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PRECAUTION OF CONCRETE DURABILITY SYNDROME WITH HIGH PERFORMANCE CEMENT

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ABSTRACT

Sulphate ion and chloride ion existed in the alkaline saline soils may cause serious problem on the durability of reinforced concrete, while it is found that superfine mineral powder plays positive role in the precaution of the alkaline saline corrosion. A new composite cement of our research, the high performance cement (H.P.C), composed of different superfine mineral powders in appropriate proportions, exhibits good properties in preventing concrete from alkaline saline soil corrosion. Mortar bar test and visual examination showed that the cement could effectively control AAR and sulphate ion related expansion, and the charge passed was decreased to "negligible" level for concrete with W/B ratio of 0.3, and "very low" grade for concrete with W/B ratio of 0.45 and 0.55 when the high performance cement was used. Other properties such as low hydration heat and anti-freezing properties, as well as the uniformity of the blends, made it an indispensable material in the construction of concrete structure in alkaline saline soils.

Key words: Test methods durability syndrome, High performance cement (H.P.C), Mineral powder, Alkaline saline soils, Alkali-aggregate reaction (AAR), Charge passed

1 INTRODUCTION

In the alkaline saline area of the Yellow River delta in shandong province of china, where the Dongying Yellow River Bridge located, the underground water may cause serious corrosion of the reinforced concrete, as the concentration of SO_4^{2-} and Cl^- in the water reaches 6260mg/l and 57300mg/l respectively [1]. In the mean time, aggregate used in the engineering were either alkali-silica reactive or alkali-carbonate reactive, or both [2], while the concrete was also subjected to freezing and thawing damage, with the lowest temperature of −18°C in winter. Consequently, effective measures must be taken to prevent the deterioration of concrete durability syndrome in the process of construction [3].

In the research of the syndrome precaution, it is found that the substitution of superfine mineral powder for cement and the decrease of W/B ratio are the most effective ways to defend concrete durability, and the durability of concrete under different deteriorating factors was also related to the type, fineness and percentage of the mineral powders [4-6]. However, the disease of concrete durability was the result of comprehensive deterioration factors that could not be resolved by only one type of mineral powder, and the mix of different powder with different functions was an important solution to the durability syndrome problem. On this assumption, a new type of cement composed of different mineral powders, with properties such as chemical corrosion-resistant, saline resistant and freezing damage resistant was developed. The

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cement could also suppress the AAR expansion, and satisfy the requirement of the Chinese national standard GB-12958, and was named as high performance cement (H.P.C).

2 PROPERTIES OF THE HIGH PERFORMANCE CEMENT

The high performance cement was a compound of Portland cement and different mineral powders, belonging to composite cement type according to china national standard GB-12958. The composition of H.P.C and controlled ordinary Portland Shanlü cement was shown in table 1, and the properties of composite cement including strength and other related ones, according to the national standard of GB12958-1999, was shown in table 2.

Table .1 composition of the Shanlü cement and high performance cement(H.P.C)

cement	composition (%)									
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O	Na_2O	LOI	f-CaO
Shanlü	20.36	5.04	3.70	62.04	2.85	1.75	0.62	0.33	2.67	1.22
H.P.C	31.24	14.06	2.56	40.97	3.78	3.03	0.53	0.21	1.19	/

Table 1. The requirement of GB-12958 and the properties of the high performance cement

Properties	MgO	SO_3	Residue of 80μ	Setting time Initial	Setting time Final	Soundness	3d strength (MPa) Compressive	3d strength (MPa) Bending	28d strength (MPa) Compressive	28d strength (MPa) Bending
National standard	≤ 10%	≤ 3.5%	≤ 10%	≥ 45min	≤ 10h	Qualified	11.0	2.5	32.5	5.5
Value measured	3.78	3.03	3.7	2h30m	7h	Qualified	11.4	3.68	40.0	9.03
All the values satisfied the requirement of GB-12958										

3 STRENGTH OF CONCRETE MIXED WITH HIGH PERFORMANCE CEMENT (H.P.C)

Strength of concrete mixed with high performance cement was compared with the controlled one mixed with Shanlü cement P. O. 32. 5, the mix proportion of concrete was shown in table 2, and the compressive strength at 7d and 28d of curing age was shown in table 3.

Table 2 Material used in concrete

NO	cement	W/C	Material used in concrete (Kg/m^3) cement	water	sand	gravel	Air entraining agent	superplasticizer (%)
1	H.P.C32.5	0.30	550	142	740	1000	0.5%*C	1.5
2		0.45	450	192	760	1040		0.5
3		0.55	350	180	810	1090		0.5
4	Shanlü P.O.32.5	0.30	550	142	740	1000	0.5%*C	1.5
5		0.45	450	192	760	1040		0.5
6		0.55	350	180	810	1090		0.5

Table.3 7d and 28d compressive strength of the concrete

NO	Compressive strength (MPa)	
	7d	28d
1	57.4	81.2
2	27.6	40.1
3	20.4	34.4
4	55.0	65.4
5	31.2	41.8
6	22.6	34.2

It is found that the 28d strength of specimen No.1 was 24% higher than that of the controlled one (No.4) when W/C ratio is 0.30, and the strength variance of concretes with W/C ratio of 0.45 and 0.55 were slight.

4 EFFECT OF HIGH PERFORMANCE CEMENT ON CONCRETE DURABILITY

4.1 Effect of high performance cement on ACR expansion

The suppression effect of high performance cement on ACR expansion was tested with the concrete microbar method raised by the former Nanjing University of Chemical Engineering [7]. The two cements were mixed with ACR reactive aggregate of 5-10mm with proportion of 1:1 respectively, then the mix was blended with water at W/C ratio of 0.30, during which KOH was added to increase the R_2O dosage to 1.5% of the cement used, Specimens with size of 20mm×20mm×80mm were made and put into 80°C water for 24 hours after 1d of standard curing and de-molding, then the length of the specimens were measured as initial length. The microbars were then cured in 80°C1N NaOH solution and measured at 1,3,7,10,14,21,28d of curing age. The length change of the mortar bar was calculated to evaluate the effectiveness of the high performance cement on the inhibition of ACR expansion, and the proposed limit of expansion was 0.1%, the ratio of less than 0.1% was regarded as qualified.

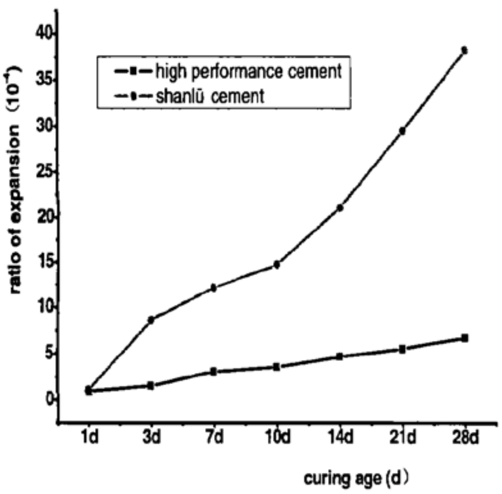

Fig.1 Effect of Shanlü cement and high performance cement on ACR expansion

It is known from fig.1 that the expansion ratio of the controlled specimen (Shanlü cement) was 0.38%, far bigger than the up limit of 0.1%, while the expansion of the high performance cement specimen was only 0.07%, showing its effectiveness of alkali-carbonate reaction inhibition.

4.2 Effect of high performance cement on ASR expansion

ASTM C441 [8] was used to measure the effect of high performance cement on ASR expansion. Quartz glass was crushed to 0.15-4.75mm as aggregate, with size and percentage shown in table 4.The cement was mixed with quartz glass aggregate with C/A ratio of 2.25 and blended with water at W/C ratio of 0.47. Specimens with size of 25mm×25mm×285mm were cast and measured for initial length after 1d of standard curing and de-molding, then the specimens were cured in 38°C and RH 100% environment, and periodically measured for length change till 14 days. The expansion of the mortar bars was compared to determine the effectiveness of the mineral powders.

Table 4 Size and percentage of the quartz glass aggregate required in ASTMC441

Diameter	0.15-0.3mm	0.3-0.6mm	0.6-1.18mm	1.18-2.36mm	2.36-4.75mm	Total
Percentage	15%	25%	25%	25%	10%	100%

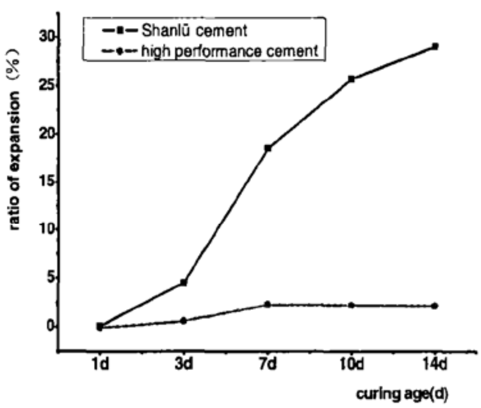

Fig 2 Suppression effects of high performance cement on ASR expansion

It is shown in fig.2 that the expansion ratio of the Shanlü cement was nearly 0.3%, but the high performance cement mortar bar's expansion ratio was only 0.026%, less than 10% of the controlled one, showing its excellencein in the suppression of ASR expansion.

4.3 Charge passed of concrete mixed with high performance cement

According to ASTM C1202, the concrete mixed with Shanlü cement and the high performance cement were measured to evaluate chloride ion penetration, the grade and respond charge passed data was specified in table 5. Mix proportion of the concrete was shown in table 2 and the result was given in table 6.

Table 5 the grade of chloride penetration ability evaluated by the charge passed

6h total charge passed(coulombs)	Cl^- diffusion ability
>4000	High
2000-4000	medium
1000-2000	low
100-1000	very low
<100	negligible

Table 6 28d charge passed of concrete

specimens	W/C	6h total charge passed (coulombs)	Cl^- diffusion ability
H.P.C1	0.3	75	negligible
H.P.C2	0.45	170	very low
H.P.C3	0.55	279	very low
Shanlü P.O.1	0.3	963	very low
Shanlü P.O.2	0.45	1630	low
Shanlü P.O.3	0.55	2824	medium

It is seen from table 6 that the high performance cement has excellent ability of defending Cl^- diffusion.

4.4 Effect of high performance cement on sulfates aggression

The effect of high performance cement on sulphates aggression was tested by wetting-drying method [1,9], with immersion of the specimens in 15%NaCl+5%$MgSO_4$ or 5%Na_2SO_4 solution for 16 hours and drying at 80°C for 6 hours. Weight loss and visual evaluation was used to determine the sulphate aggression resistant ability. The mix proportion was similar to table 2, and the drying and wetting result were shown in table 7, 8 and photo1 and 2.

Table 7 The drying-wetting result of concrete immersed in 5%Na_2SO_4 solution

NO	Cement	Initial weight(g)	Weight loss after 12 cycles	Weight loss after 15 cycles	Weight loss after 30 cycles	Wetting –drying cycles
1	H.P.C1	2481、2468、2484			4.25%	33
2	H.P.C2	2386、2423、2405		5%		15
3	H.P.C3	2423、2396、2383	5.78%			12
4	ShanlüP.O1	2512、2532、2516			4.81%	31
5	ShanlüP.O2	851、857、855		4.95%		15
6	ShanlüP.O3	884、874、854		5.05%		15

Table 8 The drying-wetting result of concrete immersed in 15%NaCL+5%$MgSO_4$ solution

NO.	cement	Initial weight (g)	Weigh loss after 30 cycles	Weigh loss after 90 cycles
F1	H. P. C	2504、2506、2527	-1. 46%	+0. 6%
F2	H. P. C	2427、2424、2389	-1. 15%	+2. 14%
F3	H. P. C	2400、2431、2441	-1. 29%	+2. 85
K1	ShanlüP. 0	2518、2535、2524	-2. 46%	-2. 39
K2	ShanlüP. 0	848、853、853	-1. 72%	-0. 47
K3	ShanlüP. 0	850、875、865	+0. 05%	+0. 12

Photo-1 the appearance of specimens K1 and F1 after 35 cycles of drying-wetting in 5%Na_2SO_4 solution

Photo-2 the appearance of specimens K2,K3 and F2,F3 after 35 cycles of drying-wetting in 5%Na_2SO_4 solution

4.5 Effect of high performance cement on freezing and thawing of concrete.

The freezing and thawing aggression on concrete was tested according to quick freezing and thawing method. The mix proportion was similar to table 2, and the specimens were immersed in water and salt solution respectively, the center temperature of specimens was −18°C±2°C, and the result was given in table 9.

It is seen that the high performance cement based concrete exhibits better quality in freezing and thawing resistance than Shanlü cement, provided that the air entrained was equal.

4.6 Other properties of high performance cement

Apart from the excellent durability deliberated above, the high performance cement owned other outstanding properties as follows:

1). Conservation of energy and resource, alleviation of air pollution

The clinker dosage of the H.P.C was only 50%, while the other materials used was industrial residue, as a result, half of the natural resource was conserved, and only half of the carbon dioxide was emitted. The discharge of other pollutant such as NO_x and SO_x was also decreased considerably. In the mean time, the full use of the industrial residue was also benefical for environment improvement and the conservation of energy.

2) Low hydration heat and low heat-isolation temperature increase

The hydration heat released was only half of the ordinary Portland cement's, and the heat-isolation temperature increase of the concrete was also half of the common concrete with similar strength grade, which is beneficial for construction of large volume concrete.

Table 9 the freezing and thawing result of high performance cement based concrete

No.	Immersed in 3% Na_2SO_4		Immersed in water	
	Freezing and thawing cycles	Modulus ratio of dynamic elasticity	Freezing and thawing cycles	Modulus ratio of dynamic elasticity
H.P.C1	155	>60%	300	>80%
H.P.C2	150	>60%	300	>85%
H.P.C3	100	>60%	155	>70%
ShanlüP.O.1	100	>60%	200	>60%
ShanlüP.O.2	87	< 60%	155	>60%
ShanlüP.O.3	87	< 60%	145	>60%

3). Properties of concrete blends

The blends were uniformly mixed, no bleeding and segregation occurred after blending, and the slump loss was easy to control. However, the curing condition should be strengthened as the percentage of mineral powder with low reactivity was higher

5 CONCLUSION

The high performance cement was developed on the basis of composite effect of superfine mineral powders, aiming to defend the deterioration of the Dongying Yellow River Bridge, as well as the deteriorations brought by the concrete materials. Different deteriorations might be cured with different mineral powders, and the mix of appropriate type and percentage of superfine mineral powders could cure concrete structure of durability syndrome, such as salt disease, freezing damage, sulphate aggression, and ACR and/or ASR expansion, etc. The cement was also endowed with other properties such as uniformity of the concrete blends, and low hydration heat as well. As the cement was excellent in decreasing charge passed and defending NaCl and $MgSO_4$ aggression, the product was also quite suitable for oceanic and offshore engineering.

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