INFLUENCE OF BASALT FIBER AND AIR-ENTRAINING ADMIXTURE ON THE PROPERTIES OF RIGID CONCRETE PAVEMENT

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Influence of basalt fiber and air-entraining admixture on the properties of rigid concrete pavement was investigated. Concretes without fiber and with 0.50, 0.75 and 1.0 kg/m³ fiber were produced. The amount of air-entraining admixture varied from 0 to 0.15% of the cement mass. Due to dispersed reinforcement, the compressive strength of concrete increased by 13-24%, and the tensile strength increased by 21-29%. The use of air-entraining admixture did not affect the tensile strength of concrete, but reduced compressive strength by 2-21%. Concrete without dispersed reinforcement and air-entraining admixture has a frost resistance F200. The use of basalt fiber increases the frost resistance of concrete up to F300. When using 0.05% air-entraining admixture, the frost resistance of concrete decreases, but when using 0.15% admixture, the frost resistance of concrete without fiber increases from F200 to F300. The air-entraining admixture does not affect the abrasion resistance of concrete, and the dispersed reinforcement reduces the abrasion resistance by 14-15%, which contributes to the increase in the durability of the pavement. The use of dispersed reinforcement and complex modification with polycarboxylate type superplasticizer and air-entraining admixture made it possible to obtain concrete for rigid concrete pavement with high durability and the required strength.

Keywords: *rigid concrete pavement, basalt fiber, air-entraining admixture, durability, strength, frost resistance*

1. Introduction

A significant part of highways in European countries, USA and China are built using rigid concrete pavements [1,2]. The task of improving the quality and durability of rigid pavements is relevant because its solution allows extending the overhaul intervals and reducing road maintenance costs [2]. Part of the road infrastructure of Ukraine was destroyed during the war, so the task of obtaining concrete for rigid pavement with high durability and rational cost has become even more important.

According to the requirement of the national standard GBN V.2.3-37641918-557:2016 [3], when designing rigid pavement, it is necessary to provide for the widespread use of local and new modern road construction materials. According to the standard DBN V.2.3-4:2015 [4], it is necessary to use plasticizing and air-entraining admixtures for preparing concrete for rigid pavements.

The use of an air-entraining admixture simultaneously with a superplasticizer is a well-known method for increasing the frost resistance of concrete [5]. According to the Ukrainian standard DBN V.2.3-4:2015 for concrete of rigid pavement, the amount of entrained air in the mixture should vary from 5% to 6% [4], but most researchers have concluded that a range of air from 5% to 7% is rational [6,7].

The results of practical research confirm the feasibility of using air-entraining admixtures for concrete of rigid pavements. This way [8], due to the use of a complex modification, this explored and has been reported as the main reason for improving the pozzolana, the strength and durability of airfield toughness of the mortar and includes an air-entraining admixture and pavement concretes increases. A similar effect was achieved in [9], where the combination of microsilica and a highly effective air-entraining admixture significantly improved the resistance of pavement concrete to frost-salt destruction. In [10], the use of an air-entraining admixture improved the resistance of airfield pavement concrete to frost damage and the effects of substances that are used to prevent aircraft icing.

However, in [7] it was found that due to the technological features of transportation and compaction of pavement concrete, there are significant discrepancies between the volume of air drawn in the freshly prepared mixture and the actual value of this indicator when determined in the pavement. This difference is also affected by the type of air-entraining admixture. Such discrepancy may affect the durability of the rigid pavement and may also be the basis for the imposition of fines by the customer. Also, the amount of entrained air depends on the mixing time of the concrete mixture and the method of its compaction [11].

Dispersed reinforcement is a well-known method of improving the properties of concrete, which affects the durability of rigid pavement in typical Ukrainian and European climatic conditions [12,13]. Fibers of various types are used for reinforcement, but the most common are polypropylene, steel and basalt [14,15, 16]. Basalt fibers can be considered one of the most effective in terms of their cost and corrosion resistance [17-19]. For example, in [17] it was determined that, in

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order to achieve high compressive and tensile strength of concrete pavement, the optimal reinforcement is the use of 8 kg/m^3 basalt fiber 36 mm long. Due to the use of basalt fiber, the autogenous shrinkage of rigid concrete pavement is reduced, their strength and crack resistance are increased [18]. As it was shown in [19], due to the use of basalt fiber, the tensile strength of concrete pavements can be increased by 20%, and the compressive strength by 9.4%. In this case, the length of the fibers has a significant influence, and the irrational use of reinforcement can even lead to a deterioration in the mechanical properties of the material.

Thus, the combination of dispersed reinforcement and a complex modification, including an air-entraining admixture, is a common method for improving the mechanical properties and increasing the durability of rigid concrete pavement. An analysis of the results of many researchers on the use of these methods shows that their effectiveness depends significantly on the type of fiber, admixtures, or cement, and other features of the concrete composition.

This is why, the task of increasing the strength and durability of concrete for rigid pavements with basalt fiber and an air-entraining admixture is relevant. It is also necessary to consider the existing raw material base, as well as the technological features of the preparation of the concrete mixture and the production of rigid concrete pavement.

This study analyzes the complex effect of the use of basalt fiber and air-entraining admixture on the strength of concrete for rigid pavement, as well as on the characteristics of concrete that ensure its durability. At the same time, all components of the concrete mix were produced in Ukraine, which is important for supporting the economy in the reconstruction of infrastructure after the war.

2.Materials and methodology

The aim of the research is to determine the effect of basalt fiber and air-entraining admixtures on the strength, frost resistance and abrasion resistance of concrete of rigid pavement.

Such materials were used for the manufacture of concrete mixtures:

- Portland cement CEM I 42,5 R, manufactured by Dyckerhoff Ukraine;
- washed quartz sand with a modulus of 2.2;
- crushed stone fraction of 5-20 mm;
- polycarboxylate superplasticizer STACHEMENT 2570/5/G manufactured by Stachema (Ukraine);
- basalt fiber BAUCON®-basalt manufactured by Bautech-Ukraine; fiber length 12 mm, fiber diameter 18 μm;
- air-entraining admixture MICROPORAN manufactured by Stachema (Ukraine).

In the experimental study, the amount of BAUCON®-basalt fiber in the concrete composition varied from 0.50, 0.75 and 1.0 kg/m^3. In each batch of concrete samples, a control unreinforced composition of concrete was also produced.

3 batches of 4 concrete compositions each were produced: without fiber and with three different dosages of fiber. In the first batch (No.1–No.4), concrete compositions were produced without air-entraining admixture. In the second batch (No.5 –No.8), concretes and fiber-reinforced concretes of similar compositions were produced, but additionally modified with the MICROPORAN air-entraining admixture in an amount of 0.05% by weight of cement. In the third batch (No.9 –No.12), the amount of MICROPORAN admixture was 0.15% by weight of cement. Such admixture dosages were chosen based on the results of previous experiments and considering the manufacturer's recommendations. The use of MICROPORAN at 0.10% did not produce a significant difference in the volume of air entrained in the concrete mixture compared to the admixture of 0.05%. Also at this dosage, the quality of the mixture and the amount of air entrained were very dependent on the mixing time.

All concretes were modified with superplasticizer STACHEMENT in the amount of 0.6% by weight of cement. All concrete mixtures had equal workability S1, slump 2–4 cm, determined according to the national standard DSTU B V.2.7-114-2002 [20]. Such workability was chosen as the most typical when paving with the use of a concrete paver with a sliding formwork. The compositions of 12 tested concretes are shown in Table 1.

The actual change in the amount of cement and aggregates per 1 m^3 of concrete was due to the entrainment of air into the mixture. This change was considered when selecting concrete compositions. Thus, the concretes compositions were proportionally recalculated, considering the increase in their porosity and the decrease in average density.

For each concrete and fiber-reinforced concrete composition compressive strength was determined on 10×10×10 cm cubes and tensile strength was determined on 10×10×40 cm prisms according to the national standard DSTU B V.2.7-214:2009 [21]. The abrasion resistance was determined on an abrasive wheel by DSTU B V.2.7-212:2009 [22]. The frost resistance was measured by the accelerated method according to national standard DSTU B V.2.7-49-96 (the third method, freezing and thawing in salt water) [23].

3.Research results and analysis

For all concrete mixtures, the amount of entrained air was controlled according to the.

Table 1

The compositions of the investigated concretes and fiber concretes (kg/m^3)

No.	Cement *(±0.5 kg/m³)*	Crushed stone *(±1 kg/m³)*	Sand *(±1 kg/m³)*	STACHEMENT 2570/5/G *(±1%)*	BAUCON®-bazalt *(±1%)*	MICRO-PORAN *(±1%)*	Water *(±0.5 kg/m³)*
1	350	1205	775	2.10	0	0	135
2			774		0.500		136
3			774		0.750		136
4			774		1.000		136
5	343±0.5	1185	764	2.05	0	0.171	127
6			763		0.500		128
7			763		0.750		128
8			763		1.000		128
9	336±0.5	1160	740	2.02	0	0.505	125
10			739		0.500		126
11			739		0.750		126
12			739		1.000		126

Table 2

Physical and mechanical properties of concretes and fiber concretes (`±` *indicates standard deviation*)

No.	Entrained air, %	Average density, kg/m^3	Compressive strength, MPa	Tensile strength, MPa	Abrasion, g/cm^2	Frost resistance
1	2.0	2440 ± *10.3*	51.0 ± *0.79*	6.33 ± *0.07*	0.46 ± *0.025*	F200
2	1.9	2463 ± *8.1*	60.4 ± *0.85*	6.83 ± *0.06*	0.43 ± *0.007*	F300
3	2.3	2463 ± *11.0*	63.0 ± *0.64*	6.97 ± *0.09*	0.42 ± *0.010*	F300
4	1.9	2450 ± *11.5*	63.2 ± *0.76*	7.63 ± *0.03*	0.39 ± *0.021*	F300
5	5.3	2401 ± *9.5*	50.0 ± *0.55*	5.83 ± *0.06*	0.47 ± *0.016*	F200
6	4.9	2408 ± *7.4*	52.8 ± *0.83*	6.03 ± *0.05*	0.44 ± *0.014*	F200
7	5.4	2430 ± *12.6*	52.9 ± *0.70*	6.97 ± *0.05*	0.44 ± *0.020*	F200
8	4.8	2427 ± *8.9*	56.8 ± *0.97*	7.50 ± *0.07*	0.40 ± *0.011*	F300
9	10.9	2320 ± *10.4*	46.3 ± *0.68*	6.03 ± *0.04*	0.49 ± *0.008*	F300
10	10.2	2351 ± *8.3*	50.2 ± *0.75*	7.01 ± *0.09*	0.45 ± *0.019*	F300
11	11.0	2330 ± *10.8*	52.1 ± *0.69*	7.16 ± *0.08*	0.43 ± *0.014*	F300
12	10.8	2334 ± *11.7*	52.4 ± *0.82*	7.66 ± *0.06*	0.41 ± *0.020*	F300

national standard DSTU B V.2.7-114-2002 [20]. For concrete were determined their average density, compressive and tensile strength, abrasion, and frost resistance. Physical and mechanical properties of the researched mixtures, concretes and fiber concretes are shown in Table 2

An analysis of the data in Table 2 shows that dispersed reinforcement with basalt fiber has almost no effect on the amount of entrained air in the concrete mixture, but the amount of air is expected to change when using the admixture MICROPORAN. In a batch of concrete without an air-entraining admixture (No.1–No.4), the amount of entrained air was in the range of 1.9–2.3%. When using 0.05% MICROPORAN (No.5–No.8), the amount of air in the mixture increases to 4.8-5.4%. When using 0.15% MICROPORAN (No.9–No.12), the amount of entrained air was from 10.2 to 11.0%. In general, the effect of the use of air-entraining admixture coincided with the results of most studies [5,6,8,24].

Accordingly, the average density of the researched concretes also depended mainly on the amount of air-entraining admixture. When using MICROPORAN in an amount of 0.05% by weight of cement, the average density of concretes is reduced by about 1.5% compared to concretes without air-entraining admixtures, from 2440-2460 kg/m^3 to 2401-2430 kg/m^3. When using MICROPORAN at 0.15%, the average density is reduced by about 4.8% to 2320–2351 kg/m^3. This trend reflects the change in the actual amount of entrained air in the concrete mixture remaining in the material after the mixture has been compacted. As it is shown in [7] and [24], the volume of entrapped air in the mixture after preparation and after compaction can differ significantly. Accordingly, it can be assumed that when using 0.15% MICROPORAN, an additional volume of entrapped air is involved in the concrete composition, which is approximately equal to the reduction in the average density of the material in percent, that is, approximately 5%.

Usage of basalt fiber and air-entraining admixture significantly affects the strength of concrete. Due to dispersed reinforcement, the compressive strength of concrete (Fig.1.a) without MICROPORAN increases by up to 12.2 MPa (by 24%), concrete with 0.05% MICROPORAN – by up to 6.8 MPa (by 14%), concrete with 0.15 %

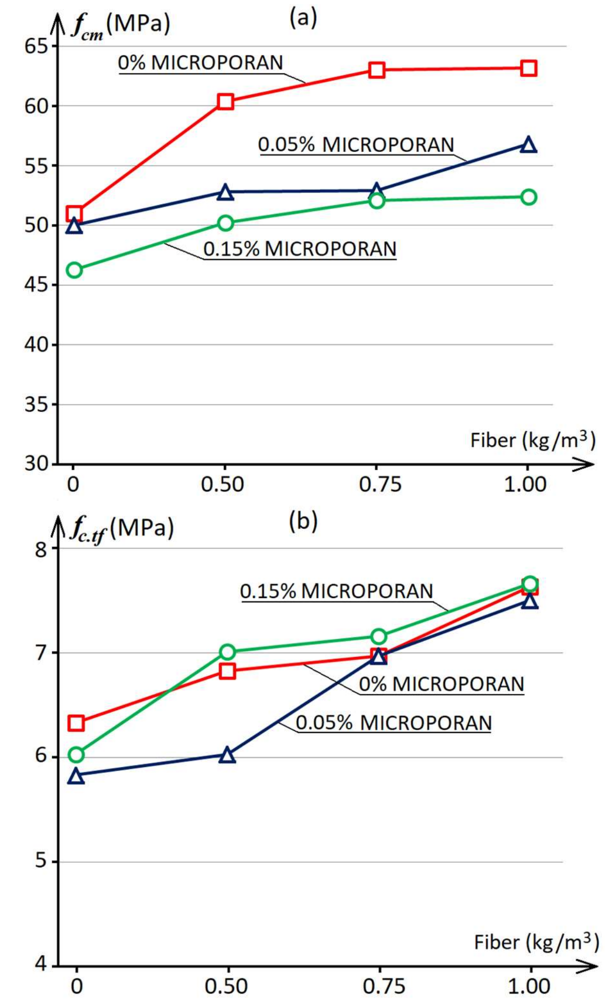

Fig. 1. The effect of the amount of fiber and air-entraining admixture on the compressive strength of concrete (a) and tensile strength of concrete (b).

MICROPORAN – by up to 6.1 MPa (by 13%). Dispersed reinforcement has an even more significant positive effect on the tensile strength of concrete (Fig.1.b). When using basalt fiber in the amount of 1 kg/m^3 for concrete without MICROPORAN, the tensile strength increases by 1.3 MPa (21%), for concrete with 0.05% MICROPORAN – increases by 1.7 MPa (29%), for concrete with 0.15% MICROPORAN – increased by 1.6 MPa (27%). That is, dispersed reinforcement has a great influence on the tensile strength of concrete, which is a well-known effect [12,14-16,18,19].

Usage of an air-entraining admixture reduces the compressive strength of concrete by 2-16% when using 0.05% MICROPORAN and by 9-21% when using 0.15% MICROPORAN (Fig.1.a). Such effect is known in materials science and is explained primarily by a decrease in the average density [6,7,25]. Additional air pores affect the construction of the matrix of the composite material, as well as the reduction in cement consumption per 1 m^3 of concrete, which occurs when the consumption of mixture components is recalculated for the same volume of concrete.

Admixture MICROPORAN has almost no effect on the tensile strength of concrete, despite the actual reduction in the amount of cement in the composition of the material (Fig.1.b). This way, the tensile strength of concretes without an air-entraining admixture and with a different amount of this admixture with the same amount of fiber is approximately equal.

It should be noted that for concrete of rigid pavements, it is the tensile strength that determines their main structural characteristics [3,14,15]. That is, the use of the air-entraining admixture MICROPORAN makes it possible to obtain concrete with the required level of tensile strength with less cement per 1 m^3. Dispersed reinforcement makes it possible to additionally increase the tensile strength of the rigid concrete pavement.

Wear resistance is also an important indicator for quality of pavements, which is determined by the abrasion of the material. Wear resistance determines the durability of concrete under dynamic conditions [15]. Fig.2 shows graphs built on the data of Table 2, reflecting the effect of the amount of fiber and air-entraining admixture on the abrasion of concrete. An analysis of the graphs shows that when using the admixture MICROPORAN, the abrasion of concrete increases by 2-7%. That is, the wear resistance of the material is slightly reduced. This effect is explained by a decrease in the average density of concrete and the actual amount of cement in its composition [26]. At the same time, dispersed reinforcement with basalt fiber reduces the abrasion of concrete by 14-15%, respectively, increases its durability [15,18].

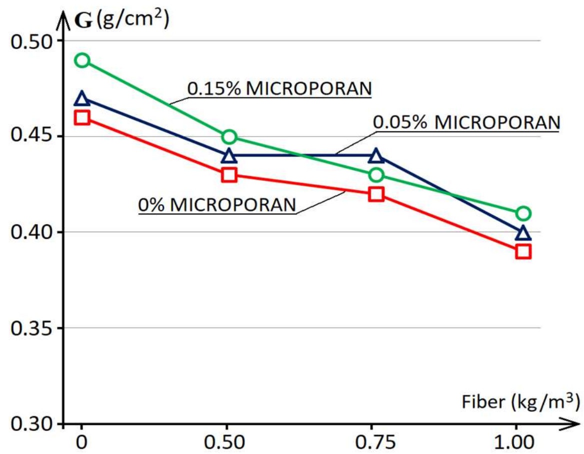

Fig. 2 - Influence of the amount of fiber and air-entraining additive on the abrasion of concrete

The frost resistance of the investigated concretes was also analyzed. This important indicator of concrete quality for rigid pavement for all concrete compositions was provided at a high level from F200 to F300. This level of frost resistance was achieved using the effective superplasticizer STACHEMENT 2570/5/G and high-quality washed aggregates. The W/C mixtures due to the use of such components ranged from 0.37 to 0.39.

It should be noted that the accuracy of determining the actual level of frost resistance of concrete is significantly limited. This is because the accelerated method for determining the level F was used according to DSTU B V.2.7-49-96 “Concrete. Accelerated methods for determining frost resistance during repeated freezing and thawing” (third method, freezing in salt water at -50°C) [23]. Other methods for determining frost resistance require too much time to experiment and are laborious. But the accelerated method for determining the frost resistance of concrete for road and airfield pavements discretely distinguishes only grades F100, F150, F200, F300, and so on. This discreteness does not prevent us from evaluating the direction of the influence of variable composition factors on the frost resistance of concrete but does not allow us to determine this indicator in the range between F200 and F300.

Experimental studies have determined that the use of basalt fiber has a positive effect on the frost resistance of concrete (Table 2). Composition No. 1 without dispersed reinforcement had a frost resistance of F200, and when fiber was used (compositions No. 2-4), the level of frost resistance of concrete reached F300. When using fiber simultaneously with an air-entraining admixture, the effect of dispersed reinforcement is reduced. This can be explained by a more significant effect of the capillary-pore structure on the resistance of concrete to freezing and thawing [5,6,26]. The positive effect of fiber, when used simultaneously with admixture MICROPORAN, was revealed only for composition No. 8. In this concrete composition, when using 1 kg/m^3 of dispersed reinforcement, frost resistance increases in comparison with concretes of compositions No. 5-7.

The effect of an air-entraining admixture on the frost resistance of concrete varies significantly depending on its amount in the composition of the material. When using MICROPORAN in an amount of 0.05% by weight of cement, the frost resistance of concrete (compositions No. 5-7) is reduced to F200 with the amount of fiber up to 0.75 kg/m^3, but with an increase in the amount of MICROPORAN to 0.15%, the frost resistance of concrete again rises to F300, and concrete without fiber (No. 9) also has a frost resistance F300. It is important to note that concretes with admixture MICROPORAN provide high frost resistance with less cement per 1 m^3 of concrete. The effect of positive influences of the maximum amount of the air-entraining admixture can be explained by the fact that the volume of entrained air after the preparation of the mixture and after its compaction is different, as mentioned earlier and in [7,10]. Accordingly, for compositions No. 9-12, the actual volume of entrained air was not 10.2-11.0%, but close to rational, which is 5-7% [4,6,7].

4. Conclusions

Based on the research results, the following conclusions can be drawn. Usage of BAUCON®-basalt fiber into the concrete composition in an amount of up to 1 kg/m^3 increases the compressive strength of concrete by 13-24%, tensile strength by 21-29%, frost resistance by up to 100 cycles and reduces abrasion by 14-15%. Usage of air-entraining admixture reduces the average density of concrete by 1.9-5.4% and compressive strength by 2-21%. Usage of MICROPORAN also slightly increases the abrasion of concrete. When using 0.05% air-entraining admixture, the frost resistance of concrete decreases, and when using 0.15% MICROPORAN, this indicator increases from F200 to F300 for concrete without fibers.

Thus, concrete for rigid pavement with high durability and the required strength was obtained using dispersed reinforcement with basalt fiber and complex modification with polycarboxylate type superplasticizer STACHEMENT 2570/5/G and an air-entraining admixture MICROPORAN. That is, the complex use of additives and fiber made it possible to obtain concrete with rational properties. Usage of modified fiber-reinforced concrete is economically beneficial, because with a slight increase in the cost of the material, the cost of maintaining rigid pavements is significantly reduced. At the same time, only Ukrainian-made components were used, which is important for the economy during the aggression against our country.

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