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COMPARISON OF THE EFFECTIVENESS OF SUPERPLASTICIZERS IN CONCRETES FOR RIGID PAVEMENT

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Abstract. More and more roads with hard cement concrete pavements are built in developed countries, including Ukraine. The production of almost all types of concrete involves the use of plasticisers. Today, polycarboxylate additives are the most effective plasticisers. However, the effect of water-reducing modifiers depends on the formulation and technological characteristics of a concrete. In the construction of hard pavements, concrete mixes with relatively low mobility are used, in which it is necessary to determine the effectiveness of various plasticisers, taking into account the type of cement. Accordingly, the purpose of the study is to establish how the strength of concrete pavements is determined by different types of plasticisers.

The strength of concretes with four different plasticisers was compared. The plasticisers considered were: Polyplast SP-1 (based on a mixture of sodium salts and polyethylene of phthalate sulphuric acids); Coral ExpertSuid-5 (based on carboxylic acid polymers and esters), Coral MasterSilk (based on lignosulphonates), and Sika® Plastiment®-1230 (produced on the basis of lignosulphonates). These were added in two dosages – 0.8 and 1.2% by weight of cement. The cement used was PC II/A-Sh-500 R-H in the amount of 350 kg/m3, the crushed stone was as fine as 5–20 mm, and the washed quartz sand had the fineness modulus 2.4.

The mobility of all concrete mixes was S1 and depended on the composition of the concrete. It has been found that the use of Coral ExpertSuid-5 can reduce the water/cement ratio most significantly. The use of Coral MasterSilk reduces the water/cement ratio to a slightly lesser extent. SP-1 and Sika® Plastiment®-1230 have approximately the same, and the lowest, effectiveness in reducing the water demand of the mixture.

At the design age, the highest strength (55.9-57.5 MPa) was observed in concrete pavements modified with Coral ExpertSuid-5 and Sika® Plastiment®-1230 plasticisers. At the age of 3 days, concretes with the Coral ExpertSuid-5 additive have the highest strength. An increase in the dosage of these two plasticisers from 0.8% to 1.2% increases the early strength of concrete, but does not change the strength at the design age. The strength of the concrete modified with the Polyplast SP-1 and Coral MasterSilk additives was lower at the early and design ages. That is, taking into account the use of mixtures of low mobility and cement PC II/A-S-500 R-H, the effectiveness of the additive based on carboxylic acid polymers in increasing the strength of concrete at the design age is approximately equal to that of the lignosulphonate-based additive.

Keywords: rigid pavement, superplasticiser, effectiveness, concrete, strength.

Introduction. Roads with rigid cement concrete pavements are widely used in developed countries. In recent years, the share of roads with cement concrete pavements has also increased significantly in Ukraine, due to their technical advantages. The main ones are their high durability, resistance to formation of corrugations and ruts, and low dependence of their performance on the ambient temperature. An important economic advantage of hard-surfaced roads for Ukraine is that the production of cement concrete does not use bitumen, which otherwise must be exported. Accordingly, in the process of post-war reconstruction of the country, the construction of cement concrete roads will also be highly practical economically.

In recent decades, plasticisers of one kind or another have been used to produce almost all types of concrete. At the current stage of development of the construction industry, polycarboxylate superplasticisers are the most effective, especially in the manufacture of concrete mixes with high mobility. However, it is concrete mixes with relatively low mobility that are used in the construction of rigid concrete pavements. Besides, new plasticisers and complex additives never stop appearing on the domestic market. Therefore, selecting rational superplasticisers for hard pavement concretes is a topical task. To solve it, one should also take into account the type of cement used.

Analysis of research and publications. Cement concrete can effectively distribute the stresses that loading produces on the road base, and withstands repeated loading better than asphalt concrete does. So, rigid pavements prove the most effective with high traffic intensity [1].

It is economically practical to use rigid pavements, primarily because roads with such pavements are two or more times as durable as those with asphalt concrete pavements [2].

Due to its lighter colour, cement concrete has better surface visibility, which increases traffic safety in the dark. Also, the properties of hard pavements hardly change with fluctuations in the ambient temperature [3].

When laying rigid pavements, a project must specify the requirements for concrete, primarily the tensile strength class, compressive strength class, and frost resistance. DBN B.2.3-4:2015 specifies, depending on the road category, the minimum design class of concrete for cement concrete pavements [4].

Today, virtually all concrete is produced using plasticising additives (most often superplasticisers), because it is necessary to ensure the specified strength and frost resistance of the material while minimising production costs [5]. The most effective superplasticisers on the market are polycarboxylate additives [6–9]. For example, the study [6] shows that the use of polycarboxylates doubled the strength of concrete, as compared with unmodified concrete, and amounted to more than 60 MPa. When lignosulphonate superplasticisers were used, the strength was more than 45 MPa, and with naphthalene sulphomaldehyde superplasticisers, it was about 40 MPa. In the paper [9], it is shown that cement stone with a polycarboxylate additive has a higher compressive strength than cement stone containing naphthalene-based superplasticisers. However, the effect of water-reducing modifiers depends on the formulation and technological characteristics of the concrete. Particular attention should be paid to the compatibility of the type of cement and the superplasticiser [10]. For example, it is known that polycarboxylate-based plasticisers have better water reduction in high-mobility concrete mixes. So, when using low-mobility or stiff mixes, the effectiveness of plasticisers must be additionally determined.

When using a slipform paver for pavement construction, which is the most common technology, in accordance with the requirements of DBN B.2.3-4:2015 [4], the concrete mix should have a cone slump of 1 to 5 cm, depending on the speed of the paver. That is, the mixtures have low mobility, and determining the effectiveness of plasticisers of various types in these mixtures is a task of current importance. The optimal consumption of plasticiser can only be determined in the laboratory, taking into account the characteristics of the aggregates and cement used [5].

The purpose of the study is to establish how plasticisers of different types determine the strength of concrete in rigid pavements.

Materials and methods. The experiment compared the strength of concrete with four different plasticisers available on the domestic market:

– Polyplast SP-1 (company Polyplast, Novomoskovsk). The additive is made on the basis of a mixture of sodium salts of polyethylene of phthalate sulphonic acids of different molecular weights;

– Coral ExpertSuid-5 (company Coral, Zaporizhzhia). It is produced on the basis of polymers of carboxylic acids and esters [11];

– Coral MasterSilk (company Coral, Zaporizhzhia). It is produced on the basis of lignosulphonates [12];

– Sika® Plastiment®-1230 (Sika, Switzerland). Is also produced on the basis of lignosulphonates [13].

The cement used was PC II/A-Sh-500 R-H manufactured by Dickerhoff Cement Ukraine. The amount of cement in all concretes was 350 kg/m^3. Crushed stone as fine as 5–20 mm and washed quartz sand with the fineness modulus 2.4 were also used.

All additives were introduced in two dosages – 0.8 and 1.2% by weight of cement. Thus, 8 concrete compositions were investigated (Table 1). The workability of all concrete mixes was S1 with a cone slump of 2 to 3 cm. This meets the requirements of DBN B.2.3-4:2015 *Highways*, according to which, as shown above, the mobility of concrete mixes for pavement construction should be 1 to 5 cm [4]. The equal mobility was achieved by selecting the amount of water, along with a corresponding adjustment of the concrete composition.

Table 1 – Compositions of the concretes analysed

№ points	Concrete composition (k/m^3)					
	Portland - cement	Crushed stone	Sand	Additive		Water
				type	quantity	
1a	350	1205	766	SP-1	2.8 (0.8%)	145
1b			770		4.2 (1.2%)	140
2a			779	Coral ExpertSuid-5	2.8 (0.8%)	128
2b			780		4.2 (1.2%)	127
3a			770	Coral Master Silk	2.8 (0.8%)	139
3b			774		4.2 (1.2%)	134
4a			766	Sika® Plastiment®-1230	2.8 (0.8%)	145
4b			765		4.2 (1.2%)	146

Research results. Since the mobility of all the concrete mixes studied was equal, the amount of water in them and, accordingly, the water/cement ratio depended on the composition, i.e., based on the experimental conditions, on the type and amount of a plasticising additive (Table 2).

The data in Table 2 have allowed building the diagram shown in Fig. 1. It visualises the effect of plasticisers on the water/cement ratio of the concrete mixes.

Table 2 – Water/cement ratio of concrete mixes and compressive strength of the concretes analysed

Points	Additive	W/C	Compressive strength, MPa	
			at the age of 3 days	at the age of 28 days
1a	SP-1 (0,8%)	0,414	13,5	1a
1b	SP-1 (1,2%)	0,400	14,5	1b
2a	Coral ExpertSuid-5 (0,8%)	0,366	16,9	2a
2b	Coral ExpertSuid-5 (1,2%)	0,363	17,6	2b
3a	Coral MasterSilk (0,8%)	0,397	13,7	3a
3b	Coral MasterSilk (1,2%)	0,383	14,7	3b
4a	Sika® Plastiment®-1230 (0,8%)	0,414	12,8	4a
4b	Sika® Plastiment®-1230 (1,2%)	0,417	13,6	4b

As can be seen from the diagram in Fig. 1, the water/cement ratio of a mix of the equal mobility S1 is most reduced when using the polycarboxylate additive Coral ExpertSuid-5. The use of the Coral MasterSilk additive reduces the water/cement ratio to a slightly lesser extent. The additives SP-1 and Sika® Plastiment®-1230 are about equally effective in reducing the water consumption of the mix, but are the least effective of the plasticisers considered in the study.

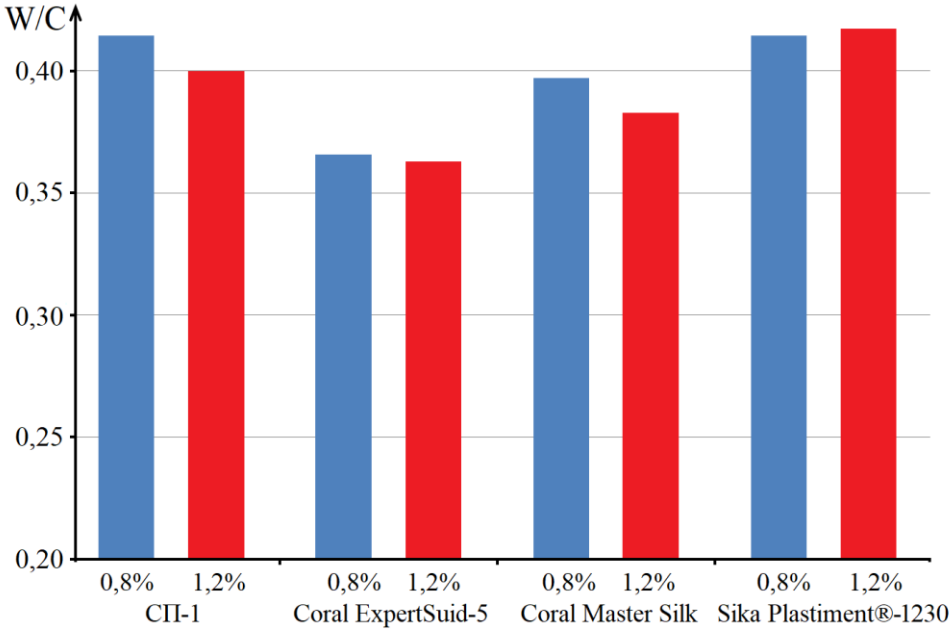

Fig. 1. Effect of the type and amount of a plasticiser on the water/cement ratio of concrete mixes

With an increase in the dosage of the plasticisers SP-1, Coral ExpertSuid-5, and Coral MasterSilk from 0.8% to 1.2% by weight of cement, the water/cement ratio of the mixtures decreases still more. However, when using the lignosulphonate-based additive Sika® Plastiment®-1230, changing its dosage from 0.8% to 1.2% does not affect the water/cement ratio of a mixture.

The compressive strength of concrete was tested at the age of 3 and 28 days (Table 2). The diagrams based on the data in Table 2 and presented in Fig. 2 show how the type and amount of a plasticiser affect the strength.

Analysis of the data in Table 2 and the diagrams shows that at both the early age and the design age of 28 days, the highest strength is that of the concretes modified with the additive based on carboxylic acid polymers Coral ExpertSuid-5. At the age of 3 days, concretes modified with SP-1 and Coral MasterSilk are about equally strong. Concretes with Sika® Plastiment®-1230, which are the highest in their water/cement ratio among the tested ones, have the early strength lower by 0.7–1.1 MPa, as compared with the concretes modified with SP-1 and Coral MasterSilk.

However, at the design age of 28 days, the strength of concretes with Sika® Plastiment®-1230 is by 2.5–4.7 MPa higher than that of concretes with SP-1 and Coral MasterSilk, and only by 0.7–1.6 MPa lower than that of concretes modified with Coral ExpertSuid-5.

At the age of 3 days, with an increase in the dosage of all additives from 0.8 to 1.2% by weight of cement, the strength of concrete increases by 0.7–1 MPa. At the age of 28 days, an increase in the amount of the additive based on carboxylic acid polymers Coral ExpertSuid-5 results in no increase in the concrete strength. For other plasticisers, increasing their dosage to 1.2% causes an increase in the concrete strength by 0.4–2.1 MPa.

This effect of plasticisers on the strength is primarily due to their effect on the water demand and, accordingly, the water/cement ratio of concrete mixes. Fig. 3 shows diagrams that visualise how a water/cement ratio of a mix affects the strength of concrete at the age of 3 and 28 days.

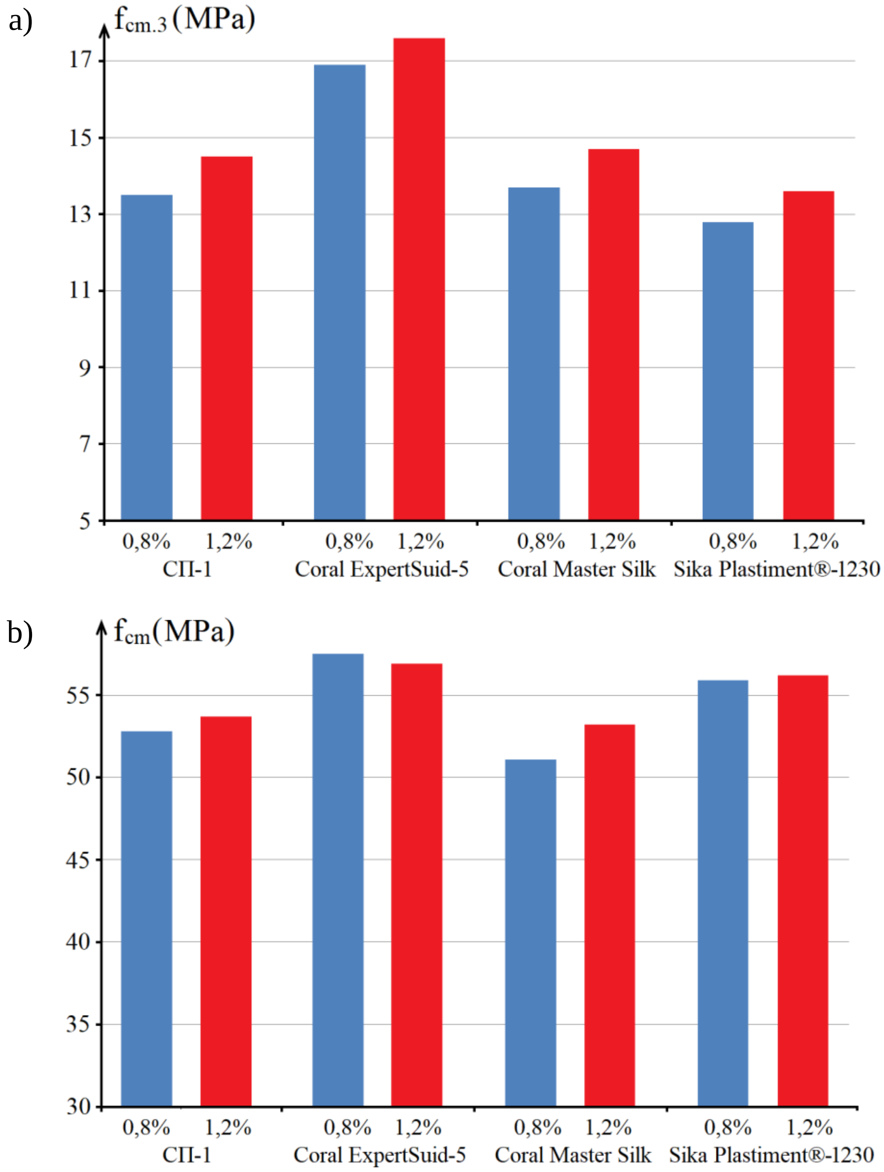

Fig. 2. Effect of the type and amount of a plasticiser on the compressive strength of concretes: a – at the age of 3 days; b – at the age of 28 days

It is known that the effect of the water/cement ratio on the concrete strength is close to a linear relationship [5]. Analysis of the diagrams in Fig. 3 shows that the water/cement ratio of a mix has a more pronounced effect on the strength of concrete at the age of 3 days. The correlation coefficient r (W/C, $f_{cm.3}$) is 0.94. At the design age, the effect of the water/cement ratio on the strength is not as obvious, with r (W/C, f_{cm}) = 0.46. This can be explained by the fact that as the age of concrete increases, its strength is increasingly influenced by the peculiarities of the capillary-porous structure, as well as by the structure density and total porosity.

Conclusions and prospects for further research. At the design age, the highest strength was observed in the hard pavement concretes modified with Coral ExpertSuid-5 (based on carboxylic acid polymers and esters) and Sika® Plastiment®-1230 (based on lignosulphonates). At the early age, the concretes containing Coral ExpertSuid-5 had the highest strength. An increase in the dosage of these two plasticisers from 0.8% to 1.2% by weight of cement increased the early strength of concrete, but did not cause significant changes in the strength at the design age. Thus, taking into account the use of low mobility mixes typical of hard pavement concretes, as well as PC II/A-S-500 R-H cement, the effectiveness of the carboxylic acid polymer-based additive is approximately the same as that of the lignosulphonate-based additive. However, as noted above, this conclusion is only applicable to the concrete strength at the design age.

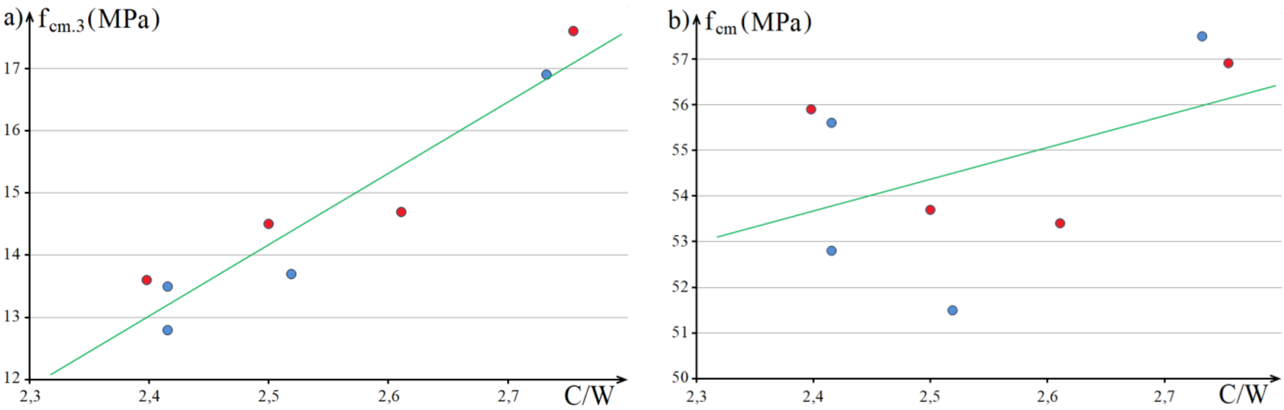

Fig. 3. Effect of the W/C ratio of mixes with equal mobility on the compressive strength of concretes:
a – at the age of 3 days; b – at the age of 28 days

In the future, it is planned to study how plasticisers of the same type affect the complex of properties of concretes and fibre-reinforced concretes, in particular their frost resistance and wear resistance, which are the parameters that determine the durability of rigid pavements. Experimental design methods will be used in the study.

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ПОРІВНЯННЯ ЕФЕКТИВНОСТІ СУПЕРПЛАСТИФІКАТОРІВ В БЕТОНАХ ЖОРСТКИХ ДОРОЖНІХ ПОКРИТТІВ

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Анотація. Дороги з жорсткими цементобетонними покриттями все частіше будуються в розвинених країнах світу, зокрема в Україні. При виробництві майже всіх типів бетонів використовуються добавки пластифікатори. На сьогодні найбільш ефективними серед пластифікаторів є добавки полікарбоксилатного типу. Проте вплив водоредукуючих модифікаторів залежить від рецептурно-технологічних особливостей бетону. При влаштуванні жорстких покриттів використовуються бетонні суміші з відносно низькою рухомістю, в яких необхідно визначати ефективність різних пластифікаторів з урахуванням типу цементу. Відповідно метою роботи є визначення впливу пластифікаторів різного типу на міцність бетонів жорстких дорожніх покриттів.

Порівняно міцність бетонів з чотирма пластифікаторами: Поліпласт СП-1 (на основі суміші натрієвих солей і поліметиленуфталінсульфокислот); Coral ExpertSuid-5 (на основі полімерів карбонових кислот та ефірів), Coral MasterSilk (на основі лігносульфонатів) і Sika® Plastiment®-1230 (виробляються на основі лігносульфонатів). Усі добавки вводилися у двох дозуваннях – 0,8 і 1,2% від маси цементу. Використовувався цемент ПЦ ІІ/А-Ш-500 Р-Н у кількості 350 кг/м^3, щебінь фракції 5-20 мм і митий кварцовий пісок з модулем крупності 2,4.

Рухомість всіх бетонних сумішей була рівною S1, відповідно залежала від складу бетону. Встановлено, що використання Coral ExpertSuid-5 В/Ц дозволяє найбільш істотно знизити В/Ц. Застосування Coral Master Silk дозволяє знизити В/Ц в дещо меншому ступені. СП-1 і Sika® Plastiment®-1230 мають приблизно однакову і найменшу ефективність у зниженні водопотреби суміші.

Встановлено, що у проєктному віці найбільшу міцність (55,9-57,5 МПа) мають бетони жорстких дорожніх покриттів, модифіковані пластифікаторами Coral ExpertSuid-5 і Sika® Plastiment®-1230. У віці 3-х діб найбільшу міцність мають бетони з добавкою Coral ExpertSuid-5. Зростання дозування даних двох пластифікаторів від 0,8% до 1,2% підвищує ранню міцність бетону, але не викликає змін міцності у проєктному віці. Міцність модифікованих добавками Поліпласт СП-1 і Coral MasterSilk бетонів була нижчою у ранньому і проєктному віці. Тобто з урахуванням використання сумішей невисокої рухомості та цементу ПЦ ІІ/А-Ш-500 Р-Н ефективність у підвищенні міцності бетону у проєктному віці добавки на основі полімерів карбонових кислот є приблизно рівною ефективності добавки на основі лігносульфонатів.

Ключові слова: жорстке дорожнє покриття, суперпластифікатор, ефективність, бетон, міцність.

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