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Effects of nano silica on carbonation resistance of concrete

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Abstract. In tandem with recent development of nanotechnology and reduction in cost of production, many nano-materials have been tried in concrete. In this study, the effect of nano silica (NS) on the carbonation resistance of concrete was investigated by producing a number of trial concrete mixes with varying water and NS contents for carbonation depth test. The results demonstrated that the addition of NS could significantly reduce the 28-day and 56-day carbonation depths of concrete, indicating that NS may be a promising supplementary cementitious material for producing high-performance concrete.

1 Introduction

To produce high-performance concrete (HPC), supplementary cementitious materials (SCM), including fly ash, silica fume, granulated blast furnace slag, is typically an essential ingredient [1-3]. In tandem with recent development of nanotechnology and reduction in cost of production, many nano-materials have been tried in concrete [4-6]. Among them, nano-silica (NS), benefiting from its nano size and very high pozzolanic reactivity, has shown its potential in producing concrete [7-11].

In the study presented herein, a series of trial concrete mixes with various water/cementitious materials (W/CM) ratios, NS contents and superplasticizer (SP) dosages were made for workability test and carbonation test. On the basis of the carbonation test results, the effects of NS in respect of the carbonation resistance of concrete were evaluated.

2 Experimental programme

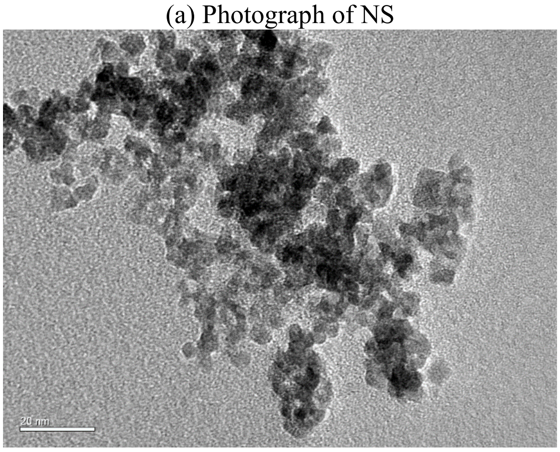
2.1 Materials

Two cementitious materials, namely: ordinary Portland cement (OPC) and nano-silica (NS), were used in the current study. The OPC was of strength class 52.5N and specific density of 3.11. The NS employed was in white powder form (as shown in Figure 1(a)) and with specific density of 1.94 and particle size ranging from 5 to 20 nm (as shown in Figure 1(b)).

Two aggregates, namely: fine aggregate and coarse aggregate were employed for making the concrete mixes. One was river sand fine aggregate with maximum size of 5 mm, relative density of 2.64, moisture content of 0.11% and water absorption of 1.10%. The other one was crushed granite rock coarse aggregate with maximum size of 10 mm, relative density of 2.68, moisture content of 0.11% and water absorption of 1.04%.

To achieve sufficient workability, a superplasticizer (SP) was dosed to each concrete mix. The SP was a third generation polycarboxylate-based SP. It was in liquid form and had relative density of 1.08 and solid mass content of 20%.

(a) Photograph of NS



(b) Microscopy image of NS

Fig. 1. Photograph and microscopy image of NS

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2.2 Mix designs

A serial of concrete mixes were designed. Three mix parameters, including the W/CM ratio, NS content and SP dosage were varied. The W/CM ratio was varied from 0.30 to 0.45 by mass in steps of 0.05, the NS content (expressed as a percentage by mass of total cementitious materials) was varied among 0%, 0.5% and 1%. To ensure that all the concrete mixes have reasonably good and similar workability of slump within 100 to 200 mm, the SP dosage was not fixed but determined by trial mixing during which the SP was dosed bit by bit until the target range of slump was achieved. The SP dosage (also expressed as a percentage by mass of total cementitious materials) so determined was then applied in the formal production of concrete mixes for testing. On the other hand, the paste volume (volumetric ratio of cementitious paste to concrete) was fixed at 30% and the fine to total aggregate ratio by mass was fixed at 0.4. For ease of reference, each concrete mix was given a label in the form of X-Y, where X and Y are respectively the W/CM ratio and NS content in %.

2.3 Testing methods

The slump cone test stipulated in Chinese Standard GB/T 50080-2016 was performed to measure the workability of the fresh concrete in terms of slump. The test procedures were as follows: fill the slump cone with fresh concrete mix until full, lift the slump cone vertically and smoothly, and finally measure the drop in height of the concrete mix as the slump value.

The carbonation test stipulated in British Standard BS EN 14630:2006 was carried out to evaluate the carbonation resistance of the hardened concrete. After curing for 26 days, heating for 2 days, the specimens were placed into carbonation chamber to carry out carbonation for 28 days or 56 days. After that, the specimens were split along the direction of carbonation depth and sprayed with phenolphthalein alcohol solution. The carbonation depth was determined as the average depth of the colourless zone.

3 Test results

3.1 SP dosage and slump

The SP dosages applied in the actual production of the concrete mixes are tabulated in the second column of Table 1, and plotted against the NS content for different W/CM ratios in Figure 2. Since the SP served the purpose to adjust the workability to within the target range, the SP dosage reflected the influence of various mix parameters on the workability. For example, regardless of the NS content, the higher was the W/CM ratio, the lower was the SP dosage. For instance, when NS content was 0.5%, increasing the W/CM from 0.30 to 0.45 would reduce the SP dosage from 5.00% to 0.50%, whereas when NS content was 1%, increasing the W/CM from 0.30 to 0.45 would reduce the SP dosage from 5.40% to 0.83%. Such phenomenon is expected as a result of increasing the W/CM ratio.

Conversely, at given W/CM ratio, the SP dosage gradually increased when the NS contents increased. For instance, at W/CM ratio of 0.30, increasing the NS content from 0% to 1% would increase the SP dosage from 4.50% to 5.40%, whereas at W/CM ratio of 0.45, increasing the NS content from 0% to 1% would increase the SP dosage from 0.30% to 0.83%. This was due to the very large specific surface areas of the ultrafine NS particles, which demanded much more SP to disperse than the OPC particles.

Although the SP dosage was adjusted such that the workability was within the target range, the measured slump varied slightly due to the addition of the SP in increments. For record purpose, the slump results are summarised in the third column of Table 1, where it can be seen that the slump varied from 130 to 181 mm, all within the target range of 150±50 mm.

Table 1. Test results of concrete mixes

Mix no.	SP dosage (%)	Slump (mm)	28-day carbonation depth (mm)	56-day carbonation depth (mm)
0.30-0	4.50	140	4.2	5.9
0.30-0.5	5.00	158	3.7	5.5
0.30-1	5.40	130	3.5	5.1
0.35-0	2.40	157	6.7	9.2
0.35-0.5	2.60	160	5.2	7.4
0.35-1	3.00	150	4.2	6.6
0.40-0	0.70	181	10.6	14.6
0.40-0.5	0.85	175	8.2	11.6
0.40-1	1.18	169	6.5	10.0
0.45-0	0.30	125	17.9	22.7
0.45-0.5	0.50	120	12.6	18.0
0.45-1	0.83	110	9.7	15.1

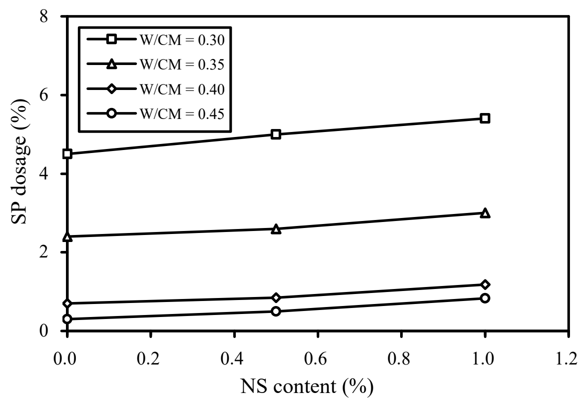

Fig. 2. SP dosage versus NS content

3.2 Carbonation depth

The 28-day and 56-day carbonation depth results are respectively listed in the fourth and fifth columns of Table 2, and plotted against the NS content for different W/CM ratios in Figures 3 and 4.

Comparing these two figures, it is obvious that as the carbonation time increased from 28 days to 56 days, the carbonation depth generally increased. For example, for the concrete mix 0.30-0.5, the 28-day carbonation depth was 3.7 mm and 56-day carbonation depth was 5.5 mm, whereas for the concrete mix 0.45-1, the 28-day carbonation depth was 9.1 mm and 56-day carbonation depth was 15.1 mm

Comparing the curves in the same figure, it is also obvious that at given NS contents, both the 28-day and 56-day carbonation depths decreased with increasing W/CM ratio. For example, For instance, when NS content was 0.5%, increasing the W/CM from 0.30 to 0.45 would reduce the 28-day carbonation depth from 3.7 mm to 12.6 mm and reduce the 56-day carbonation depth from 5.5 mm to 18.0 mm, whereas when NS content was 1%, increasing the W/CM from 0.30 to 0.45 would reduce the 28-day carbonation depth from 3.5 mm to 9.7 mm and reduce the 56-day carbonation depth from 5.1 mm to 15.1 mm.

More importantly, at given W/CM ratio, both the 28-day and 56-day carbonation depths significantly decreased with increasing NS content. For example, at W/CM ratio of 0.30, increasing the NS content from 0% to 1% would decrease the 28-day carbonation depth from 4.2 mm to 3.5 mm and decrease the 56-day carbonation depth from 5.9 mm to 5.1 mm, whereas at W/CM ratio of 0.45, increasing the NS content from 0% to 1% would decrease the 28-day carbonation depth from 17.9 mm to 9.7 mm and decrease the 56-day carbonation depth from 22.7 mm to 15.1 mm. It is indicated that the addition of NS had effectively improve the carbonation resistance.

To quantify the effects of NS on carbonation resistance, the percentage decreases in 28-day and 56-day carbonation depths are calculated and listed in Tables 2 and 3, respectively. From these tables, it is evident that at given NS contents, the percentage decreases in 28-day and 56-day carbonation depths were generally larger at higher W/CM ratio. Particularly, at a W/C ratio of 0.30, the addition of 1% NS decreased the 28-day carbonation depth by 16.7% whereas at a W/C ratio of 0.45, the addition of 1% NS decreased the 28-day carbonation depth by 45.7%. Similarly, at a W/C ratio of 0.30, the addition of 1% NS decreased the 56-day carbonation depth by 12.6% whereas at a W/C ratio of 0.45, the addition of 1% NS decreased the 56-day carbonation depth by 35.5%. Therefore, the effectiveness of adding NS to mitigate carbonation was higher when the W/CM ratio was higher.

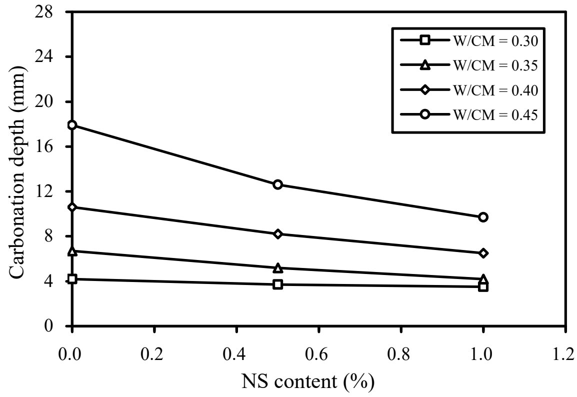

Fig. 3. 28-day carbonation depth versus NS content

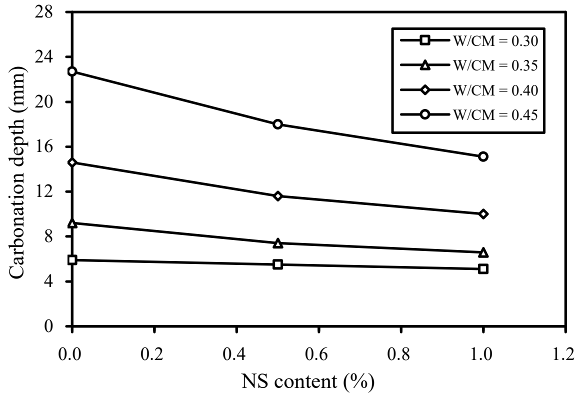

Fig. 4. 56-day carbonation depth versus NS content

Table 2. Percentage decrease in 28-day carbonation depth due to addition of NS

Due to addition of	Percentage decrease in 28-day carbonation depth			
	W/CM = 0.30	W/CM = 0.35	W/CM = 0.40	W/CM = 0.45
0.5% NS	11.0	23.0	23.2	29.4
1% NS	16.7	36.8	38.7	45.7

Table 3. Percentage decrease in 56-day carbonation depth due to addition of NS

Due to addition of	Percentage decrease in 56-day carbonation depth			
	W/CM = 0.30	W/CM = 0.35	W/CM = 0.40	W/CM = 0.45
0.5% NS	6.8	20.0	20.2	20.8
1% NS	12.6	28.2	31.3	33.5

4 Conclusion

The effects of NS on the carbonation resistances of concrete have been studied by testing trial concrete mixes with varying W/CM ratio, NS content and SP dosage for their slump and 28-day and 56-day carbonation depths. The research findings are summarised in the following:

(1) As expected, higher W/CM ratio would require lower SP dosage to achieve the target slump of

150±50 mm and cause the reduction of carbonation resistance.

(2) The addition of NS would increase the SP dosage required to achieve the target slump.

(3) The addition of NS would improve the carbonation resistance as demonstrated by reduced 28-day and 56-day carbonation depths.

(4) The effectiveness of adding NS to mitigate carbonation would be higher when the W/CM ratio is higher.

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