https://doi.org/10.26906/znp.2018.50.1064

UDK 666.946.3

Bondar V.O., *DSc, Professor*
ORCID 0000-0001-8671-2890 vabondar04@gmail.com
Akhmednabiyev R.R., *post-graduate*
ORCID 0000-0002-8292-9504
Poltava National Technical Yuri Kondratyuk University

DURABILITY OF HEAVY CONCRETE USING BOILER SLAGS WITH CIRCULATING FLUIDIZED BED

The results of studying the influence of boiler ash slags with a circulating fluidized bed on the freeze-thaw resistance of heavy concretes are presented. The following materials were used in the studies: Portland cement PPC 500 N, sand with the fineness modulus M_f =1.05, crushed granite fraction 5-10 mm, boiler ashes with circulating fluidized bed, hyperplasticizer «Fluid Premia-196». The study was performed using mathematical planning of the experiment. It is proved that with the replacement of sand with ashes, the freeze-thaw resistance is somewhat reduced, but the hyperplasticizer compensates the reduction of freeze-thaw resistance by reducing the W/C ratio, resulting in the formation of super-fine pore structure of concrete. Fine pores in the concrete structure compensate the ice formation stress at low ambient temperatures. The optimal cement consumption has been established in terms of freeze-thaw resistance, both at full and partial replacement of sand with ash. It was also determined that the optimum should be considered the consumption of a hyperplasticizer in the amount of 1.2-1.4% of the cement mass.

Key words: *ash and slag, fluidized bed, freeze-thaw resistance, mathematical planning.*

Бондар В.О., *д.т.н. професор*
Ахмеднабієв Р.Р., *аспірант*
Полтавський національний технічний університет імені Юрія Кондратюка

ДОВГОВІЧНІСТЬ ВАЖКИХ БЕТОНІВ З ВИКОРИСТАННЯМ ЗОЛОШЛАКІВ КОТЛІВ ІЗ ЦИРКУЛЯЦІЙНИМ КИПЛЯЧИМ ШАРОМ

Наведені результати дослідження впливу золошлаків котлів із циркуляційним киплячим шаром на морозостійкість важких бетонів. В дослідженнях було використано портландцемент ПЦ 500Н, пісок з модулем крупності $М_{кр}$ = 1,05; щебінь гранітний фракції 5-10 мм; золошлаки котлів із циркуляційним киплячим шаром, гіперпластифікатор «Fluid Premia-196». Дослідження проведені з використанням математичного планування експерименту. Доведено, що із заміщенням піску золошлаками морозостійкість дещо знижується, але гіперпластифікатор сприяє компенсації зниження морозостійкості за рахунок зниження В/Ц відношення, як наслідок, утворення супердрібної порової структури бетону. Тонкі пори у структурі бетону компенсують напруження від процесу утворення льоду при низьких температурах навколишнього середовища. Встановлено оптимальна витрата цементу з точки зору морозостійкості, як при повній заміні, так і при частковій заміні піску золошлаки. Визначено також, що оптимальним слід вважати витрати гіперпластифікатора в кількості 1,2 - 1,4% від маси цементу.

Ключові слова: *золошлаки, киплячий шар, морозостійкість, математичне планування.*

Introduction. Destruction of concrete in a saturated water state influenced by the cyclic action of positive and negative temperatures, as well as varying negative temperatures, is due to a number of physical corrosion processes causing deformations and mechanical damages to products and structures.

Freeze-thaw resistance of concrete depends on its structure, particularly on the porosity nature, as the latter will determine the volume and distribution of ice that will be formed in the concrete body at low temperatures, and, therefore, the value of the stress produced during the process of the concrete structure weakening.

Literature review: In concrete micropores sizing 10^{-5} cm, there is usually bound water that does not turn into ice even at extremely low temperatures (up to –70°C), therefore micropores do not significantly affect the concrete freeze-thaw resistance [1]. The latter depends on concrete macropores and on their structure.

A number of laboratory studies have demonstrated that concrete containing fly ash and ash-slag may be less resistant to frost during freezing and thawing [2 – 4], while low-cement concretes or high-cement concretes have lower freeze-thaw resistance, but part of the cement in them is replaced with ash – fly ash or ash slag [5, 6].

Concrete with fly ash can provide satisfactory freeze-thaw resistance, provided that waterproof cement is used and W/C (water-cement ratio) does not exceed 0.45, and the fly ash content does not exceed 20-30%. In this case, of course, it is assumed that the concrete has an adequate porous structure [7].

The degree of ashes and ash slag influence on the concrete properties not only depends on their amount in the mixture, but also on other parameters, including the composition and ratio of other ingredients in the concrete mixture, the type and size of the particular component, the compaction conditions during the forming and the hardening conditions, as well as construction methods [8, 9].

Aim of the study: analyzing the influence of ash slabs of boilers with circulating fluidized bed on freeze-thaw resistance, and hence on the durability of heavy concretes designed for operation in the climatic conditions of Ukraine.

Materials and methods of the study: The following materials were used in the work: Portland cement PPC 500 N produced by «Haldeberg zement Ukraine»; sand with the fineness modulus M_f = 1.05 taken from the local deposits; ashes of boilers with circulating fluidized bed [9]; "Fluid Premia-196" hyperplasticizer based on modified polycarboxylates; crushed granite fraction of 5-10 mm taken from Kremenchuk deposit. For more complete detection of the ash slag and hyperplasticizer's influence on the concrete freeze-thaw resistance, a three-level experiment planning matrix was implemented in the study.

Freeze-thaw resistance was determined by the rapid method. According to DSTU BV 2.7-47-96 several methods for determining the freeze-thaw resistance of concrete, including two rapid methods are established. The dilatometric method of determining the freeze-thaw resistance by freezing in the kerosene medium was used in the work. According to this method, the freeze-thaw resistance is determined by the maximum difference between volumetric deformations of concrete and standard samples. The standard sample is an aluminum cube with a side length of 100 mm. Measurement of volumetric deformations was carried out using the «Beton-Frost» dilatometer (Fig. 1).

When planning the experiment the input parameters were taken:

X_1 – cement consumption;

X_2 – hyperplasticizer consumption;

X_3 – degree of sand replacement with ash slabs.

Terms of the experiment planning are presented in the Table. 1.

Figure 1 – Illustration of the dilatometer with the measuring electronic unit

Table 1 – Terms of the experiment planning

Level	Variable factors		
	X_1	X_2	X_3
maximal	1	1	1
medium	-1	-1	-1
minimal	0	0	0

Concrete samples were made according to the mathematical planning matrix of the experiment. For each set, three test cubes with an edge length of 100 mm were made. After 28 days, the samples were exposed to water saturation according to the following procedure: the first day samples were immersed in water at the depth of 1/3 height, the second day at 2/3 height, the third day the samples were completely immersed in water and the thickness of water over the sample was 5 cm. For three days of water saturation the exact volume was determined for each sample by the method of weighing in water. All the three samples of each set were tested for freeze-thaw resistance. The samples were placed into the measuring chamber of the device, the chamber was filled with kerosene and sealed hermetically, whereupon the device was fit into «Feutron» climate chamber. The chamber was connected to the electronic unit via cables. Freezing of the device with samples lasted for 4.5 hours. During this period, the electronic unit was recording changes in the sample's deformation. For all the samples, the maximum relative increase in the difference between the volume deformations Θ was determined by the formula

$$\Theta = \frac{\Delta V_i}{V_o}$$

where ΔV_i – maximum difference of deformation values for the concrete and the standard samples at freezing;

V_o – initial volume of the sample,см^3. According to this difference, using the table of DSTU B V. 2.7-47-96, the concrete freeze-thaw resistance was determined.

Basic material and results. The results of studies on concretes produced according to the experiment planning matrix are presented in Table 2.

According to the study results, the surfaces of the experiment planning input parameters' influence on the concrete freeze-thaw resistance were constructed, and are shown in Fig. 2 to 4.

Table 2 – Results of testing concretes for freeze-thaw resistance

№	Variable parameters			Freeze-thaw resistance		
	X_1	X_2	X_3	$\Theta = \dfrac{\Delta V_i}{V_o}$	Number of cycles	Respective grade, F
1	600	2	ash	0.304	480	400
2	400	2	ash	0.783	238	200
3	600	0.8	ash	0.548	332	300
4	400	0.8	ash	1.77	105	100
5	600	2	sand	0.147	633	600
6	400	2	sand	0.586	380	300
7	600	0.8	sand	0.184	580	500
8	400	0.8	sand	0.538	365	300
9	600	1.4	0.5+0.5	0.154	538	500
10	400	1.4	0.5+0.5	0.522	360	300
11	500	2	0.5+0.5	0.313	487	400
12	500	0.8	0.5+0.5	0.319	408	400
13	500	1.4	ash	0.362	390	300
14	500	1.4	sand	0.298	435	400
15	500	1.4	0.5+0.5	0.299	424	400
16	500	1.4	0.5+0.5	0.309	416	400
17	500	1.4	0.5+0.5	0.247	464	400

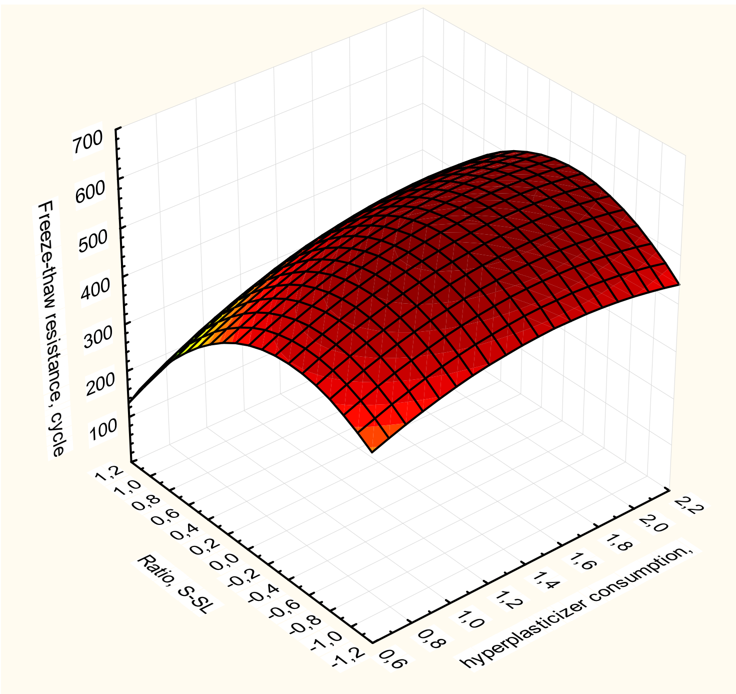

Figure 2 – Surface of hyperplasticizer consumption and the degree of sand replacement with ash slag influence on the concrete freeze-thaw resistance

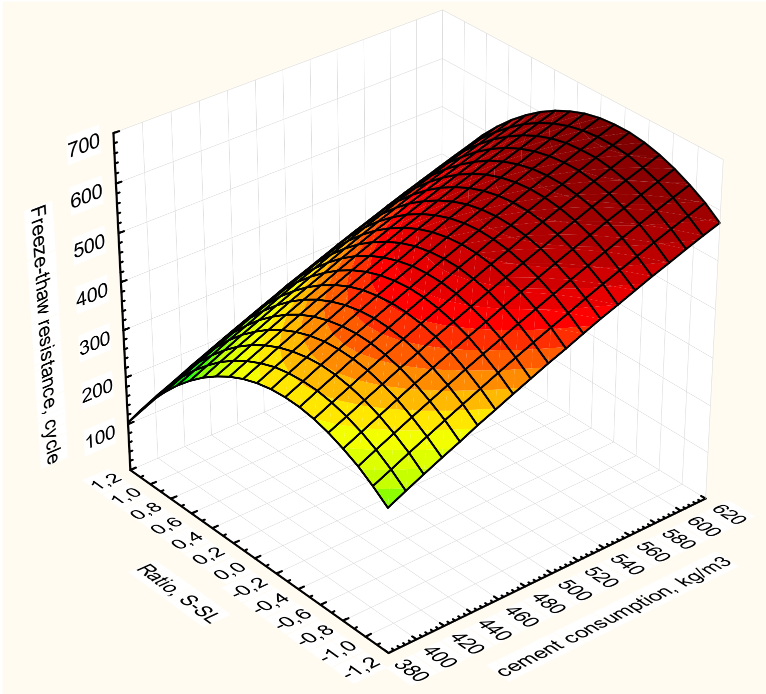

Figure 3 – Surface of cement consumption and S-AS (sand – ash slag) ratio influence on the concrete freeze-thaw resistance

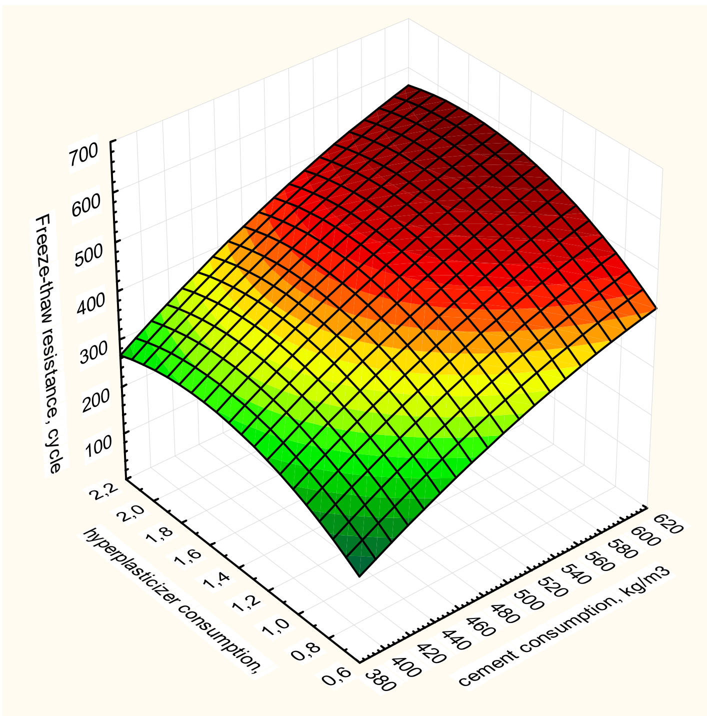

Figure 4 – Surface of cement consumption and additives on the concrete freeze-thaw resistance

Analysis of the sand replacement with ash slag degree and the hyperplasticizer consumption combined effect shows that with the amount of ash slag increasing in concrete, initially freeze-thaw resistance of concrete grows slightly, but with the further ash slag increase their freeze-thaw resistance is reduced. The maximum increase is observed at replacing half of the sand with ash slag, i.e. S-AS (sand – ash slag) = 0.5. At the maximum sand replacement with ash slag, the freeze-thaw resistance is reduced from 400 to 100 cycles.

Analysis of the surface of influence on the freeze-thaw resistance by the cement consumption and the degree of sand replacement with ash slabs shows that an increase in the concrete freeze-thaw resistance with an increase in the cement consumption is almost proportional. This fact is unmistakable, but it is known that the main component of concrete, contributing to the increased freeze-thaw resistance, is cement.

With the increase of ash slag in the composition of concrete freeze-thaw resistance tends to decrease. But on the surface of influence the maximum is observed at the value of AS-S (ash slag – sand) = 0.5, i.e. the ash slag only replaces sand by half. At the reduced sand replacement with AS in the concrete mixture, a sedimentation process was observed due to the increased mobility of the concrete mixture. Meanwhile, with the increased replacement, the freeze-thaw resistance also tends to decrease, because AS contribute to the increase of concrete porosity. As it is known, the freeze-thaw resistance of concrete depends on the porosity and the pores nature. It is obvious that concrete pores, which are formed due to the introduction of porous ash slab, are bigger than gel pores of cement stone. As it was explained above, gel pores of the cement stone contribute to the concrete freeze-thaw resistance increase, acting as compensators in water’s turning into ice.

On the diagrams, we observe that with increasing cement, as expected, the freeze-thaw resistance grows, but not proportionally. The maximum value of the freeze-thaw resistance is observed with the cement consumption of 460 - 500 kg / m^3 at the plasticizer consumption of 1.2 – 1.4% of the cement mass. Thus, the optimum ratio should be considered when the cement consumption makes 460 - 500 kg / m^3, and that of plasticizer – 1.0 -1.4% of the cement mass.

Conclusions: Analyzing the data obtained as a result of the performed studies, we can state the following:

1. Studies confirm that the greatest impact on the freeze-thaw resistance is caused by the cement consumption. Although in the process of hardening, a well developed pore structure is formed in cement stone, yet it also forms gel pores where water at low temperatures – up to 30 – 40^{o}C – does not freeze, therefore, they compensate the stress that occurs during the water turning into ice and thereby contribute to the increase of the concrete freeze-thaw resistance.

2. Introduction of ashes into the concrete mixture leads to a decrease in the freeze-thaw resistance of concrete. This phenomenon is explained by the fact that the ash-slag has the water consumption three times higher than the sand they replace does, therefore they contribute to an increase in the *W/S* ratio. With the increase of *W/S* ratio grows both the total volume of open pores, and their mean size. At the same time, permeability and water absorption grow, and in such concretes less reserve pores are formed. In order to increase the concrete freeze-thaw resistance, it is customary to restrict *W/S* ratio depending on the concrete operation conditions. Reducing *W/S* is possible both due to reducing water consumption using plasticizer additives, and by increasing the cement consumption.

3. The influence of hyperplasticizer consumption on the concrete freeze-thaw resistance possesses a positive nature. It contributes to the reduction of the *W/S* ratio and thus contributes to the reserve pores formation. It should be noted that the *W/S* ratio in all the concrete mixtures within the experiment did not grow by more than 0.45. However, the mobility of the mixture fluctuated within the range of 5 to 13 cm of the cone settlement.

References

1. *Bazhenov Yu. M. Concrete Technology / Yu. M. Bazhenov // Manual for high school students. – M. : VSh, 1987. – 414 p.*
2. *Timms A. G. Use of fly ash in concrete / A. G. Timms, W. E. Grieb // Proceedings of ASTM. – 1956. – Vol. 56. – P. 1139 – 1160.*
3. *Gebler S. H. Effect of Fly Ash on the Durability of Air-Entrained Concrete / S. H. Gebler, P. Klieger // Proc. of the 2nd Intern. Conf. on Fly Ash, Silica Fume, Slag, and Natural Pozzolans in Concrete (ACI SP-000): American Concrete Institute. – Farmington Hills; MI, 1986. – P. 483 – 519.*
4. *Johnston C. D. Effects of Microsilica and Class C Fly Ash on Resistance of Concrete to Rapid Freezing and Thawing and Scaling in the Presence of Deicing Agents / C. D. Johnston // Concrete Durability (ACI SP-100): American Concrete Institute. – Farmington Hills, MI, 1987. – P. 1183 – 1204.*
5. *Johnston C. D. W/CM Code Requirements Inappropriate for Resistance to Deicer Salt Scaling / C. D. Johnston // Proc. of the 3rd Intern. Conf. on the Durability of Concrete (ACI SP-145): American Concrete Institute. – Farmington Hills, MI, 1994. – P. 85 – 105.*
6. *Whiting D. Strength and Durability of Residential Concretes Controlling Fly Ash / D. Whiting // RD099, Portland Cement Association. – Skokie: IL, 1989. – 48 p.*
7. *Afrani I. The Effects of Different Cementing Materials and Curing on Concrete Scaling / I. Afrani, C. Rogers // Cement, Concrete, and Aggregates. – 1994. – Vol. 16 (2). – P. 132 – 139.*
8. *Malhotra V. M. High-Performance, High-Volume Fly Ash Concrete / V. M. Malhotra, P. K. Mehta // Supplementary Cementing Materials for Sustainable Development Inc. – Ottawa (Canada), 2005. – 124 p.*
9. *Bondar V. A. Influence of fly ash and slags of boiler with circulating fluidized bed on properties of concrete / V. A. Bondar, R. R. Akhmednabiev, R. R. Akhmednabiev // Збірник наукових праць. Серія: Галузеве машинобудування, будівництво. – Полтава: ПолтНТУ, 2016. – Вип. 2 (47). – С. 148 – 154.*