 kN. The test load is 142 kN. The speed of loading was 30 kN / min, then 10 kN / min at the moment of rise from 130 to 190 kN. The first moment of crack formation is 170 kN (Fig.5a), which is 19% more than the test load, the transverse crack width is 0.05 mm, and the length is 20 mm.

In both rail seats, the results were identical. As per GOST 33320-2015, when testing for crack resistance, the appearance of a visible crack at a test load is determined (a transverse crack is visible with a width of opening at the base of more than 0.05 mm and a length of more than 30 mm).

In a sleeper without additional reinforcement (Fig.5b), the first moment of crack formation was equal to a load of 160 kN, which is 5.8% lower than in a sleeper with additional reinforcement. But this advantage of additional reinforcement, in our opinion, is not significant, since it requires additional charges and funds associated with its manufacture and installation during production.

a)



b)

Fig. 5. The moment of crack formation during application of dead-weight loads.
a - with additional reinforcement, b - without additional reinforcement.

4. CONCLUSIONS

In the manufacture of concrete cube patterns using superplasticizers, it was noted that it is possible to adjust the dosage of the additive depending on the used type of sand and gravel mixture (in a sand with a particle size of 2.9, it is possible to reduce the consumption of the additive by 0,1-0,2%).

When using sand and gravel mixture produced by "KKK Beton" LLP, a decrease in water demand of concrete mix by 5% was noted.

The use of superplasticizers (on a polycarboxylate basis) made it possible to reduce cement consumption by 4% compared with the test composition (where superplasticizer based on naphthalene sulfate base Polyplast SP 1 is used). The dosage of Polyplast SP 1 is 1.8-2% in the test composition, the dosage of superplasticizers is from 0.6 to 1.1%.Using all of these additives, it was possible to obtain the required transfer strength of 49.5 MPa and the design grade strength for concrete class B 50.

A variant of the additional reinforcement of the area of the rail seat is proposed, which serves to strengthen this zone and resist the pull-out of the plastic dowel. The field tests of sleepers for crack resistance have been carried out, show that work in this direction should be continued and require further study.

1. ACKNOWLEDGMENTS

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