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Study on the performance of a new type of water-repellent admixture for cement mortar

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Abstract

A special water repellent for mortar is made from the combination of polyacrylamide as a principal raw material and FDN-2 as an additive. Every item of comparison test and research for the technical features of the compound water-repelling admixture (CWRA) has been carried out in building antiseepage mortar. The result shows that the main properties of the mortar have satisfied China's national standard. The permeability of mortar added with the agent has been greatly improved. The mortar has high effective penetration resistance and good workability. This paper discusses the waterproofing mechanism of the agent.

Keywords: Admixture; Mortar; Permeability; Penetration resistance; Workability

1. Introduction

For durability and practical application, it is accepted that cement mortar, especially external wall cement mortar, should possess low permeability. Unfortunately, it has been found impossible so far to set limits for permeability, which can be subjected to practical tests. Mortar possesses a pore structure and, in this respect, is different from metals. The capillary pore structure allows water under pressure to pass slowly through the mortar, but the rate of flow through dense, good-quality mortar is extremely slow. The degree of compaction of the mortar, the extent of porosity due to the pore voids, capillarity, and the pressure head of the retained liquid and its viscosity determine the degree of permeability of the mortar barrier [1–5]. The degree of permeability is a measure of the ability of the mortar to allow liquid or water to flow through the mortar barrier due to the difference in the hydraulic pressure gradient between the opposite faces of the mortar element. The subject of permeability is very complex. The following are relative factors involved:

(a) the quality and quantity of the cement paste—the quality of the cement paste depends on the amount of cement in the mix, the water–cement ratio (w/c), and the degree of hydration of the cement;
(b) the bond developed between the paste and the aggregate;
(c) the degree of compaction of the mortar;
(d) the presence or absence of cracking; and
(e) the standard of curing.

Permeability will result in the phenomenon of water leakage going inward into the structure from the external wall mortar. However, sometimes, a good type of admixture used in the mix may greatly improve these factors mentioned above, and the mortar will have high penetration resistance [6–8].

The author has successfully trial-manufactured one type of highly effective admixture for water-repelling concrete. It is made from a combination, with polyacrylamide as a principal raw material and naphthalene sulfonic acid formaldehyde condensation product, named FDN-2, as an additive. The former is a fine powder that serves as a thickener, while the

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latter is a special water-reducing agent. At first, this water repellent is specially designed for concrete. The author, however, wanted to know what the results were when it is used in mortar, especially in building antiseepage mortar.

2. Experimental proposals and results

Every item of comparison test and research for the technical features of the compound water-repelling admixture (CWRA) was designed in building antiseepage mortar, according to Chinese standard JC474-1999 «Water-repellent admixture for mortar and concrete» [9].

2.1. Raw materials

- Cement—Class 42.5-Mpa Portland ordinary cement.
- Sand—Class middle with fineness modulus 2.67.
- Mixing water—general drinking water liquid.

2.2. Proportion and properties of testing mortar

The mixing proportion (I) for the testing mortar is shown in Table 1, and the main properties of the mortar with CWRA can been seen in Table 2. From Table 2, the main properties of the mortar with CWRA have satisfied the demand of the excellent product in Chinese standard JC474-1999. Some were even better than the standard, especially the ratio value of penetration resistance at 7d, which was more than 500%, making it incomparably superior to the value in the standard.

2.3. The effect of each component in CWRA

The mixing proportion (II) for the testing mortar and the results are shown in Tables 3 and 4, respectively. Table 4 showed that the penetration resistance was greatly strengthened, while the testing mortar was only added with the principal. However, the compressive strength decreased at the same time. When the testing mortar was added with only the additive, which existed in CWRA, it was not only the penetration resistance that increased, but also the compressive strength as well. Therefore, the effect of the principal was mainly for the ability of penetration resistance, but that of the additive was mainly for water reduction and augmentation of strength.

Table 1
Mixing proportion (I) for testing mortar

Sample	Proportion by weight				w/c
	Cement	Sand	Principal	Additive	
Basic mortar with no admixture	1	3			0.62
Mortar with CWRA	1	3	0.02	0.01	0.52

Table 2
Main properties of a mortar with CWRA

Items		Property indication		Measured value
		Excellent	Qualified	
Stability of volume		OK	OK	OK
Setting time	Initial setting (min) [not less than the value]	45	45	170
	Final setting (h) [not more than the value]	10	10	6
Ratio of compressive strength (%) [not less than the value]	7d	100	95	111
	28d	90	85	97
	90d	85	80	88
Ratio of penetration resistance at 7d (%) [not less than the value]		300	200	>500
Ratio of total inhaled water weight in 48 h (%) [not more than the value]		65	75	56
Ratio of shrinkage on 90d (%) [not more than the value]		110	120	107

2.4. The influence of cement quantity

The cement quantity used in testing samples was expressed with the cement–sand ratio (c/s; by weight). The principal in the testing sample was 2% (by cement weight), and the additive was 1% (by cement weight). The c/s values for Samples 1, 2, 3, 4, and 5 were 1:2.0, 1:2.5, 1:3.0, 1:3.5, and 1:4.0, respectively.

The results are shown in Table 5. As the ratio was more than 1:3.0, both the penetration resistance and the compressive strength sharply decreased. Therefore, the proportion of cement to sand in practical utilization should not be higher than the value of 1:3.0.

2.5. The influence of sand fineness

The raw materials were the same as mentioned earlier. The principal and additive in the testing samples were 2%

Table 3
Mixing proportion (II)

Samples	Proportion by weight				w/c
	Cement	Sand	Principal	Additive	
Basic mortar with no agent	1	3			0.62
Water-repellent mortar A	1	3	0.02		0.58
Water-repellent mortar B	1	3		0.01	0.56

Table 4
Main properties of a mortar with a single component in CWRA

Items		Property indication		Mortar with single component	
		Excellent	Qualified	A	B
Stability of volume		OK	OK	OK	OK
Setting time	Initial setting (min) [not less than the value]	45	45	90	250
	Final setting (h) [not more than the value]	10	10	5	7
Ratio of compressive strength (%) [not less than the value]	7d	100	95	96	116
	28d	90	85	83	110
	90d	85	80	78	107
Ratio of penetration resistance at 7d (%) [not less than the value]		300	200	500	330
Ratio of total inhaled water weight in 48 h (%) [not more than the value]		65	75	52	63
Ratio of shrinkage on 90d (%) [not more than the value]		110	120	113	101

and 1%, respectively. The fineness modulus of sand in Samples 6, 7, 8, and 9 was separately 3.00, 2.67, 2.14, and 1.67, respectively. The results are listed in Table 6.

With the decrease in the fineness modulus of sand, the compressive strength gradually descended. According to the measurement of the highness of water in the sample, the penetration resistance would decrease when the modulus was below 2.14; although at this moment, it still remained at the high-level value. Therefore, it could be deduced that sand, in practice, cannot be too fine.

2.6. Properties of analogue product

An analogue product was designed for practice. In view of the operation procedure of building an antiseepage mortar on site and the possibility of further increasing the penetration resistance, the maximum diameter of sand granule should not be more than 3 mm. The c/s was 1:2.5, the principal was 2%, and the additive was 1%. The consistency of the mortar was controlled at about 6.0. The relative result is shown in Table 7.

Table 5
Properties of samples with different cement quantities

Samples	Penetration resistance (MPa)	Highness of water in sample (mm)	Compressive strength on 28d (MPa)
Sample 1	>1.5	10.9	34.3
Sample 2	>1.5	12.8	27.8
Sample 3	>1.5	18.0	26.5
Sample 4	0.9		20.6
Sample 5	0.6		16.0

Table 6
The influence of sand fineness on property

Item	Sample 6	Sample 7	Sample 8	Sample 9
Penetration resistance (MPa)	>1.5	>1.5	>1.5	>1.5
Highness of water in sample (mm)	28	24	20	27
Compressive strength on 28d (MPa)	33.5	31.8	26.8	23.1

3. Other properties of fresh mortar with CWRA

3.1. High fluidity

Fresh mortar with CWRA had high flow characteristics. The mortar would achieve full and uniform compaction without the need for any help from vibration. It was one of a self-compacting type and was distinctly different from other types of a conventional workability mortar. Its characteristics of high fluidity and stability were achieved by a combination of a low water–binder ratio and a superplasticiser, and supplemented by viscosity-enhancing agents or "thickeners" (the principal, polyacrylamide, in raw materials). In rheological terms, the properties of high fluidity and stability required a very low yield stress and a moderate to high plastic viscosity (but not so high that flow times were excessive). The behavior of the fresh mortar essentially followed the Newton model. Fig. 1 showed the fluidity curves of fresh mortar with or without CWRA.

It could be seen that if w/c was fixed, the fluidity of testing fresh mortar with CWRA was much higher than that of basic mortar with the increase of the principal quantity added in the mortars (Fig. 1a). However, if w/c was lower than 0.52, the result would be quite contrary due to the requirement of dissolving the principal in mixing water. If the weight of the principal was kept to be same, the fluidity of testing fresh mortar added with CWRA speedily increased with the increase of w/c (Fig. 1b). On the contrary, the fluidity of basic fresh mortar slowly increased. High

Table 7
Properties of an analogue product

Item	Basic mortar	Analogue mortar
Penetration resistance on 7d (MPa)	1.2	>1.5
Highness of water in sample on 7d (mm)	–	8
Penetration resistance on 28d (MPa)	1.3	>1.5
Highness of water in sample on 28d (mm)	–	8
Compressive strength on 7d (MPa)	23.0	26.6
Compressive strength on 28d (MPa)	29.8	30.6

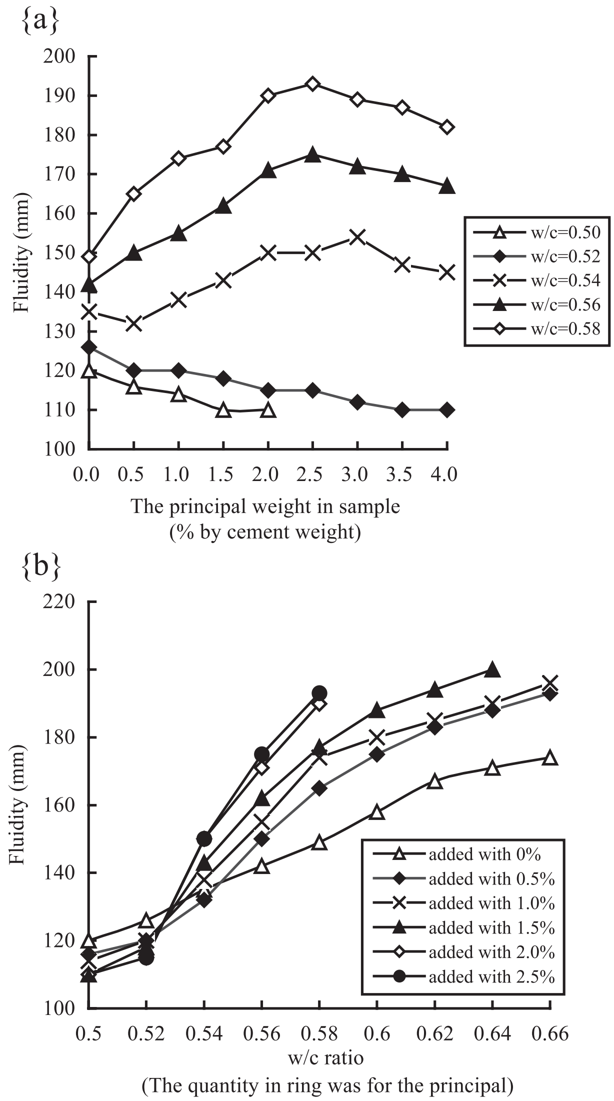

Fig. 1. Fluidity comparison of different fresh mortar.

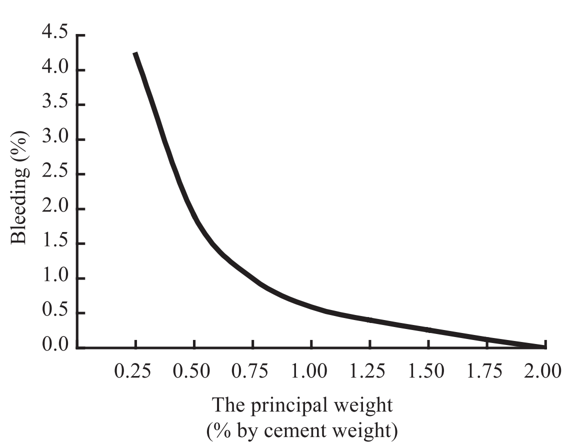

Fig. 2. Relationship between bleeding and the quantity of the principal in the samples.

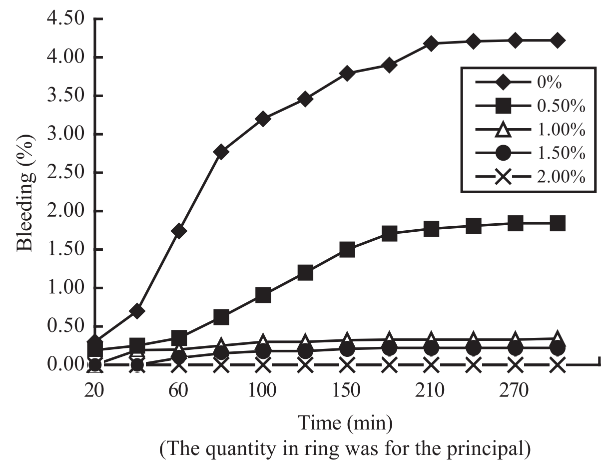

Fig. 3. Relationship between bleeding and time.

flow characteristics of testing mortar would have self-leveling behavior.

3.2. Low bleeding

Bleeding phenomenon exists in a conventional fresh mortar or one added with a water-reducing admixture. However, both the bleeding of water and segregation between aggregates and paste would nearly disappear if adequate principal (i.e., polyacrylamide) were added into the mortar mixture before mixing. Fig. 2 shows the relationship between the bleeding ratio and the quantity (percent of cement weight) of the principal when w/c was 0.56. The changing traces of water bleeding for different mortars in a limited period of time are expressed in Fig. 3.

4. Waterproofing mechanism of a mortar with CWRA

During the mixing process, the principal, polyacrylamide, gradually dissolves into mixing water and adheres to the surface of cement granules. Thus, the system composed of cement, sand, and water takes the form of net connection, but it is amorphous, with no regular shape and size. The system expresses a situation of flocculent structure [10]. The activity of cement particles in the area of this flocculation status is limited. They do not fully contact with outside mixing water. As a result, there therefore seems much free water outside of the flocculation area. Meanwhile, the additive, FDN-2, begins to exert its strongly dispersing ability, reducing the force of attraction in flocculation structure, breaking the structure, and scattering cement particles into outside water uniformly [11]. With the development of the setting process, the viscid solution gradually loses water and becomes gelling. The principal, polyacrylamide, will become a film in the whole system during drying.

The film is cross-connected in hardened mortar. Matters of the principal are in every area of the system and will grow with hydration products [8]. The whole system of the mortar is seemingly divided into a lot of small districts (like chambers) by the filmy matter. Most of the pores in the mortar are choked up or fully sealed by the film. Therefore, bigger pores become small or tiny ones, and continuous pores or creaks become a lot like small isolated ones. Thus, the characteristic of the system has changed, the total volume of pores and creaks in the mortar added with CWRA reduces and will be less than that in the conventional mortar without CWRA. The stress status in the cement mortar has been improved due to a lower value of the elastic modulus of the film. It will keep hardened mortar from forming or developing creaks, while it is stressed by outside loading. The screen function of the film makes it difficult for water to penetrate the structure of hardened mortar.

5. Conclusions

The effect of CWRA was very obvious according to the results of a series of comparison tests. Every item of the tests generally exceeded the relative indication in Chinese standard for water-repelling mortars. The effect of the principal and additive are different in fresh mortars.

They should be used together in the mortar mixture for producing best results. Neither the principal nor the additive will produce wholly satisfactory results of a water-repelling mortar if one of them is singly added into the mortar mixture. Mortar added with adequate CWRA would have very effective penetration resistance and good workability. The research has indicated that this compound water repellent is quite suitable for manufacturing building water-repelling mortar with high penetration resistance.

References

[1] T.C. Powers, The physical structure and engineering properties of concrete, Res. Bull., vol. 90, Portland Cement Association, Skokie, 1958.
[2] T.C. Powers, L.E. Copeland, J.C. Hayes, H.M. Mann, Permeability of Portland cement paste, Proc., ACI J. 51 (1958) 285–298.
[3] P.H. Perkins, Repair, Protection and Waterproofing of Concrete Structure, Elsevier, New York, 1986.
[4] T. Wang, Crack Control in Construction Structure, China Construction Industry Press, Beijing, 1997.
[5] B. Liu, Concrete Technology, Traffic Press, Beijing, 1998.
[6] X. Wang, Trial-manufacture and application of micro-crystal water repellent for cement mortar, New Build. Mater. 2 (1999) 29–33.
[7] B. Zhang, Property research of effective admixture for construction mortar, New Build. Mater. 8 (1999) 31–34.
[8] Z. Lu, X. Zhou, The waterproofing characteristics of polymer sodium carboxymethyl-cellulose, Cem. Concr. Res. 30 (2) (2000) 227–231.
[9] China Ministry of Construction, Water-Repellent Admixture for Mortar and Concrete, Standard JC474-1999, China Construction Industry Press, Beijing, 1999.
[10] Z. Lu, Flocculation in SCMC–H_2O–OPC system, J. Shanghai Jiaotong Univ. 30 (8) (1996) 60–66.
[11] Z. Lu, X. Zhou, An unknown function of water reducing admixture SN-2, New Build. Mater. 8 (1996) 30–31.