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CALCULATION OF THE CLOSE PACKING OF FINE AGGREGATE ON THE BASIS OF SCREENING FOR FINE GRAINED CONCRETE

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ABSTRACT

The paper considers the calculation of the maximum packing density of fine aggregate. The selection of the granulometric composition of the aggregate is given. The bulk densities and packing densities of standard screening fractions were determined. The content of each fraction in the mixture and the packing density of the aggregate mixture are calculated by the introduction of a subsequent finer fraction. Topological calculation of sandstone screening was performed. The results of sieving of sandstone screening are presented. The high-density grain composition of aggregate for fine-grained concrete is obtained. The compositions of concrete mixtures have been designed. The volume ratio of aggregate and cement paste in the concrete mix, the average mass size of the aggregate grains in the mixture, the volume fractions of cement and water in the concrete mixture are determined. The physicomechanical characteristics of fine-grained concrete of various compositions with a high density aggregate are shown. Results of testing the control samples for compressive strength are given. The density of the obtained samples was determined. Conclusions are drawn on the work.

Keywords: Fine-grained concrete, fine aggregate, granulometry, screenings, sandstone, high-density aggregate

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INTRODUCTION

Selection of the granulometric composition of the aggregate is performed in order to achieve the maximum packing density of grains and their minimum voidness, which allows to significantly reduce the binder consumption. In addition, obtaining a high-density aggregate composition under the condition of complete coating and minimal spreading of aggregate grains with a cement test makes it possible to increase the strength of the material by engaging the aggregate in the work and creating a structural framework that takes part of the destructive load [1–5].

Main part

The calculation was carried out for the screening of quartzite sandstone crushing, which is a waste of the mining and processing enterprise public corporation «Lebedinsky mining processing plant (Lebedinsky GOK)» (Russia). The size modulus of screening of sandstone M_k = 3,7. The average density is 1520 kg/m^3, the true density is 2710 kg/m^3, the bulk density is 1415 kg/m^3. The particle size distribution is shown in Table 1.

Table 1. Granulometric composition of sandstone screening

Residue on the sieve, % diameter, mm						
more than 5	5–2,5	2,5–1,25	1,25–0,63	0,63–0,315	0,315–0,16	less than 0,16
1	28	16,5	29,5	22,5	1	1,5

To perform a topological calculation, the sandstone screenings of the Lebedinsky deposit with maximal size 10 mm was screened by standard sieves with a cell size of 10; 5; 2.5; 1.25; 0.63, 0.315 and 0.14 mm (Table 2).

Table 2. Granulometric composition of sandstone screening of the Lebedinsky mining processing plant

Size fraction, mm	Sampleweight, g	Partial residuals, g	Partial residuals, %	Total residuals, %
10…5	1590			
5…2,5	1555	1555	29,4	29,4
2,5…1,25	495	495	9,4	38,8
1,25…0,63	750	750	14,2	53,0
0,63…0,315	605	605	11,5	64,5
0,315…0,14	1005	1005	19,0	83,5
<0,14	870	870	16,5	100
Total	6870	5280	100	

For each fraction, the bulk density in the dry state and the bulk density in the aqueous medium in the vibrocompacted state were determined. The packing density of each fraction was calculated by the formula [6]:

$$\eta=(\rho_b/\rho_{av}),$$

where [rho]$_b$, [rho]$_{av}$ – the bulk and average densities of each fraction respectively; for sandstone the average density was assumed equal to 2650 kg/m^3. The results of the studies are given in Table 3 and Figure 1.

Table 3. Bulk density and packing density of standard fractions of sandstone screenings 10-0 mm

Screensize(sieve residue)	dry state		in the aqueous medium	
	bulk density ρ_b, g/cm^3	packing density	bulk density ρ_b, g/cm^3	packing density
5	1,485	0,560	1,545	0,583
2,5	1,510	0,569	1,515	0,572
1,25	1,535	0,579	1,639	0,619
0,63	1,495	0,564	1,612	0,608
0,315	1,461	0,551	1,682	0,635
0,14	1,522	0,574	1,594	0,601
0	1,508	0,569	1,579	0,596

a

b

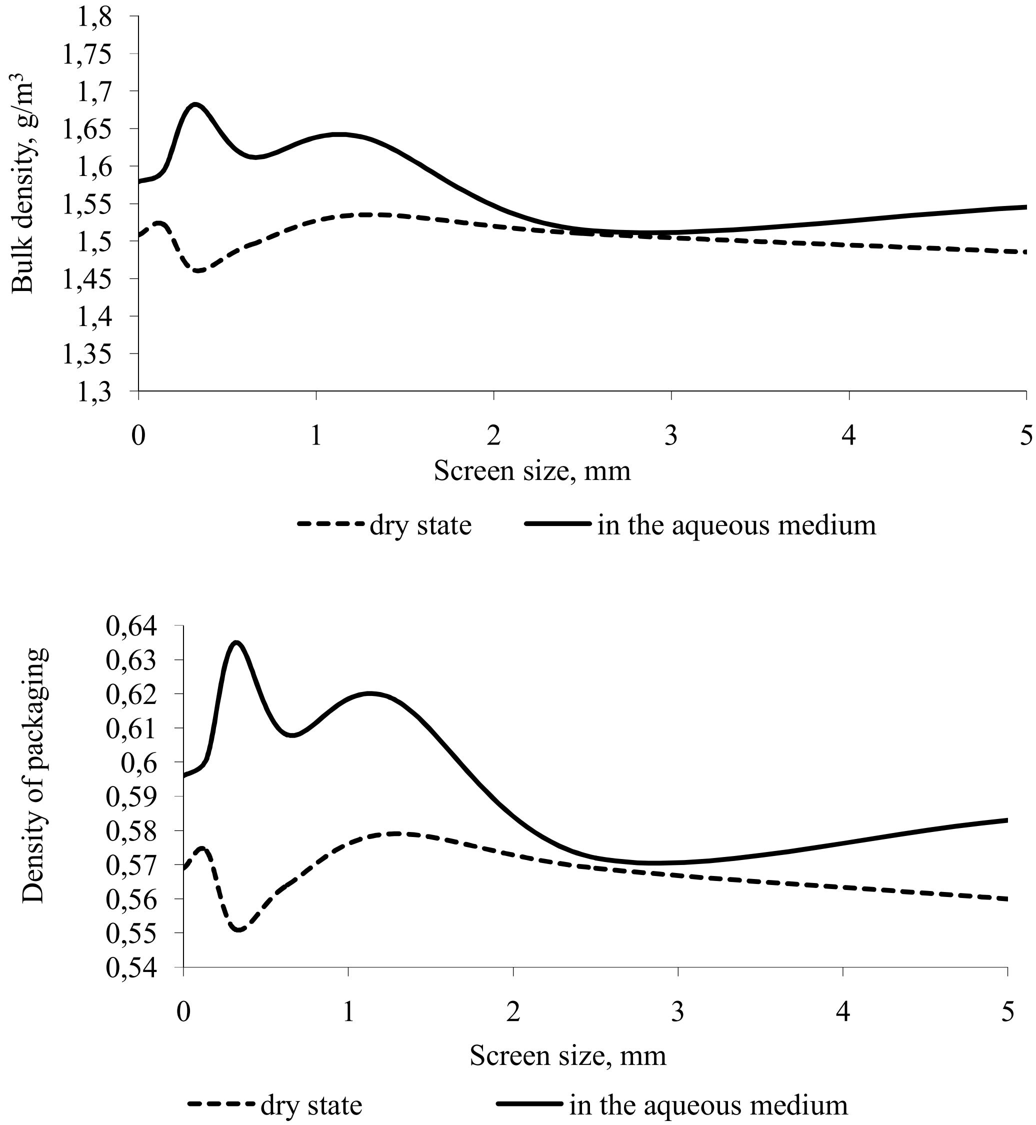


Fig.1. Results of sandstone screenings sieving

a – bulk density, b – packing density

The average grain size of the aggregate dn of each subsequent fraction introduced into the mixture is determined depending on the granulometry class (m), as well as the characteristics of the largest fraction according to the previously established regularity [6]:

$$d_n=(0,2549/\eta_1)^{m(n-1)/3}d_1,$$

where d_1 – average grain size of the largest aggregate fraction, with d_{max}=10 mm

$$d_1 = \sqrt{d_{\max} \times d_{\min}} = \sqrt{10\text{ mm} \times 5\text{ mm}} = \sqrt{50} = 7{,}07\text{ mm};$$

n – number of the next aggregate fraction introduced into the mixture;

η_1 – the packing density of the grains of the filler of the first fraction with a size of 10 ... 5 mm, in our case η_1=0,583.

For cement concrete it is recommended to use a filler with the granulometry continuity class m = 6. By calculating the above formula, we get:

$$d_2=(0{,}2549/0{,}583)^{6(2-1)/3}\cdot 7{,}07=1{,}352 \text{ mm},$$

$$d_3=(0{,}2549/0{,}583)^{6(3-1)/3}\cdot 7{,}07=0{,}258 \text{ mm},$$

these average sizes correspond to the fractions 2.5 ... 1.25 and 0.315 ... 0.14; the actual average sizes of aggregate grains in each fraction were determined as

$$d_2=\sqrt{d_{\max}\cdot d_{\min}}=\sqrt{2{,}5\cdot 1{,}25}=\sqrt{3{,}125}=1{,}77 \text{ mm},$$

$$d_3=\sqrt{d_{\max}\cdot d_{\min}}=\sqrt{0{,}315\cdot 0{,}14}=\sqrt{0{,}0441}=0{,}21 \text{ mm}.$$

To calculate the content of each fraction in the mixture and the packing density of the aggregate mixture with the introduction of a subsequent finer fraction we take the mass fraction of the largest fraction of 10 ... 5 as one (G1=1) [7]. Then the quantity of each subsequent smaller fraction, introduced into the mixture for dense filling of the remaining free volume in the layer, is determined by the formula:

$$G_n=(1-\sigma_{n-1})\cdot\beta_n\cdot\frac{\eta_n}{\sigma_{n-1}}\cdot\sum_{i=1}^{n-1}G_i$$

где [sigma]$_{n-1}$ – packing ratio of the mixture consisting of n-1 fractions;

[eta]$_n$ – the packing factor of the next fine fraction introduced into the mixture;

[beta]$_n$ – coefficient of expansion of aggregate grains with the introduction of each subsequent smaller fraction; for aggregates for coarse aggregate cement concrete it is recommended 1–1,1, for fine grained – 1,2, we take [beta]$_n$=1,2.

The packing ratio of particles in a high-density mixture of n fractions is calculated by the formula:

$$\sigma_n=\sigma_{n-1}+\frac{(1-\sigma_{n-1})}{\beta_n}\cdot X_n,$$

$$X_n=\frac{\sum_{i=1}^{n-1}\sum_{j=i+1}^{n}\psi_{ij}^{m}}{n/2\cdot(n-1)}.$$

The values of [psi]$_{i,j}^{(m)}$ as a function of m are given in Table 4.

Table 4. Dependence of the degree of filling of a free volume in a layer of granular material on the degree of the distribution system

M	[psi]$_{ij}^{m}$
0	[epsilon]$_i^3$[eta]$_i^3$
1	[epsilon]$_i^2$[eta]$_i^3$
2	[epsilon]$_i^2$[eta]$_i^2$
3	[epsilon]$_i^2$[eta]$_i$
4	[epsilon]$_i^2$
5	[epsilon]$_i^2$/[eta]$_i$
6	[epsilon]$_i$[eta]$_i$
7	[epsilon]$_i^2$/[eta]$_i^2$
8	[epsilon]$_i$
9	[eta]$_i^2$
10	[epsilon]$_i$/η_i
11	1-[eta]$_i^2$
12	[eta]$_i$

$$G_2=(1-\sigma_1)\cdot\beta_1\frac{\eta_2}{\sigma_1}\cdot G_1=(1-0{,}583)\cdot 1{,}2\cdot\frac{0{,}619}{0{,}583}\cdot 1=0{,}531 \text{ m.p.}$$

To determine X2, we compose a scheme for the distribution of particles in relative dimensions, as shown in Figure 2:

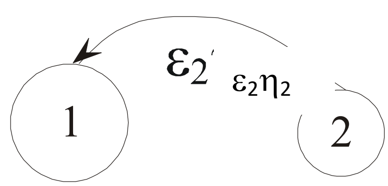


Fig.2. The particle size distribution scheme for determining X_2

$$X_2=\frac{(1-\eta_2)\eta_2}{(2/2)\cdot(2-1)}=\frac{(1-0{,}619)\cdot 0{,}619}{1}=0{,}236,$$

$$\sigma_2=\sigma_1+\frac{1-\sigma_1}{\beta_2}X_2=0{,}583+\frac{1-0{,}583}{1{,}2}0{,}236=0{,}632,$$

$$G_3=(1-\sigma_2)\cdot\beta_3\cdot\frac{\eta_3}{\sigma_2}\cdot(G_2+G_1)=(1-0{,}632)\cdot 1{,}2\cdot\frac{0{,}601}{0{,}632}\cdot 1{,}531=0{,}634 \text{ m.p.}$$

To determine X_3, we compose a scheme for the distribution of particles by relative dimensions (Figure 3):

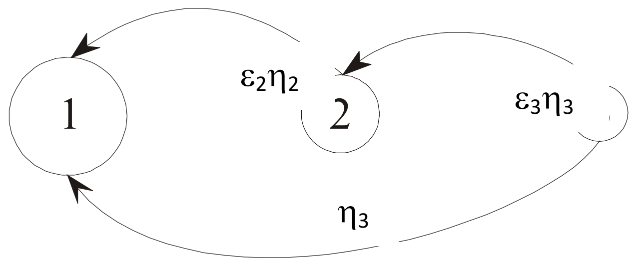


Fig.3. The particle size distribution scheme for determiningX_3

$$X_3=\frac{(1-\eta_2)\eta_2+(1-\eta_3)\eta_3+\eta_3}{(3/2)\cdot(3-1)}=\frac{(1-0{,}619)\cdot 0{,}619+(1-0{,}601)\cdot 0{,}601+0{,}601}{3}=0{,}359,$$

$$\sigma_3=\sigma_2+\frac{1-\sigma_2}{\beta_3}X_3=0{,}632+\frac{1-0{,}632}{1{,}2}0{,}359=0{,}742.$$

We find the percentage content of each fraction in the aggregate mixture:

$$G_1(\%)=G_1\cdot 100\%/(G_1+G_2+G_3)=1\cdot 100\%/(1+0{,}531+0{,}643)=46{,}00\%,$$

$$G_2(\%)=G_2\cdot 100\%/(G_1+G_2+G_3)=0{,}531\cdot 100\%/(1+0{,}531+0{,}643)=24{,}43\%,$$

$$G_3(\%)=G_3\cdot 100\%/(G_1+G_2+G_3)=0{,}643\cdot 100\%/(1+0{,}531+0{,}643)=29{,}58\%.$$

We find the expense of each fraction on a 1 m3 high density aggregate mixture, kg:

$$G_1(kg)=G_1(\%)\cdot\sigma_{CM}\cdot 2650/100=46{,}00\cdot 0{,}742\cdot 2650/100=904{,}50\ ,$$

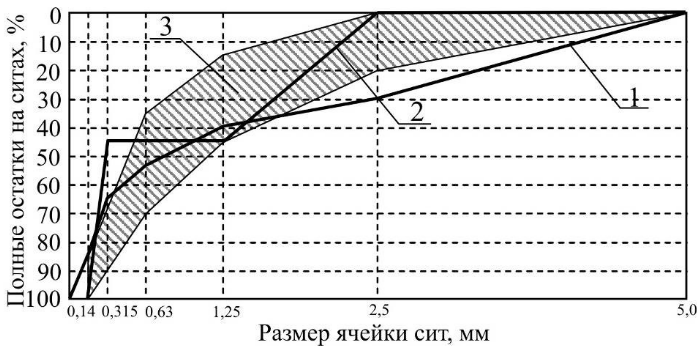
$$G_2(kg)=G_2(\%)\cdot\sigma_{CM}\cdot 2650/100=24{,}43\cdot 0{,}742\cdot 2650/100=480{,}37\ ,$$

$$G_3(kg)=G_3(\%)\cdot\sigma_{CM}\cdot 2650/100=29{,}58\cdot 0{,}742\cdot 2650/100=581{,}64.$$

The obtained high-density composition([eta]=0,742) of fine-grained concrete (Table 5), calculated by the method of A.N. Kharhardin[8–10] has agrain size composition close to the standard screening area (Figure 4) and the absence of grains less than 0.14 mm.

Table 5. High-density grain composition of aggregate for fine-grained concrete

Size fraction, mm	Consumption, mass part	Density of packing in the mixture with the introduction of the n fraction	The content of fractions in the mixture, %	Consumption, kg per 1 m^3 of high-density mixture of aggregates	Partial residuals, %	Total residuals, %
10…5	1,0	0,583	46,0	904,5		
2,5…1,25	0,531	0,632	24,4	480,4	45,2	45,2
0,315…0,14	0,632	0,742	29,6	581,6	54,8	100
Total	2,174		100	1966,5		



Total residuals, % / Screensize

Fig.4. Dependence of fractionation of the composition of fine aggregate when creating high-density packaging:

1 – screening of sandstone; *2* – high-density composition of aggregate;

3 – area of optimal grain composition of fine-grained concrete

Using the obtained high-density mixture of aggregate (Table 5), we design the compositions of concrete mixtures. In the first case, the ratio between binder and aggregate is assumed to be 1: 3; the given ratio is most often used at the enterprises of the construction industry to produce vibro-pressed fine-grained concrete. In the second case, we will determine the ratio based on the thickness of the spreading of the aggregate grains with a cement test equal to 30 µm.

The volume ratio of aggregate and cement paste in a concrete mixture is determined by the formulas:

$$\varphi_A = \frac{\sigma_{CM}}{\left(1+2\frac{\delta}{d_{av}}\right)^3} ,$$

$$\varphi_{CP} = 1 - \varphi_3$$

where d_{av}– average mass size of grains in the mixture, mm,

[delta] – the size of the expansion of the grains of the aggregate with a cement test, mm.

Determine the mass-average size of aggregate grains in the mixture:

$$d_{av} = \frac{d_1+G_1+d_2+G_2+d_3+G_3}{G_1+G_2+G_3} = \frac{7{,}07\cdot 1+1{,}77\cdot 0{,}465+0{,}21\cdot 0{,}441}{1+0{,}465+0{,}441} = 4{,}19 \text{ mm},$$

$$\varphi_A = \frac{0{,}742}{\left(1+2\frac{0{,}03}{4{,}19}\right)^3} = 0{,}707,\ \varphi_{CP} = 1-0{,}707 = 0{,}293.$$

Determine the volume ratio of cement and water in a concrete mixture:

$$\varphi_C = \varphi_{CP}\frac{1}{\left(1+W/C\frac{\rho_C}{\rho_W}\right)} = 0{,}293\frac{1}{\left(1+0{,}23\frac{3{,}1}{1}\right)} = 0{,}171 ,$$

$$\varphi_W=\varphi_{CP}\frac{W/C}{\left(W/C+\frac{\rho_W}{\rho_C}\right)}=0,293\frac{0,23}{\left(0,23+\frac{1}{3,1}\right)}=0,122.$$

With the knowledge of the volume ratio of aggregate, cement and water in the concrete mix, you can easily determine the consumption of materials in kg per 1 m3 of concrete mixture, multiplying the volume fractions by the true density of materials:

$$C=\varphi_C\cdot\rho_C=0,171\cdot3100=530,1,$$

$$W=\varphi_W\cdot\rho_W=0,122\cdot1000=122$$

$$A=\varphi_A\cdot\rho_A=0,707\cdot2650=1873,6,$$

$$\rho_{CM}=C+W+A=530,1+122+1873,6=2525,7\ kg/m^3.$$

Thus, the ratio between binder and aggregate is ≈ 1:.5.

$$A_1=A\cdot G_1(\%)/100=1873,6\cdot46,00/100=861,9\ ,$$

$$A_2=A\cdot G_2(\%)/100=1873,6\cdot24,43/100=457,7\ ,$$

$$A_3=A\cdot G_3(\%)/100=1873,6\cdot29,58/100=554,2.$$

CONCLUSION

Approbation of the influence of the result of the calculation of the maximum packing density on physical and mechanical parameters was carried out on the fine-grained concrete compositions obtained on the basis of cement CEM I 42.5 N produced by public corporation Belgorodsky Cement, as well as low water demand binder (VNV) with the ratio "cement : quartz component" = 50:50 (VNV-50). When obtaining VNV-50, a superplasticizer Melflux 1641 F was used. Also for comparison, the factory composition of concrete of the usual composition was used i.e. based on cement and non-fractionated aggregate.

For studies cylinders samples were made with diameter 5 cm and height 5 cm, volume

$$V=S\cdot h=(3,14\cdot2,5^2/5)\cdot5=98,125\ cm^3 or\ 98,125\cdot10^{-6}m^3.$$

The control samples were tested for compressive strength (Table 6, Figure 5), and the density of the samples was also determined.

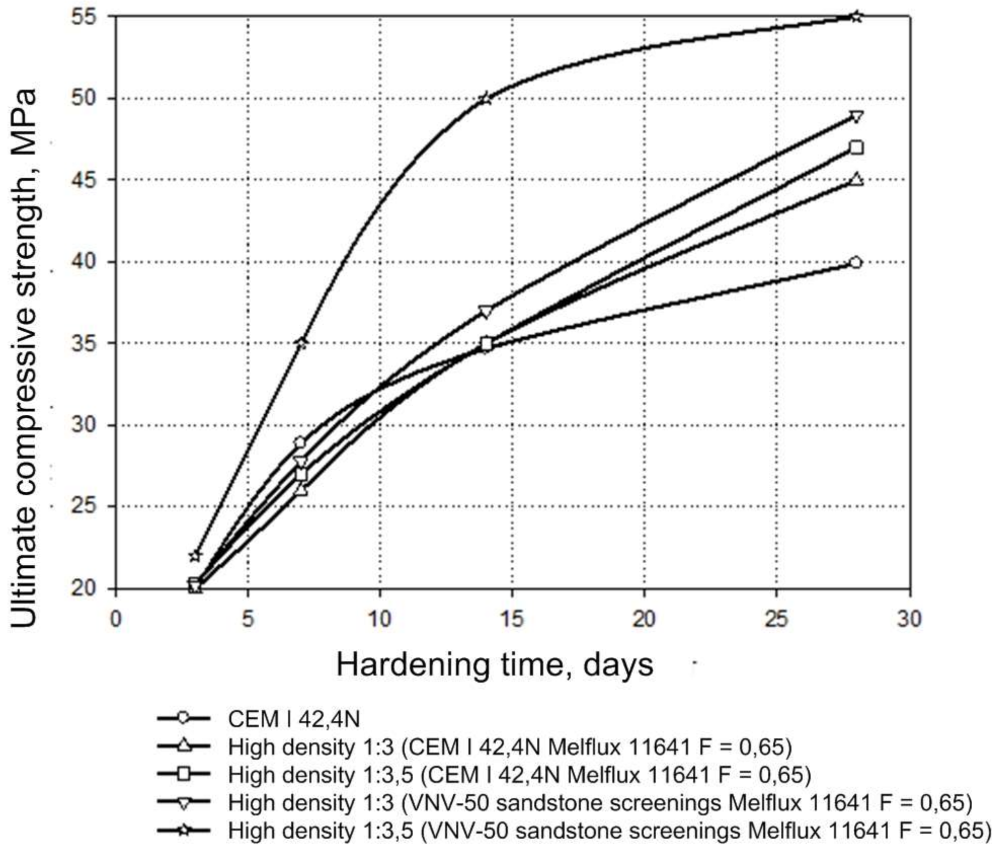


Table 6. Physical and mechanical properties of fine-grained concrete of various compositions with high-density aggregate

#	Composition	Consumption of materials, kg			Age, days	R_{comp}, MPa	Water absorption,%	Resistance to abrasion,%	Frost resistance	Efflorescence degree
		Binder (cement)	Fine aggregate (sandstone screenings)	Water						
1	Traditional CEMI 42,5 H, sand	561,0	1635	202,0	3	20,0	5,8	0,59	200	+++
					7	28,9				
					14	34,7				
					28	39,9				
2	High density 1:3	600,0 (300,0)	1800	138,0	3	20,0	3,3	0,33	200	---
					7	26,0				

	CEM I 42,5 H Melflux 1641 F=0,2				14	35,0				
					28	45,0				
3	High density 1:3,5 CEM I 42,5 H Melflux 1641 F=0,2	540,0 (270,0)	1874	122,0	3	20,3	3,3	0,33	200	---
					7	27,0				
					14	35,0				
					28	47,0				
4	High density 1:3 VNV-50 sandstone screenings Melflux 1641 F=0,2	600,0 (300,0)	1800	138,0	3	20,2	3,0	0,30	200	---
					7	27,8				
					14	37,0				
					28	49,0				
5	High density 1:3,5 VNV-50 sandstone screenings Melflux 1641 F=0,2	540,0 (270,0)	1874	122,0	3	22,0	3,0	0,30	200	---
					7	35,0				
					14	50,0				
					28	55,0				

Note: +++ large number efflorescence; + - minor amount of efflorescence; --- no efflorescence

SUMMARY

Thus, the results of the study showed that the maximum effect is achieved with increasing the ratio of "cement / sandstone screening" with the use of high-density composition from 1/3 to 1/3.5. This makes it possible to reduce the thickness of the spreading of the aggregate grains by a cement test to 30 μm, and thereby not only increase the strength and density of the material, but also reduce the binder's consumption from 600 to 540 kg.

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