About frost resistance of the contact zone of dry adhesive mixes classes C1 and C2

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Abstract. The purpose of the study: to identify the effect of the dose of redispersible polymer powders and the type of low-modulus inclusions on the frost resistance of dry adhesives mixes made using Portland cement with the concrete base. Methods of research: The research was carried out on the basis of 75 freezing-thawing cycles. The following parameters were determined: compressive and flexural strength on samples 40x40x160 mm in accordance with GOST 30744; bond strength to the concrete base after 28 days hardening and after 75 cycles of freezing and thawing in accordance with GOST 31356. The dynamic modulus of elasticity was determined by the value of the ultrasonic pulse velocity on samples of 40x40x160 mm. The influence of prescription factors on the ratio of these values after 75 freeze-thaw cycles relative to the values after 28 days hardening under normal conditions was studied. Main results: The coefficients of frost resistance of the contact zone of the adhesive mortar made using dry mixes after 75 cycles of freezing and thawing exceeds the values of the coefficients of frost resistance according to the criteria of strength or dynamic elastic modulus. Dry adhesives mixes of class C1 with a dosage of redispersible polymer powder from 1 to 3% and an air-entraining admixture after 75 freezing cycles may be corresponded to class C2. The coefficient of variation in the compressive strength of mortar inside a series of samples after 28 days of hardening under normal conditions is not appropriate to consider as an indicator of the homogeneity of the mortar structure, potentially having a high resistance to cyclic freezing-thawing.

1 Introduction

Cement binder dry mixes are widely used in modern construction for producing various types of building mortars, including various adhesives [1-8]. In accordance with GOST R 56387-2018 "Dry-mix construction cement based adhesives. Specifications» dry adhesive building mixes of classes C1 and C2 are used for indoor and outdoor using. Bond strength of this adhesives with concrete base must be more than 0.5 and 1.0 N/mm^2, respectively. Adhesives for outdoor work must be tested for the temperature effects on them during life

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cycle, including cyclic freezing-thawing. Resistance to such influences is normalized by the "frost resistance" indicator.

In accordance with GOST 31357, in addition to frost resistance, the indicator "frost resistance of the contact zone" is normalized, which characterizes the ability of the different types of building mortars to maintain the bond strength to the concrete base at normal separation after a certain number of freezing-thawing cycles. The classes for frost resistance of the contact zone are set from $F_{kz}25$ to $F_{kz}100$. The number of freezing-thawing cycles is taken as the brand, after which the bond strength to the concrete base, determined in accordance with GOST 31356, is at least 80% of the bond strength of the control samples. According to GOST R 56387, the adhesion strength to the concrete base after cyclic freezing-thawing testing should be at least 0.5 and 1.0 MPa for dry adhesive mixes classes C1 and C2.

During the production of dry building mixes for various purposes, the use of various organo-mineral modifiers is widely used, which significantly improve the workability of mixes and strength, deformation, and adhesive properties of building mortars [9-15]. Due to the limited information on the quantitative effect of various factors on the frost resistance of the contact zone [14], the purpose of this study was to identify the dependence between the frost resistance of the contact zone of adhesives mortar obtained from dry adhesives mixes made with various Portland cements and the content of various low-modulus inclusions and different redispersible polymer powders (RPP) with dosage from 0 to 3%.

As a working hypothesis, it was assumed that a preliminary assessment of the frost resistance of the contact zone between adhesive mortar and concrete base can be given on the results of tests for frost resistance according to the criteria of strength or dynamic modulus of elasticity. It was also assumed that the coefficient of variation of the compressive strength can be considered as an indicator of the homogeneity of the adhesive mortar structure. Structures of adhesive mortar with higher homogeneity, i.e. with a lower value of coefficient of variation in compressive strength inside a series of samples, can potentially be considered as more frost-resistant.

2 Methodology

The research was carried out on the basis of 75 freezing-thawing cycles. The following parameters were determined: compressive and flexural strength on samples 40x40x160 mm in accordance with GOST 30744; bond strength to the concrete base after 28 days hardening and after 75 cycles of freezing and thawing in accordance with GOST 31356. The dynamic modulus of elasticity was determined by the value of the ultrasonic pulse velocity on samples of 40x40x160 mm. The influence of prescription factors on the ratio of these values after 75 freeze-thaw cycles relative to the values after 28 days hardening under normal conditions was studied. Mixes on various cements are presented in three groups: without low-modulus inclusions, with low-modulus inclusions in the form of an ash microsphere (MS), and with low-modulus inclusions in the form of entrained air (EA). For each series of samples the value of the compressive strength, flexural strength and bond strength to the concrete base, the coefficients of variation of each type of strength in a series of Vi, the ratio of the coefficients of variation after cyclic freezing and thawing Vi,F/Vi,28; ratios of coefficients of frost resistance according to the criteria of compressive strength, flexural strength, bond strength to the concrete base and dynamic modulus of elasticity $k_{F,I} = X_{F,i}/X_{28,i}$. were calculated.

3 Materials

Dry building adhesive mixes were prepared using Portland cements:
- CEM I 42.5 N "Podgorensky Tsementnik" (1),
- CEM I 52.5 N "Oskolcement" (2),
- CEM I 42.5 N "Podolsk-Cement" (3).

All dry building adhesive mixes contained the water-retaining admixture "Rutocelle 75 RT 50000" in dosage of 0.25% by weight of the dry mixes. The redispersible polymer powder (RPP) was used in dosage up to 3% by weight of the dry mixes. RPP were selected depending on the type of cement in accordance with the results of preliminary tests: "Vinavil 06 P"; "Vinavil SL 11 P"; "Vinnapas 4042 H". The ratio cement/sand was 35/65 in all mixes. The dosage of the air entraining admixture was 0.015% by weight of the dry mixes. The dosage of the fly ash microsphere was 1.31% by weight of the dry mixes (6% by the volume of the mortar).

4 Results

In the table. 1 the values of the bond strength to the concrete base of the mortar adhesives after 28 days of hardening under normal conditions and after combined holding: 28 days under normal conditions plus 75 freezing-thawing cycles are presented.

Table 1. The bond strength of the mortar adhesive with a concrete base.

Cement	RPP dosage, %	Bond strength, N/mm^2					
		Ordinary mix		Mix with MS		Mix with EA	
		28 d	75 cycles	28 d	75 cycles	28 d	75 cycles
1	0	1.06	1.24	1.16	**0.45**	0.66	0.51
	1	1.17	1.07	0.97	0.9	**0.48**	1.09
	2	0.64	1.14	0.94	0.95	1.06	1.16
	3	0.59	1.16	**0.44**	1.17	0.87	1.19
2	0	1.03	1.2	0.79	1.29	**0.2**	1.13
	1	1.19	1.3	0.69	0.99	1.23	1.09
	2	1.41	1.29	0.97	1.26	1.22	1.12
	3	1.22	0.58	1.37	1.1	1.31	1.4
3	0	0.87	0.98	0.92	1.13	0.58	1.26
	1	1.03	1.31	0.99	0.96	0.89	1.13
	2	1.12	0.96	0.89	1.02	1.3	1.07
	3	1.12	1.16	0.96	0.95	1.22	1.0

Note: results that do not correspond to class C2 are highlighted in color; results that do not correspond to class C1 are highlighted in bold

In the table. 2 the values of the bond strength to the concrete base of the mortar adhesives after 28 days of hardening under normal conditions and after combined holding: 28 days under normal conditions plus 75 freezing-thawing cycles are presented.

Table 2. The dynamic modulus of elasticity, compressive and flexural strength of the adhesive mortar.

Cement	Type of mixes	RPP dosage, %	Dynamic modulus of elasticity Ed, compressive R and flexural strength Rf, N/mm^2					
			28 d			75 cycles		
			R	Rf	Ed	R	Rf	Ed
1	Ordinary	0	15.2	4.29	12230	15.9	5	13130
		1	10.5	3.74	9800	12	4.27	10730
		2	12.7	4.28	10005	11.6	4.15	10640
		3	10.9	3.74	8715	10.3	3.67	8930

2		0	21.1	5.43	13130	21.6	5.32	14850
		1	17.2	4.64	11680	18.4	4.61	12600
		2	13.4	4.17	9590	14	4.41	10240
		3	13.3	4.1	9560	11.7	4.1	10135
3		0	14.1	4.12	12315	16.1	4.35	12700
		1	13.3	4.06	10305	13.7	4.11	11040
		2	13.1	4.1	9690	12	4	9900
		3	11.6	3.97	9605	11.5	4.26	9775
1	With MS	0	14.5	4.14	11550	16.3	4.05	12395
		1	11.6	3.87	9395	13.2	3.78	10170
		2	10.6	3.53	8260	11.2	3.47	9005
		3	9.9	3.47	7990	11	3.46	8460
2		0	19.4	5.24	13025	21.6	5.04	13300
		1	13.3	4.36	10670	16.3	4.69	11080
		2	13.5	4.18	9455	12.2	4.61	10015
		3	10.8	4.02	9380	9.2	4.01	9995
3		0	15.6	3.91	11005	15	4.18	11105
		1	12.3	4.01	9910	13.3	4.17	10170
		2	10.5	3.78	8185	10.7	3.66	8540
		3	9.7	3.8	7345	9	3.42	7655
1	With EA	0	8.5	3.35	8685	11.2	3.21	9570
		1	10.1	3.49	9770	13	3.39	10520
		2	9.1	3.63	9450	12.2	3.49	9655
		3	10.8	3.84	9225	12.1	3.71	9470
2		0	15.8	4.12	10715	16.3	4.27	10785
		1	12.6	4.08	9420	13.7	3.66	9790
		2	14.6	4.28	9970	12.5	4.31	10490
		3	12.9	4.06	10245	11.1	4.36	10675
3		0	14.3	4.11	10995	14.4	4.17	11010
		1	13.7	4.38	9890	12	3.67	10080
		2	12.4	3.94	9460	12	3.99	10035
		3	11.3	3.92	8975	12	3.83	9250

In fig. 1 the relationship between the coefficients of frost resistance (kF = XF75 / X28) for the compressive strength (R), flexural strength (Rf), and bond strength to the concrete base (A) on the type of cement (1,2,3 before the dash), the dosage of the redispersed polymer powder (0,1,2,3 after the dash), and the presence of low-modulus inclusions MS and EA are given. The coefficient of frost resistance of the dynamic modulus of elasticity in all cases was more than 1.

In fig.2 the relationship between the coefficients of frost resistance according to the criteria of compressive strength, flexural strength, dynamic modulus of elasticity and the bond strength to the concrete base was given.

In fig. 3 the relationship between the change in the coefficient of variation of compressive strength, flexural strength and bond strength to the concrete base after 75 freezing-thawing cycles as a function of the coefficient of variation of the mortar compressive strength after 28 days of hardening under normal conditions was given.
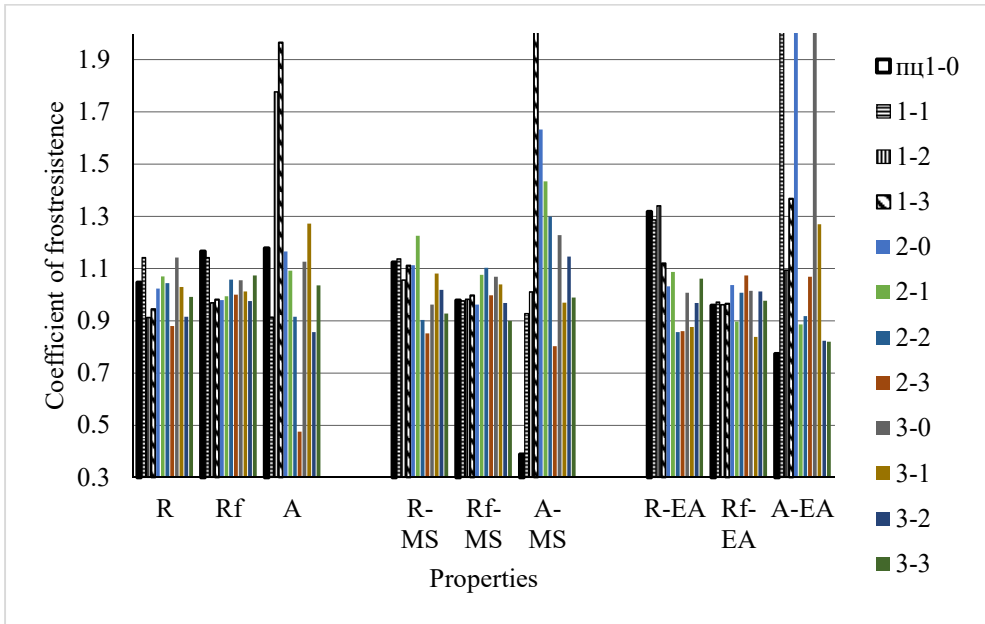
Fig. 1. Relationship between the coefficient of frost resistance for the compressive strength (R), flexural strength (Rf) and bond strength to the concrete base (A) and the type of cement, the dosage of the RPP and the presence of low-modulus inclusions
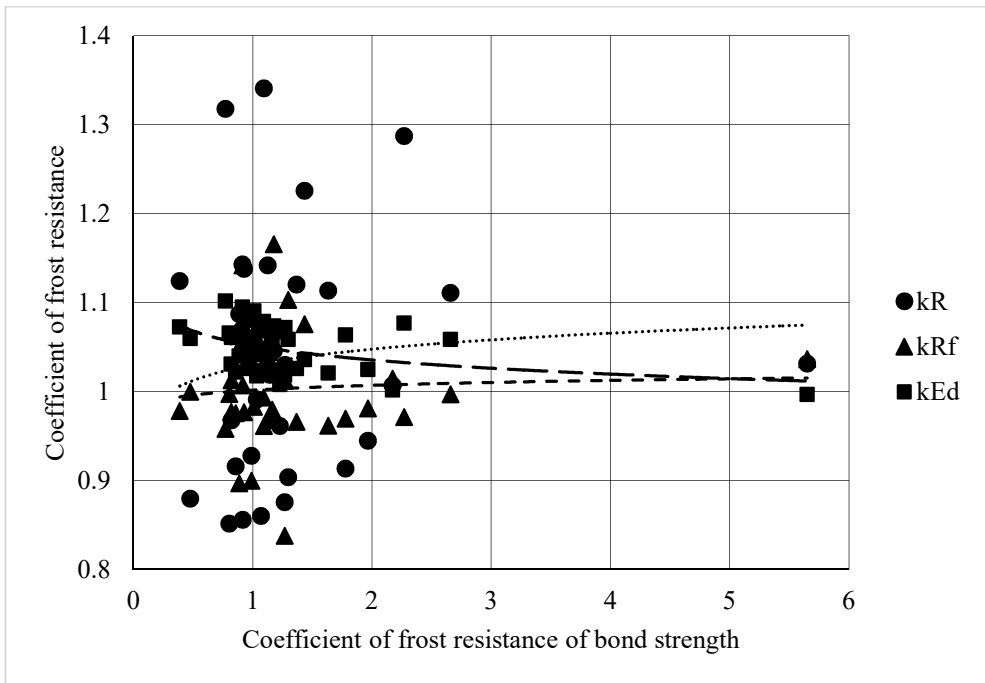

Fig. 2. Relationship between the coefficients of frost resistance according to the criteria of compressive strength, flexural strength, dynamic modulus of elasticity and the bond strength to the concrete
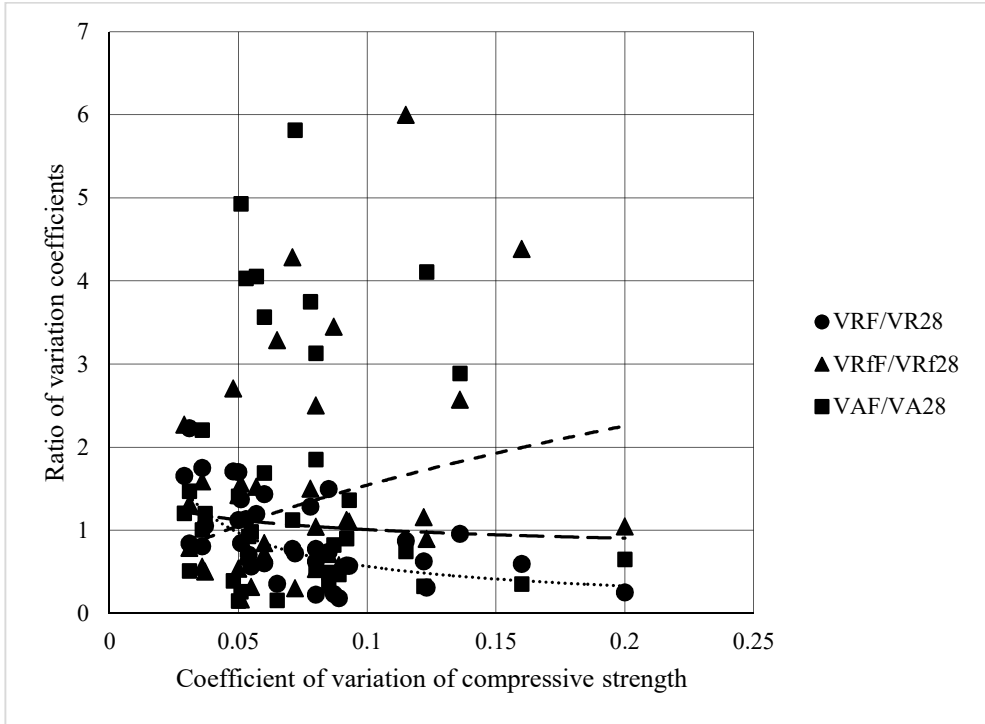
Fig. 3. Relationship between the change in the coefficient of variation of compressive strength, flexural strength and bond strength to the concrete base after 75 freezing-thawing cycles as a function of the coefficient of variation of the mortar compressive strength after 28 days of hardening under normal conditions

5 Discussion

From the presented in table. 1 data obviously:

- most of the adhesive mortars corresponding to class C1, irrespective of the conditions of testing;

- mixes of class C2 can be produced with all the studied cements, it is necessary to select the appropriate dosage of RPP;

- air entraining admixture has a positive effect on the increasing of the bond strength to the concrete base after 75 cycles of freezing and thawing;

- the fly ash microsphere as a low-modulus inclusion is not effective for obtaining mixes corresponding to class C2.

From the data shown in Fig. 1. it is obviously that the coefficient of frost resistance for the bond strength to the concrete base can vary in a much wider range in comparison with the coefficients of frost resistance according to the strength criteria. Analysis of the results showed that there is no correlation between:

- coefficients of frost resistance of the dynamic modulus of elasticity and bond strength to the concrete base (table 2);

- coefficients of frost resistance of flexural strength (compressive strength) and bond strength to the concrete base (table 3):

- between the change in the coefficient of variation of compressive strength, flexural strength and bond strength to the concrete base after 75 freezing-thawing cycles as a

function of the coefficient of variation of the mortar compressive strength after 28 days of hardening under normal conditions (table 4).

It follows from the table that the determination coefficients for the dependences obtained are 0.87-0.92, which satisfy the accuracy of the studies.

Thus, by physically simulating the formation of a dip over a rock formation on Quaternary loam and clay samples, the exponential dependence of the deformation rate of rocks on time and the polynomial dependence on humidity are established. These dependencies form the basis for the development of a combined method for eliminating a failure over production.

Table 3. Regression equations for frost resistance coefficients.

	Coefficient of frost resistance		
	Compressive strength	Flexural strength	Dynamic modulus of elasticity
eq	$k_{F,R} = 1.03 \cdot k_{F,A}^{0.025}$	$k_{F,Rf} = k_{F,A}^{0.08}$	$k_{F,Ed} = 1.05 k_{F,A}^{-0.022}$
R^2	0.0093	0.0033	0.16

Table 4. The regression equations of changes of the coefficients of variation after 75 cycles of freezing and thawing.

	Coefficient of frost resistance		
	Compressive strength	Flexural strength	Dynamic modulus of elasticity
eq	$\dfrac{V_{R,F}}{V_{R,28}} = 0.094 \cdot V_R^{-0.78}$	$\dfrac{V_{Rf,F}}{V_{Rf,28}} = 5.45 \cdot V_R^{0.55}$	$\dfrac{V_{A,F}}{V_{A,28}} = 0.7 \cdot V_R^{-0.16}$
R^2	0.334	0.072	0.006

6 Summary

Determination of the frost resistance of the contact zone between adhesive mortar and concrete base should be carried out by a direct method, the forecast for indirect indicators (flexural strength, dynamic modulus of elasticity) does not give reliable results.

The coefficient of variation in the compressive strength of mortar inside a series of samples after 28 days of hardening under normal conditions is not appropriate to consider as an indicator of the homogeneity of the mortar structure, potentially having a high resistance to cyclic freezing-thawing.

To increase the frost resistance of the contact zone, it is advisable to introduce in dry building adhesive mixes air-entraining admixture.

The coefficient of frost resistance of the contact zone after 75 cycles of freezing-thawing exceeds the values of the coefficients of frost resistance according to the criteria of strength or dynamic modulus of elasticity.

Dry building adhesive mixes of class C1 with redispersible polymer powders and an air-entraining admixture after 75 freezing cycles can be correspond to class C2.

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