

The influence of stone powder origin and superplasticizer type in the drying shrinkage of RPC

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Abstract. In the presented study, the combined effect of stone powder from mineral rocks (basic and acidic) and superplasticizers (naphthalene- and polycarboxylate-based) on drying shrinkage processes and moisture loss in Reactive Powder Concrete (RPC) is considered. Due to the peculiarities of the RPC structure, the moisture shrinkage is not restrained by the coarse skeleton and is completely determined by the characteristics of a hardening cement matrix modified with mineral additives. The paper shows that the balance of forces of internal interaction in the solid and liquid phases during the formation of the cement matrix is greatly influenced by stone powder and its origin. It has been established that the shrinkage of the RPCs with NF-based Polyplast SP-1 is higher than with PCB-based Glenium Ace 30. It was also found that shrinkage processes in RPC containing stone powder from granite and quartz sand do not always correspond to the internal moisture loss rate. Perhaps, due to the high strength of the RPC with stone powder from the listed rocks, a resistance to volumetric change increases during moisture loss, which in turn leads to a decrease in shrinkage deformations.

1 Introduction

The peculiarity of the composition and structure of the high-strength concrete (HSC) and, foremost, the Reactive Powder Concrete (RPC) is that the essence of drying shrinkage progression during operation differs from the traditional concretes [1-4]. The point is that in the absence of coarse aggregates, the drying shrinkage of the RPC is not restrained by the spatial skeleton and is determined mostly by the characteristics of the structure of a hardening cement matrix modified with mineral additives [5, 6].

The way shrinkage develops in a cement matrix is predetermined by a change in balance of capillary and surface tension forces, the forces of cohesive and adhesive interactions in dispersed particles of a cementing substance, the bond force in crystalline hydrates, and the

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forces of elastic resistance of a solid phase to deformation processes [7, 9]. The balance of these forces depends on the composition and characteristics of the cement matrix structure. The introduction of ultrafine particles of microsilica, stone powder, and superplasticizers into the composition of the mixed binder leads to a change in the structure of a cement matrix towards the mainly formation of low-basic C-S-H of greater dispersion than primary hydrosilicates, as well as the formation of smaller pores [10-13]. As the result of a structure modification of a cement matrix, an increase in the reserve of free energy is observed. This could affect the balance of forces and, at the same time, the course of the drying shrinkage development in RPC [14, 15].

It can be assumed that the nature of the change in the balance of forces will be greatly influenced by the origin of stone powder, that is, the peculiarity of the influence of the substance of the rock on the balance of the forces of bonding of the solid and liquid phases in the material.

It is also possible that the structural relationship between drying shrinkage of the RPC and the water-reducing properties of stone powder and superplasticizers exists due to the characteristics change of the modified cement matrix pore solution [16, 17].

2 **Material and methods**

In this study, the following materials were used: ordinary cement CEM I 42.5 N according to GOST 31108-2003, manufactured by Oskolcement; superplasticizers SP-1 (based on sulfonaphthalene formaldehyde) and Glenium Ace 30 (FM) (based on polycarboxylate compounds); microsilica MKU-85, manufactured by Novolipetsk Metallurgical Plant JSC; quartz sand 0.16-0.63 mm and stone powder from various rocks with a specific surface of 410 m² / kg (according to the air permeability method).

Mineral rocks with different origins (genesis) were chosen as raw materials for producing stone powder. In Table 1, some physical and mechanical properties of the following raw materials are presented: limestone (LS), dolomite (DM), and quartz sand (QS) are sedimentary rocks; diabase (DB), porphyrite (PR), gabbro-diabase (GD), and granite (GN) are igneous rocks.

Table 1. Characteristics of raw materials for producing stone powder

Name	Specific density, kg/m ³	Strength, MPa	Group	Solution
LS	2600	< 120	Sedimentary carbonate	Basic (SiO ₂ = 40...52 %)
DM	2900	< 100		
PR	2600	130...180	Igneous porphyritic	
DB	2700	200...300	Igneous intrusive	
GD	3300	200...320		
GN	2700	120...150		
QS	2650	-	Loose sedimentary	Acidic (SiO ₂ < 72%)

Shrinkage deformations were determined using specimens with dimensions 40x40x160 mm. After 3 days of normal curing, stainless steel benchmarks were glued with

a fast curing adhesive. The weight was also determined, and initial measurements were made. Then specimens were placed in a desiccator with an internal humidity of 32 % and supersaturated solution of calcium chloride.

Sequential readings (according to GOST 24544-81) were made after 1, 3, 7 and 14 days of hardening and then every two weeks before the onset of 120 days.

Taking into account the absence of coarse aggregates in the RPC and the finesse of fine aggregates, which does not exceed 0.63 mm, it is appropriate to consider that specimen dimensions are acceptable for determining drying shrinkage [15, 18].

To recalculate the experimental readings of drying shrinkage received on the RPC prisms with dimensions of 40×40×160 mm in the shrinkage deformation of standard specimens with dimensions of 150×150×600 mm the reducing coefficient K was used:

$$K = \sqrt[3]{\frac{m_i}{M}},$$

(1)

In equation 1, m_i is the surface modulus of small size prisms, M is the surface modulus of prisms of the base size, and K is the empirical coefficient equal to 1.84 for the specimens with dimensions 40x40x160 mm.

3 **Results and discussion**

The results of the moisture shrinkage, measured (ϵ_m) and reduced by equation 1 (ϵ_r), after 120 days of exposure, as well as the mechanical properties of hardened RPC, are given in Table 2. The following abbreviations are used: W/C is water to cement ratio (by mass) and W/S is water to solid ratio (by mass).

Table 2. Mechanical properties of hardened RPC and moisture shrinkage

S u p e r- p l a s t i c i z e r	Stone powder	Compressive strength, MPa, by day				W/C	W/S	Shrinkage, mm/m	
		1	3	7	28			ϵ_m	ϵ_r
S P - 1	LS	27	45	55	75	0.39	0.12	1.730	0.940
	GD	27	47	64	74	0.37	0.12	1.510	0.820
	DB	25	45	56	82	0.38	0.12	1.400	0.760
	PR	29	49	60	81	0.38	0.12	1.420	0.770
	DM	27	46	68	83	0.38	0.12	1.340	0.730
	GN	32	44	60	69	0.40	0.13	1.800	0.980

S u p e r p l a s t i c i z e r	Stone powder	Compressive strength, MPa, by day				W/C	W/S	Shrinkage, mm/m	
		1	3	7	28			ϵ_m	ϵ_r
	QS	31	43	62	72	0.40	0.13	1.670	0.901
G l e n i u m A c c e 3 0	LM	31	58	71	98	0.33	0.11	0.980	0.530
	GD	34	59	81	98	0.32	0.11	0.630	0.340
	DB	35	62	78	107	0.33	0.11	0.640	0.350
	PR	31	54	67	101	0.33	0.11	0.860	0.470
	DM	35	67	79	105	0.33	0.11	0.560	0.300
	GN	32	62	78	108	0.34	0.11	0.700	0.380
	QS	31	55	79	109	0.34	0.11	0.630	0.340

Drying shrinkage of the RPCs with various stone powders and the Polyplast SP-1 NF-superplasticizer are presented in Figure 1. Shrinkage after 120 days for the specimens (in mm/m): limestone - 1.73; gabbro-diabase - 1.51; diabase - 1.4; porphyrite - 1.42; dolomite - 1.34; granite - 1.8; and quartz sand - 1.67.

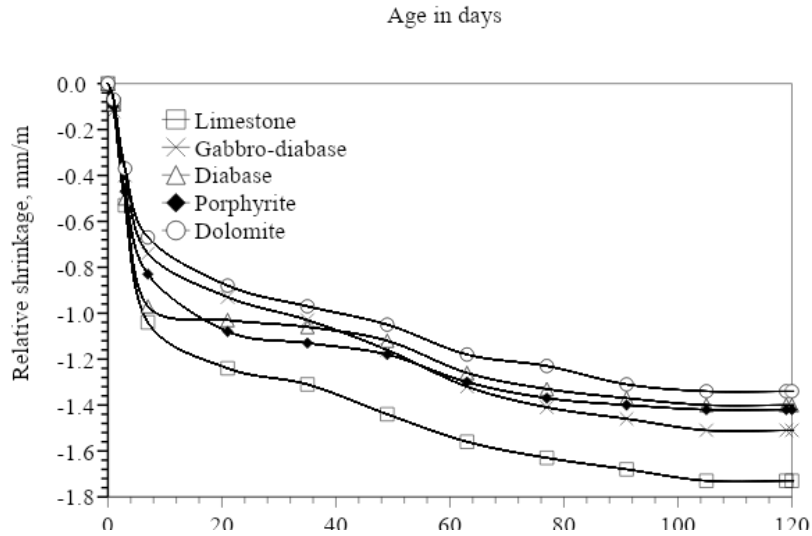


Fig. 1. Drying shrinkage deformations of the RPCs with the Polyplast SP-1 NF-superplasticizer

According to the results, drying shrinkage of the RPC cement matrix with the Polyplast SP-1 NF-superplasticizer began to grow right after the evaporation of the first portions of water (Fig. 1 and Fig. 2). Furthermore, an intensive growth of shrinkage deformation is observed in the first seven days and gradual deceleration further until the end after 105 days.

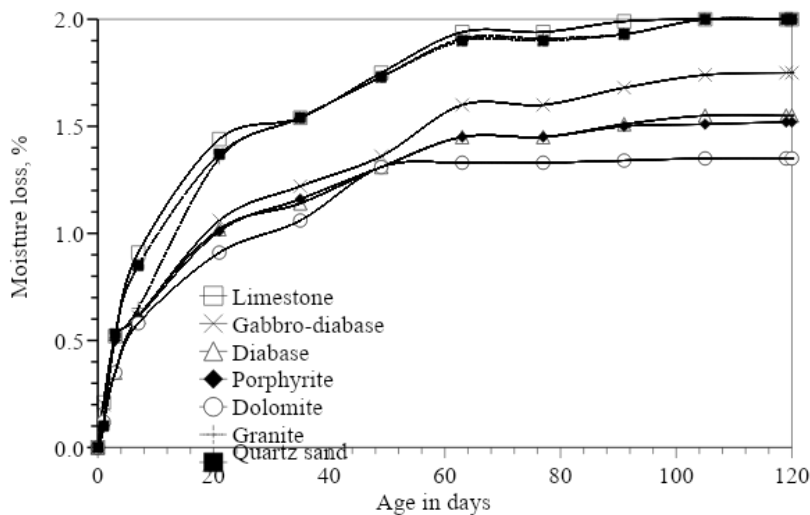


Fig. 2. Moisture loss the RPCs with the Polyplast SP-1 NF-superplasticizer during drying shrinkage test

The progress of drying shrinkage development of the RPC cement matrix (Fig. 1) is correlated with the progress of moisture loss during the experiment (Fig. 2), which, in turn, also correlates with the W/S. The largest shrinkage deformation is observed in compositions with limestone, granite, and quartz sand stone powders, which have the lowest water-reducing effect.

On the other hand, the lowest shrinkage of the RPC cement matrix is observed in compositions with stone powders from rocks, which have the greatest water-reducing effect.

Drying shrinkage of the RPCs with various stone powders and the GleniumAce 30 PCB-superplasticizer are presented in Figure 3. Shrinkage after 120 days for the specimens (in mm/m): limestone - 0.98; gabbro-diabase - 0.63; diabase - 0.64; porphyrite - 0.86; dolomite - 0.56; granite - 0.70; sand - 0.63. It should be noted that at the end of the tests, drying shrinkage had stopped only for the RPC with stone powders from dolomite, quartz sand, and granite.

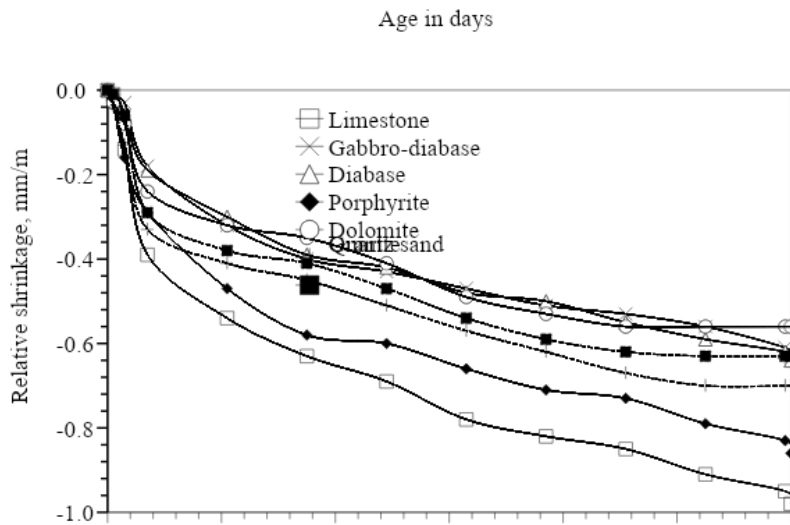


Fig. 3. Drying shrinkage deformations of the RPCs with PCB-superplasticizer GleniumAce 30

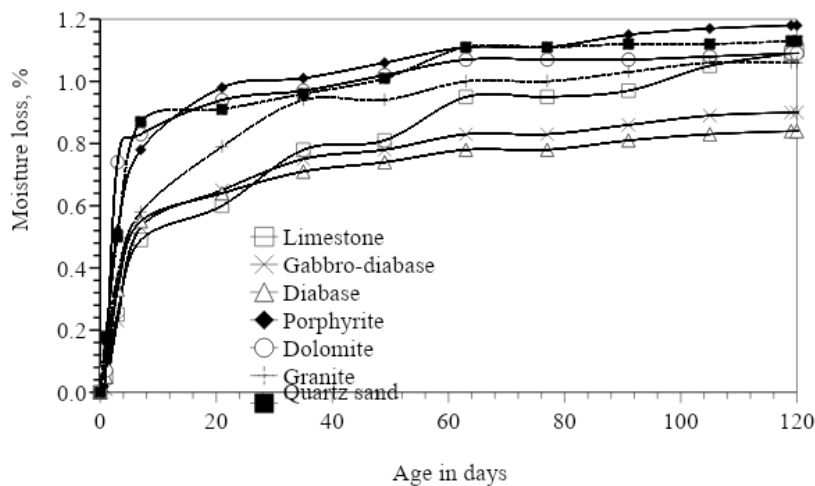


Fig. 4. Moisture loss the RPCs with the GleniumAce 30 PCB-superplasticizer during drying shrinkage test.

The progress of the moisture loss of the RPCs with the GleniumAce 30 PCB-superplasticizer during the experiment is shown in Figure 4. Dissimilar to the RPC with the Polyplast SP-1 superplasticizer, the change in shrinkage deformations over time is more uniform.

Drying shrinkage deformation of the RPCs with the Polyplast SP-1 NF-superplasticizer exceeds deformations of the RPCs with the Glenium Ace 30 PCB-superplasticizer by approximately 2÷2.5 times. As a conclusion, the shrinkage deformations of modified cement matrix with the Polyplast SP-1 superplasticizer are significantly affected by the drying process.

Perhaps, in general, the water-reducing effect of Glenium Ace 30 PCB-superplasticizer makes it possible to decrease W/S and, consequently, scale down the overall porosity and pore size of the RPC cement matrix, which, in turn, lowers the intensity of moisture loss.

4 Conclusions

In this experimental study, the drying shrinkage and moisture loss of the RPCs cement matrix with various stone powders and superplasticizers were investigated.

It was found that the development of shrinkage for the RPCs with the Glenium Ace 30 PCB-superplasticizer, in contrast to the RPCs with the Polyplast SP-1 NF-superplasticizer, does not always correspond to the moisture loss exchange. Exceptions are the RPCs with stone powders from granite and quartz sand. It was suggested that the high strength of the RPCs with stone powders from listed rocks makes them more resistant to volumetric changes during moisture loss, which, in turn, leads to a decrease in the involvement of drying shrinkage.

It is possible to conclude that the drying shrinkage of the RPCs is highly influenced not only by the type of superplasticizer (NF- or PCB-based) but also by the origin of the rock.

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