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The microstructure and sulfate resistance mechanism of high-performance concrete containing CNI

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Abstract

It is found from previous studies that the incorporation of calcium nitrite inhibitor (CNI) together with mineral admixtures could weaken the resistance of mixtures to sulfate attack. To better understand the mechanism of this phenomenon, the influence of CNI on the microstructure of cement-based materials is studied by means of quantitative X-ray diffraction, mercury intrusion porosimetry, and scanning electronic microscopy technique. The test results demonstrate that the incorporation of CNI accelerates the formation of calcium hydroxide and ettringite crystals, and weakens the pore refinement effect caused by the secondary hydration reaction of fly ash and microsilica. At the age up to one year, the relative crystal quantity in mixture containing CNI is always higher than that in control mixture without CNI. The reasons for the degradation in sulfate resistance of mixtures may be attributed to the increase of the calcium hydroxide and ettringite crystals formed, the increase of micropore size and the degradation of secondary hydration reaction. Based on the experimental results, conclusion can be drawn that NCI should be used cautiously in practical engineering when high resistance to sulfate attack is required.

Keywords: High-performance concrete; Sulfate resistance; Microstructure; Hydration products; Calcium nitrite inhibitor

1. Introduction

The deterioration of concrete is a process under the joint influence of many factors. To prolong the service life of concrete structures, the main indexes of the durability should be taken into account in accordance with their service conditions when the mixtures of the concrete are designed. For coastal and offshore engineering, one of the most important issues is the deterioration of the concrete structures caused by sulfate attack. Kalousek's research [1] demonstrated that the service life of concretes with various admixtures and mix design could be two to ten times different from each other. This means that the service life of concretes with different admixtures incorporation can vary from 20 to 200 years under sulfate attack. Hence, for coastal and offshore constructions, the resistance to sulfate attack is an important index of durability. To improve the durability of high performance concrete, the authors have studied the effects of incorporation of mineral admixtures, calcium nitrite inhibitor (CNI) and superplasticizer into concrete mixtures [2–5]. These researches demonstrate that the same admixture may have different influence on various durability index. For example, the incorporation of CNI can protect the steel bar from corrosion, but weakens the concrete resistance to sulfate attack. The CNI has been used widely in coastal engineering to protect steel, so its influence mechanism on sulfate resistance of concrete should be studied. However, the research on this subject is very limited.

In this paper, based on previous research on sulfate resistance of high performance concrete, the authors investigate the hydration products and their quantity in pastes and concrete specimens containing CNI at the different ages up to one year by means of qualitative X-ray diffraction. The microstructure change and images of hydration products are also studied by mercury intrusion porosimetry and scanning electronic microscopy technique, respectively. The purpose of the research is to better understand the influence mechanism of CNI on hydration and the microstructure of high performance concrete. The relation between microstructure and mixtures' resistance to sulfate attack is also investigated. The research in the current paper provides some

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Table 1
Compositions of different mineral additions (%)

Sample	CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	SO_3	K_2O	Na_2O	LOI
MS	0.33	90.54	0.77	1.77	1.68	0.4	1.24	0.46	2.78
PFA	3.38	49.99	37.12	3.06	0.52	0.67	0.4	0.16	3.12
Cement	65.07	20.73	6.20	3.23	0.89	2.47	0.43	0.17	0.97

theoretical foundation for the application of CNI in engineering.

2. Experimental

2.1. Raw materials

Cement used in this study was ASTM Type I Portland cement (or OPC), with relative density of 3.15 and fineness of 385 m^2/kg. The average powder diameter is 19.5 μm. The fly ash was provided by China Light & Power. According to its composition, it belonged to Class F (ASTM C618). The average powder diameter of fly ash is 11.06 μm. The microsilica is from Elkem, with bulk density of about 500 kg/m^3 and average size of 0.1 μm. The chemical components of these three mineral admixtures are listed in Table 1. Coarse aggregate used was crushed limestone with maximum size of 10 mm, and relative density of 2.57. Fine aggregate used was natural river sand with Fineness Modulus of 2.3, and relative density of 2.66. The chemical admixtures adopted in the study were CNI, D-17 (retarder to reduce slump loss) and W-19 (superplasticizer).

2.2. Preparation and testing of specimens

The concrete mix design for specimens was based on the practice in Hong Kong where the mineral admixtures are usually used as addition, rather than replacement. The water to binder ratio (W/B) was kept as a constant of 0.4 and the water content in chemical admixtures were included. Five mixtures each containing three $75 \times 75 \times 285\ mm^3$ prism and twelve $\phi 100 \times 200$ mm cylindrical specimens were prepared (see Table 2). The compressive strengths of the five mixtures were tested with cylindrical specimens by using ELE Auto Test 3000 machine at the ages of 3, 7, 28 and 91 days. Three specimens were tested for every mixture at the required age to guarantee accuracy. The mixtures and their compressive strengths at the different ages were also listed in Table 2. As can be seen from Table 2, mixture SA is a plain concrete without incorporation of fly ash, microsilica and CNI. The addition of fly ash by 25% by weight and various ratios of microsilica and CNI were incorporated in mixtures SB–SE. The water in CNI (if applicable), D-17 and W-19 solutions was all included in the total water of the mixtures. In this way, the influence of addition of fly ash, microsilica and CNI on sulfate resistance of concrete could be evaluated. Moreover, corresponding paste samples with water binder ratio of 0.3 were also prepared for QXRD, MIP and SEM tests.

All concrete specimens were mixed in a pan mixer following the procedures recommended by ASTM C192-C192M. The sulfate resistance test was carried out following the methods recommended by ASTM C1012-95A. The detailed testing procedure can be found in [3].

2.3. The determination of hydration reaction products in paste components

To investigate the mechanism of sulfate resistance of various mixtures of concrete, qualitative X-ray diffraction test was carried out with concrete specimens of the five mixtures which had been immersed into 5% sulfate solution for one year. To guarantee the reliability of the testing results, QXRD test was also done with the corresponding paste samples to determine their hydration products at the ages of 3, 28 and 240 days. Quantitative

Table 2
The different mixtures (kg/m^3) of fresh concrete and the compressive strengths[a]

Sample	SA	SB	SC	SD	SE
OPC	405	380	380	380	380
PFA	0	95	95	95	95
MS	0	0	20	0	20
Water[b]	162	190	198	190	198
F-agg	747	707	698	705	695
C-agg	1081	1024	1006	1020	1002
CNI[c]	0	0	0	6.8	6.8
D-17[c]	0.25	0.3	0.24	0.3	0.24
W-19[c]	4.5	3.8	3.0	3.8	3.0
D-3 (MPa)	29	21	21	21	25
D-7 (MPa)	51	36	36	30	35
D-28 (MPa)	73	53	70	42.0	51
D-91 (MPa)	81	75	75	58	60

[a] D-3, D-7, D-28 and D-91 in the table stand for compressive strengths of the mixtures at the ages of 3, 7, 28 and 91 days, respectively.
[b] The water in the chemical admixtures is included.
[c] The product is solution. The weight listed here is solid content only. The liquid content is included in the weight of water.

X-ray diffraction (QXRD) test was carried out by using a diffractometer (Philips Model PW 1830) with Copper kα (40 kv, 40 mA) radiation at a scan rate of 2°/2θ/min from 5 to 65°/2θ. α-Al_2O_3 was added into the sample as reference to determine the relative peak value of crystals. The content of the crystals is determined by referring to the standard curves.

2.4. The measurement of micropore size

After hydration was stopped at the ages of 3 and 91 days, the paste samples were firstly dried at 105°C for 24 h, and then were crushed to powders with diameter from 2.5 to 5 mm (passing No. 4 sieve and retaining No. 8 sieve). The measuring range of micropore was from 0.06 to 1000 μm. Cumulative pore size distributions were obtained by using an automatic scanning porosimetry (9320) with intrusion pressures up to 300 MPa, and assuming a contact angle of 140°.

2.5. The scanning electronic microscopy observation

After hydration was stopped at the age of 28 days, the paste samples were dried and gold-plated for the SEM observation. SEM tests were carried out with Model JSM 6300 instrument.

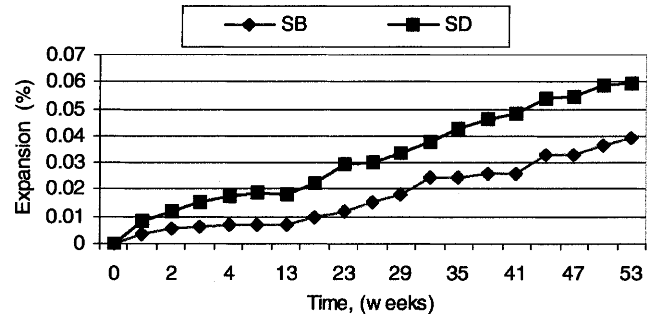

Fig. 2. Influence of NCI on the sulfate resistance of HPC containing 25% fly ash.

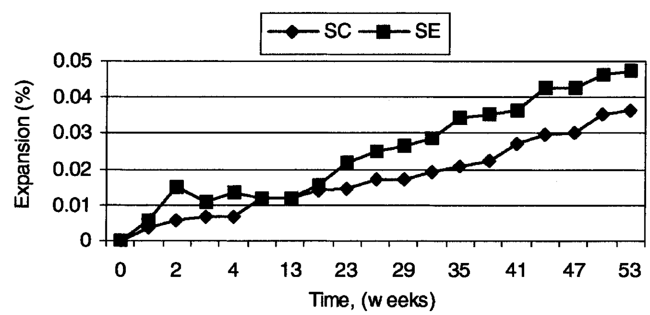

Fig. 3. Influence of NCI on the sulfate resistance of HPC containing 25% fly ash and 5% MS.

3. Results and discussion

3.1. The influence of CNI on sulfate resistance of high performance concrete

The sulfate resistance results of the five mixtures were compared in Figs. 1–3.

As can be seen from Fig. 1, the mixtures SB and SC have a better resistance to sulfate attack than mixture SA even their strengths are lower than that of SA. It demonstrates that higher strength does not necessarily mean a better durability. The incorporation of high quality fly ash and microsilica greatly improves the mixtures' resistance to sulfate attack. The mineral admixtures with high activity are important to the preparation of high-performance concrete. This has been verified by many researchers [1–7].

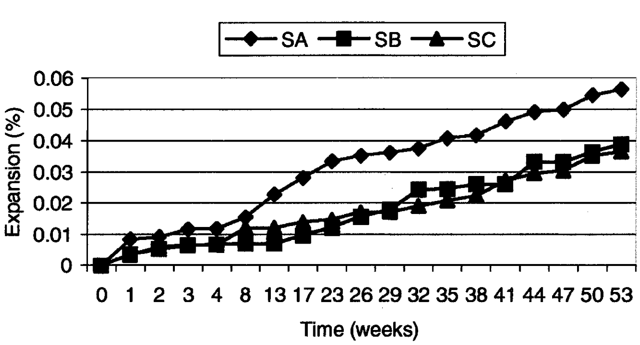

Fig. 1. Comparison of the sulfate resistance of HSC and HPC.

Fig. 2 shows the comparison between SB (without CNI) and SD (with 15 l/m^3 CNI). It can be seen that the 15 l/m^3 addition of CNI in mixture SD weakens the sulfate resistance of the mixture although other ingredients in the mixture are the same as those in SB. The addition of CNI also weakens the sulfate resistance of mixtures containing both fly ash and microsilica. This can be observed in Fig. 3, which compares the results of SC (no CNI) and SE (15 l/m^3 CNI).

To evaluate the influence of CNI on sulfate resistance of high performance concretes, the relative expansion values of various mixtures at the age of 53 weeks is shown in Fig. 4. As can be seen from the figure, the expansion of mixture SB with 25% fly ash addition by weight is reduced by 30.8%. Further addition of 5% of microsilica by weight of cement into the mixture SB reduces the expansion by 35.3%. However, the 15 l/m^3 addition of CNI greatly deteriorates the mixture resistance to sulfate attack. The expansion of mixture SD increased from 69.2% to 105.3% as compared to control mixture (SA). This means that the sulfate resistance of mixture SD is even poorer than that of control mixture. The similar situation can be observed for mixtures SC

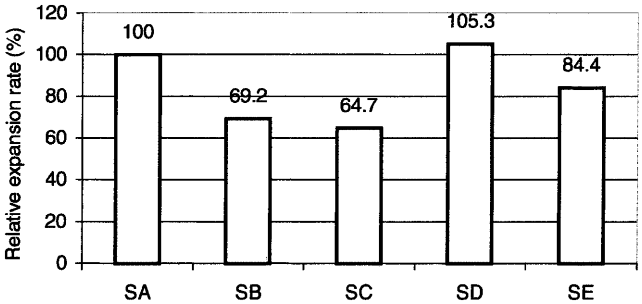

Fig. 4. Relative expansion rates of different concrete at 53 weeks.

and SE. The 15 l/m^3 addition of CNI causes the growth of expansion from 64.7% to 84.4% of the control mixture. The sulfate resistance of the mixtures containing fly ash, microsilica and CNI is better than that of the control mixture without microsilica addition.

Frearson [8] carried out a series of researches on concrete containing fly ash, slag and sulfate resisting cement. Based on his test results, Frearson proposed the method to evaluate sulfate resistance properties of mixtures according to their expansion values (Fig. 5). Comparing the test results of present study with the Frearson standard, it can be seen that the control mixture (SA) and mixture with both fly ash and CNI addition (SD) belong to the "Fairly Sulfate Resisting Concrete" and the other three mixtures (SB, SC and SE) belong to "Sulfate Resisting Concrete". This is in agreement with the sulfate resistance property of concrete made with sulfate resisting cement.

Based on the test results, the following observations can be summarized:

1. Higher strength does not necessarily mean higher resistance to sulfate attack.
2. Mineral admixtures can improve the sulfate resistance of concrete. The improvement is equivalent to that of sulfate resisting cement.
3. The incorporation of CNI could weaken the mixtures' resistance to sulfate attack. This means that the functions of CNI are conflicting: On one hand, it can protect steel from corrosion; On the other, it weakens the concrete resistance to sulfate attack. So special attention should be paid in practical engineering when CNI is used.

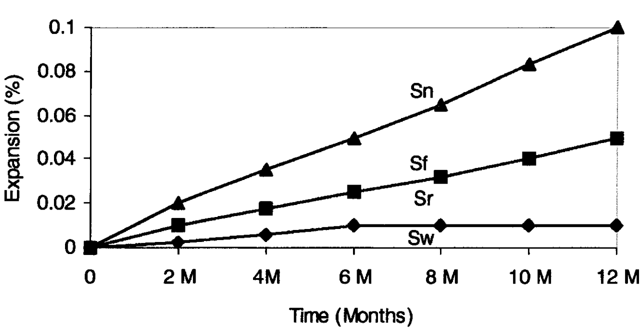

Fig. 5. Frearson's method to evaluate sulfate resistance. Sn stands for the area of not sulfate resisting. Sf stands for the area of fairly sulfate resisting. Sr stands for the area of sulfate resisting (including most SRPC). Sw stands for the area of very well sulfate resisting.

3.2. The influence of CNI on hydration products in pastes and concrete

A number of researches demonstrate that sulfate attack of concrete is a complicated physical and chemical process [1–10]. This process depends on many factors, such as the mix design of concrete, construction methods, curing conditions, and the types and concentration of aggressive ions. The deterioration of concrete may manifest in the form of expansion, crack, weight loss and strength loss. Cohen [9,10] pointed out that sulfate attack took place by the reactions between various concentration of sulfate ions and different hydration products in cement at all ages. These reactions can be expressed as follows.

(1) The formation of gypsum (produced by the reaction between sulfate ions and calcium hydroxide)

$$CH + N\overline{S} + 2H = C\overline{S}H_2 + NH \tag{1}$$

$$CH + M\overline{S} + 2H = C\overline{S}H_2 + MH \tag{2}$$

(2) The formation of ettringite (produced by the reaction between sulfate ion and calcium aluminate hydrate)

$$C_4AH_{13} + 3C\overline{S}H_2 + 14H = C_6A\overline{S}_3H_{32} + CH \tag{3}$$

$$C_4A\overline{S}H_{12-18} + 2C\overline{S}H_2 + (10 \sim 16)H = C_6A\overline{S}_3\,H_{32} \tag{4}$$

$$C_3A + 3C\overline{S}H_2 + 26H = C_6A\overline{S}_3\,H_{32} \tag{5}$$

(3) Decomposition of C–S–H gel (caused by the reaction with sulfate ion)

$$C_xS_yH_z + xM\overline{S} + (3x + 0.5y - z)H = xC\overline{S}H_2 + xMH + 0.5yS_zH \tag{6}$$

$$4MH + SH_n = M_4SH_{8.5} + (n - 4.5)H \tag{7}$$

In the reaction equations above

$C = CaO$; $S = SiO_2$; $A = Al_2O_3$; $N = Na_2O$;

$\overline{S} = SO_2$; $M = MgO$; $H = H_2O$

Although sulfate attack of hydrated cement is a complicated process and manifest in many forms, the crystal growth and crystallization pressure in hardened cement are the main causes leading to deterioration of concrete. This process has a close relation with qualitative change of calcium hydroxide and ettringite crystals in hardened cement. For this reason, in order to study the influence of CNI on hydration reaction, it is necessary to investigate the calcium hydroxide and ettringite content in pastes under sulfate attack.

The test results of QXRD with samples of five mixtures immersed in 5% of sulfate solution for a period up to one year are shown in Figs. 6–10. The qualitative analyses of calcium hydroxide and ettringite crystals were listed in Table 3. Comparing Fig. 6 (mixture SA) with Figs. 7 (SB) and 8 (SC), it can be seen that the peak values of crystals (ettringite and CH) in mixtures containing fly ash (SB) and mixture containing both fly ash and microsilica (SC) are lower than those in control mixture (SA). However, when CNI is incorporated into the mixtures (SD and SE), the content of calcium hydroxide and ettringite crystals increase obviously (Figs. 9 and 10). Adopting the characteristic peak value of calcium hydroxide (4.92 Å) and ettringite (9.09 Å) as reference index, the order for the contents of the two crystals in mixtures tested are as follows:

For calcium hydroxide:

SA > SD > SB > SE > SC

For ettringite:

SD > SA > SE > SC > SB

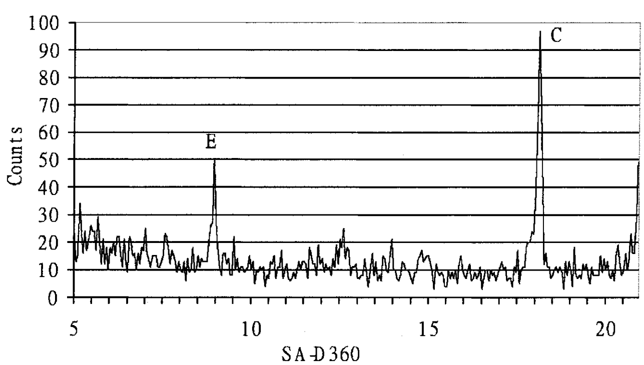

Fig. 6. XRD spectrum of concrete SA after one year's 5% Na_2SO_4 solution immersing test.

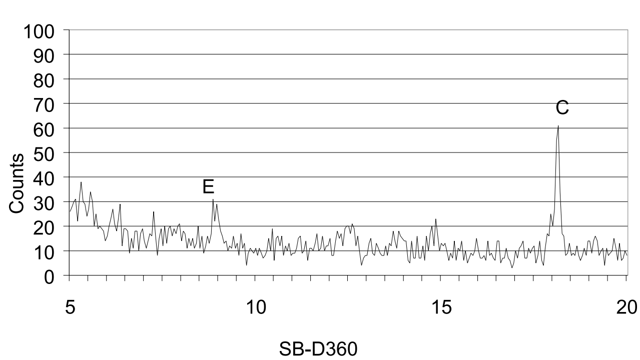

Fig. 7. XRD spectrum of concrete SB after one year's 5% Na_2SO_4 solution immersing test.

These orders, especially the one for ettringite, coincide with the sequence from low to high for the sulfate resistance of five mixtures. This observation demonstrates that the increase of calcium hydroxide and ettringite crystals in concrete could cause the deterioration of mixtures' resistance to sulfate attack. This conclusion is in agreement with the mechanism described in Eqs. (1), (3)–(5).

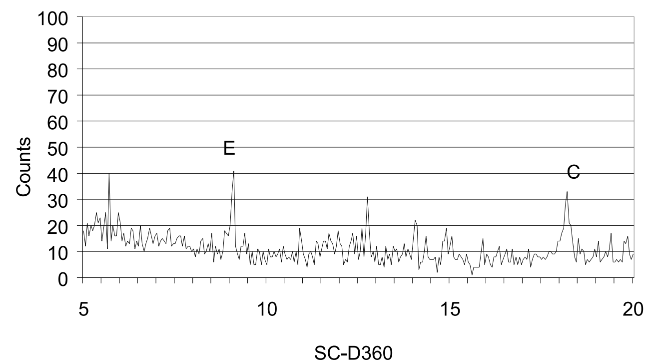

Fig. 8. XRD spectrum of concrete SC after one year's 5% Na_2SO_4 solution immersing test.

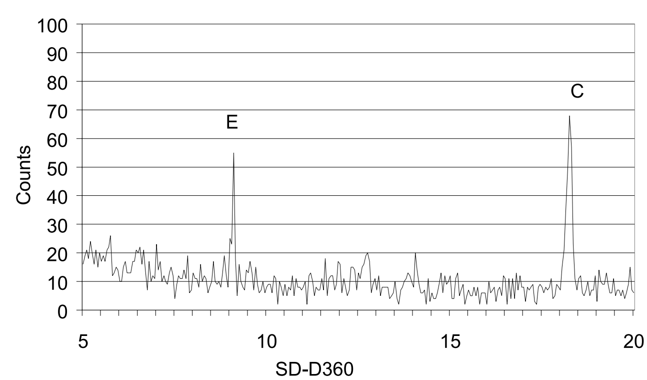

Fig. 9. XRD spectrum of concrete SD after one year's 5% Na_2SO_4 solution immersing test.

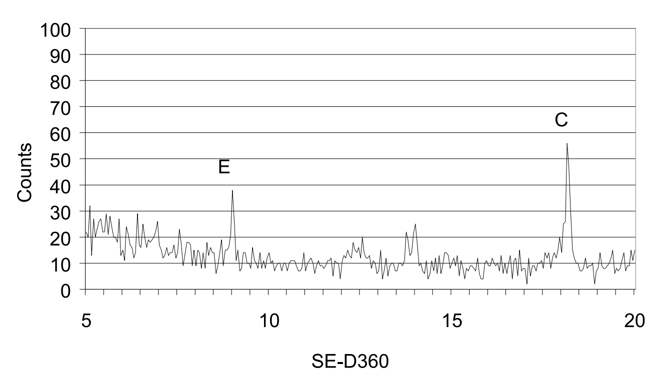

Fig. 10. XRD spectrum of concrete SE after one year's 5% Na_2SO_4 solution immersing test.

Table 3
The height, FWHA, and area of QXRD peaks of concrete sample after one year's 5% Na_2SO_4 solution immersing test

Sample	Time (days)	Height	Peak	F W H M		Area of peak	
		$Ca(OH)_2$ 4.92 Å	Ettringite 9.09 Å	$Ca(OH)_2$ 4.92 Å	Ettringite 9.09 Å	$Ca(OH)_2$ 4.92 Å	Ettringite 9.09 Å
SA	360	90	50	0.165	0.160	348	107
SB	360	60	30	0.155	0.410	226	80
SC	360	32	41	0.290	0.140	79	63
SD	360	68	56	0.185	0.075	243	121
SE	360	55	38	0.145	0.145	88	57

Although the research on influence mechanism of CNI on sulfate resistance of high performance concrete is limited, to guarantee the accuracy, the calcium hydroxide contents at the ages of 3, 28 and 240 days were also measured for four paste mixtures, pure cement paste, 70% cement plus 30% fly ash paste, 90% cement plus 10% MS paste, and cement plus 1.5% CNI paste. The results are shown in Fig. 11. As can be seen from the figure, the calcium hydroxide in cement paste containing CNI is the highest in all the mixtures for all the ages. On the contrary, at the age of three days, although the calcium hydroxide content in fly ash-cement paste is slightly higher than that in pure cement paste due to the mineral dispensing effect, as age increases, the calcium hydroxide content in fly ash-cement paste gradually becomes lower than that in pure cement paste. The crystal content in paste containing microsilica is the lowest among all mixtures at all ages. This means that microsilica is highly pozzolanic.

Summarizing the researches on hydration reaction and hydration products in paste and concrete samples, conclusion can be drawn that the incorporation of CNI into high performance concrete has an obvious influence on the relative content of hydration products. The content of calcium hydroxide and ettringite crystals increases with the addition of CNI. This could cause the deterioration of mixtures resistance to sulfate attack.

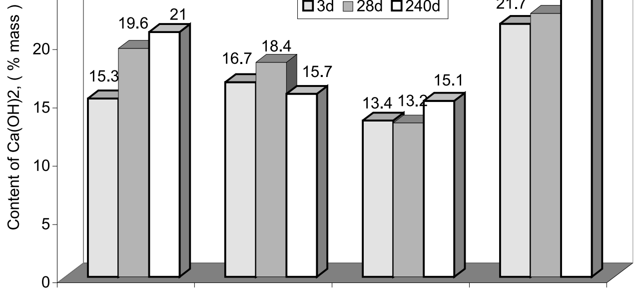

Fig. 11. QXRD results of content of $Ca(OH)_2$ in different pastes.

3.3. The CNI influence on micropores of hardened cement

The sulfate resistance of high performance concrete has a close relation with the microstructures of hardened cement. The larger pore size and higher pore volume can accelerate the diffusion of sulfate ions into the inner part of the concrete, which fastens the deteriorating process and leads to obvious decrease of concrete durability. To study the influence of CNI addition on sulfate resistance of concrete, the microstructure change caused by CNI addition should be investigated.

The micropore of cement paste with 30% addition of fly ash by weight, cement paste containing 1.5% of CNI by weight and pure cement paste at the ages of 3 and 91 days are measured using MIP and the results are shown in Figs. 12 and 13. As can be seen from Fig. 12, the order of the cumulative pore volumes of the three pastes at age of three days are as follows:

$$\mathrm{SD}(1.5\%\ \mathrm{NCI}) > \mathrm{SB}(30\%\ \text{fly ash}) > \mathrm{SA}(\text{pure cement}).$$

This demonstrates that, with the same water binder ratio (0.3), the cement paste containing CNI has the largest pore volume. The testing results of QXRD verify that

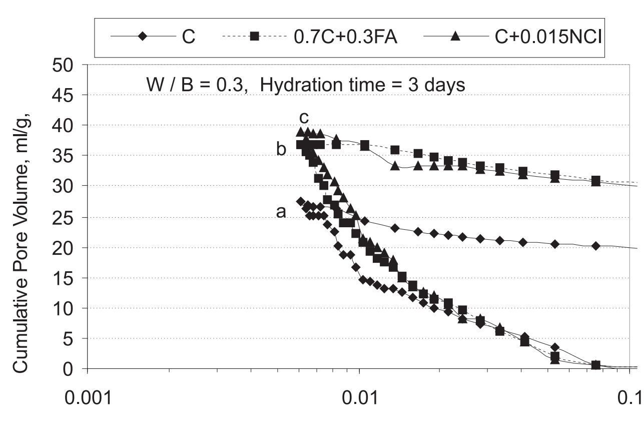

Fig. 12. MIP results for the different pastes at three days.

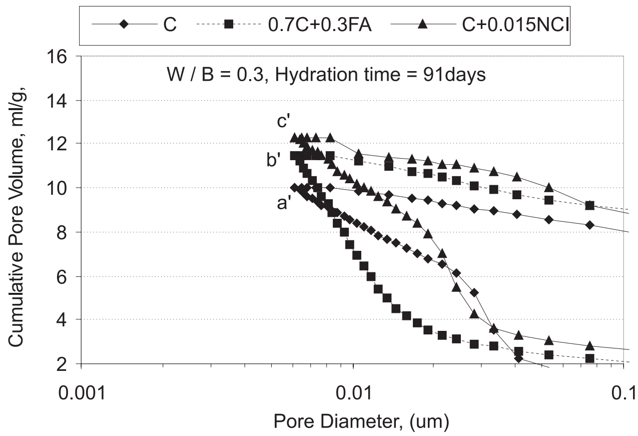

Fig. 13. MIP results for the different pastes at 91 days.

that the addition of CNI increases the crystal quantity produced in the mixture, which leads to the increase of micropore volume and diameter.

The test results in Fig.13 demonstrate that as age increases, the cumulative pore volume in all pastes decreases to different levels although the diameter range is similar to that at the age of three days. Compared with the curves in Fig. 12, further observation reveals that the upward parts of the curves of the three pastes are different. The curves of fly ash-cement paste moves towards the direction of small pore. The pore diameter distribution decreases from 0.04 to 0.02 μm, or even smaller. The pore distributes in the range of 60 to 200 Å. This means that, with the same pore volume, the portion of small pore in paste containing fly ash increases with age. This may be attributed to the formation of C–S–H gel from reaction between silicon–aluminum glassy particles and calcium hydroxide generated by cement hydration.

This observation verifies that mineral admixture with high activity is important to the improvement of concrete resistance to sulfate attack. The improvement in sulfate resistance from the incorporation of low calcium and high fineness fly ash might be attributed to the four factors:

(a) *Unit volume effect*: The incorporation of fly ash reduced the relative content of C_3S and C_3A in unit volume of the mixture. For this reason, the quantity of calcium hydroxide and ettringite produced is reduced. While for mass concrete, the probability of thermal crack caused by hydration reaction at early stage also decreases.

(b) *Secondary hydration reaction*: The pozzolanic silicon–aluminum glassy particles in fly ash react with the calcium hydroxide in cement, and produce low alkali C–S–H gel. This process refines the microstructure of hardened cement paste, and further reduces the calcium hydroxide content which is the main crystal causing expansion. At the same time, the diffusion rate of aggressive sulfate ions is also slowed.

(c) *Mini Powder Effect*: The small glassy particles (diameter smaller than 15 μm) in fly ash refine the interface of the grains and the distribution direction of calcium hydroxide crystals and the filling effect has the mini powder function on unhydrated particles in cement. So the sulfate resistance of mixture is improved.

(d) *The strong binding capability*: Fly ash has larger specific surface area and hollow inner structure. They have strong physisorption and chemisorption effect on sulfate ion. This mechanism prevents the sulfate attack on concrete.

The micropore structure of paste containing CNI is different from that of fly ash-cement paste. As can be seen from Fig. 13, on one hand, the cement paste containing CNI has the largest cumulative pore volume; On the other hand, the upwards part of the curve shows that big pores with diameter from 0.03 to 0.1 μm exist. This result demonstrates that the incorporation of CNI accelerates the formation of crystals. And after the crystals are produced, they are stabilized. This function of CNI leads to the formation of big pores in the mixture, which increases the cumulative pore volume and the quantity of hydration products reacting with sulfate ions. This process causes the increase of probability of crack propagation due to expansion, and fastens the diffusion rate of sulfate ions. All these factors cause the degradation in sulfate resistance of concrete. So CNI should be used cautiously in practical engineering, especially when high resistance to sulfate resistance is required.

3.4. The influence of CNI on microstructure of hardened cement paste

Based on the testing results of QXRD and mercury intrusion porosimetry, the scanning electronic microscopy observation was made with specimens of water binder ratio of 0.3. The test was done at the ages of 28 days. The results are shown in Figs. 14–19.

The image characteristics of mixtures SA, SB and SD are shown in Figs. 14, 16 and 18. As can be seen from Fig. 14, the main hydration products in pure cement paste are cotton-shaped C–S–H gel and plate-shaped calcium hydroxide. Fig. 16 shows that hydration products do not change obviously when fly ash is incorporated into the mixture. But spherical glassy particles of various sizes can be observed, and secondary hydration reaction takes place on part of the particles surface. The SEM observation in Fig. 18 shows that the microstructure of paste changes greatly with the incorporation of CNI. A lot of plate-shaped and short column-shaped calcium hydroxide crystal exists on the surface of the particles. These observations are in agreement with the testing results of QXRD and MIP. The differences

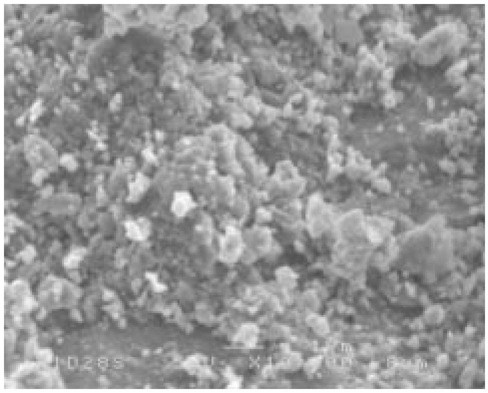

Fig. 14. SEM images of SA sample, ×1000.

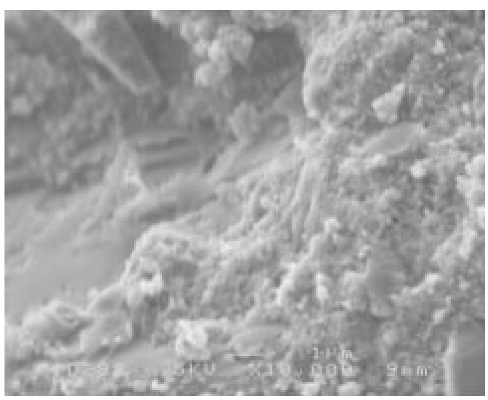

Fig. 15. CSH and $Ca(OH)_2$ in SA sample, ×10,000.

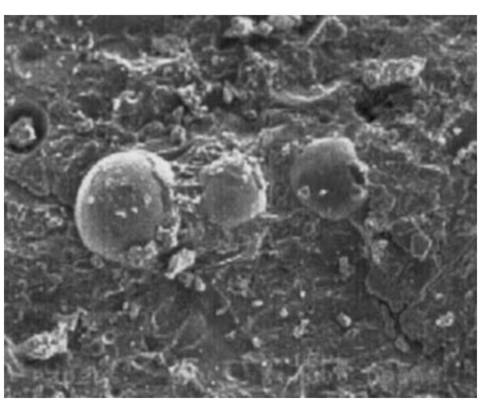

Fig. 16. SEM images of SB sample, ×1000.

discussed above can be observed more clearly by increasing the magnitude (Figs. 15, 17 and 19). Fig. 15 shows the C–S–H gel image in mixture SA. Fig. 17 shows the hydration products both in and on the surface of fly ash particles where secondary hydration reaction takes place. Fig. 19 shows that a lot of hexagon plate-shaped and short column-shaped calcium hydroxide crystals are produced in the sample containing CNI.

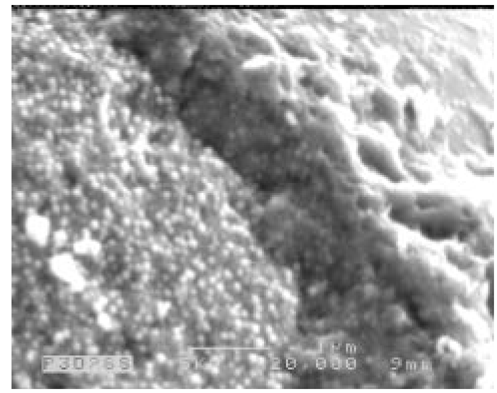

Fig. 17. The hydrating surface of fly ash particle in SB sample, ×20,000.

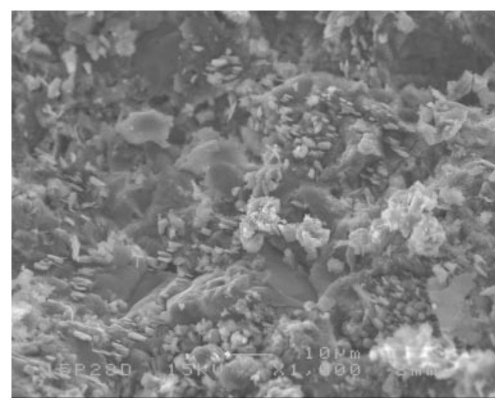

Fig. 18. SEM images of SD sample, ×1000.

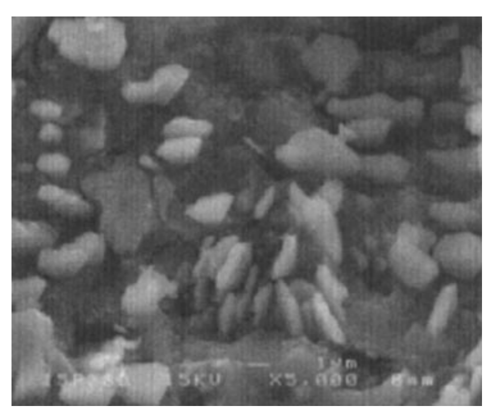

Fig. 19. $Ca(OH)_2$ in SD sample, ×5000.

The SEM observations on microstructure images verify that the incorporation of CNI accelerates the formation of calcium hydroxide and ettringite crystals in the samples. The increase of these hydrated crystal structure leads to the microstructure change of hardened cement pastes. This mechanism weakens the effect of pore refinement caused by the secondary hydration reaction of fly ash and microsilica. For these reasons, the CNI addition degrades the mixtures' resistance to sulfate attack.

4. Conclusions

The following conclusions can be summarized based on the experimental results in this study:

1. The incorporation of CNI into the high performance concrete weakens their resistance to sulfate attack. In the current investigation, with 15 l/m^3 addition of CNI into the mixtures, the expansion of concrete containing fly ash with or without microsilica increases 52% and 30%, respectively. According to Frearson's evaluation standard, the incorporation of CNI degrades the mixture from Sulfate Resisting Concrete to Fairly Sulfate Resisting Concrete.
2. The addition of CNI into high performance concrete obviously accelerates the formation of calcium hydroxide and ettringite crystals. High content of calcium hydroxide and ettringite crystals fastens the eroding process of sulfate ions, and weakens the mixtures' resistance to sulfate attack.
3. The addition of CNI obviously changes the microstructure of mixtures. Both cumulative pore volume and portion of big pores increase. This phenomenon demonstrates that CNI weakens the micropore refinement effect caused by the secondary hydration reaction of fly ash and microsilica. This mechanism causes the deterioration in sulfate resistance of high performance concrete containing CNI.
4. The test results in this paper show that CNI weakens the mixtures' resistance to sulfate attack. In practical engineering, CNI should be used cautiously, especially when high resistance to sulfate attack is required.

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