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INFLUENCE OF NANOSILICA AND MICROSILICA ON PROPERTIES OF CONCRETE

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In this study, supplementary cementing materials (SCM), such as nanosilica and microsilica, have been evaluated for optimal levels of replacement as a blending material in cement. The physical and chemical properties of these materials were first analyzed, then the properties of neat samples, mortar samples, and concrete samples were investigated. Mainly this study focused on the workability and compressive strength with different mixes at different ages of neat, mortar and concrete mixes. Test results obtained in this study indicate that up to 5% nanosilica and 10% of microsilica could be advantageously blended with cement without adversely affecting the strength. However, optimum levels of these materials are 1-3% of nanosilica and 3-8% of microsilica when we consider the strength of concrete.

Keywords: Nanosilica, Microsilica, High-strength concrete, High-performance concrete.

1 INTRODUCTION

The aim of this paper is to present the latest findings in the properties and application of nanosilica and microsilica as Supplementary Cementing Materials (SCM). Supplementary cementing materials (SCM) improve concrete properties mainly in two ways: First, they help to generate more Calcium Silicate Hydrate (CSH) in the secondary reaction with $Ca(OH)_2$, and second, it provides denser concrete due to better particle packing (Neville 1995).

2 EXPERIMENTAL PROGRAM

First, the chemical compositions of cement and SCM were analyzed. Second, research was carried out in 3 different categories to identify the effects of nanosilica and microsilica additives in concrete: neat testing, mortar testing, and concrete testing.

2.1 Chemical Analysis

Percentages of silicon dioxide (SiO_2), aluminum oxide (Al_2O_3), ferric oxide (Fe_2O_3), calcium oxide (CaO), magnesium oxide (MgO), sulfur trioxide (SO_3), sodium oxide (Na_2O) and potassium oxide (K_2O) were measured individually using X-ray fluorescence (XRF) analyzer according to the EN 196-2 standard.

2.2 Neat Testing

Testing was carried out for fixed water to cement (w/c) cement ratio of 0.3 according to ASTM standards.

In test N1, pure OPC cement was used in mix.

In test N2 and N3, cement was replaced by 2% and 4% of microsilica.

In test N4 and N5, cement was replaced by 2% and 4% of nanosilica.

2.3 Mortar Testing

First, consistency and setting time of cement pastes were measured. The initial and the final setting times of the cement paste were checked according to the ASTM 191-08 through measuring the periodic penetration of the Vicat needle through the paste.

In test M1-M9, the compressive strength of mortar prism (160 mm x 40 mm x 40 mm) were prepared and compressive strengths tested at the different ages according to EN standards (i.e., ages of 1 day, 3 days, 7 days, 28 days, 60 days and 90 days) (Priyadarshana and Dissanayake 2013).

2.4 Concrete Testing

150 mm x 150 mm x 150 mm cubic test specimens were prepared according to EN standards. The compressive strength of concrete cubes were tested at 7 days, 28 days, 60 days and 90 days for compressive strength. The components were: concrete mix (G35 concrete); cement 435 kg (cement was replaced in different percentage (1% - 50%) of SCM); water 174 kg; sand 774 kg; gravel 1026 kg (20mm aggregates); and admixtures 4350 ml (super plasticizer).

In test C1, pure OPC cement was used in the concrete mix.

In test C2-C6, cement was replaced by 1%, 3%, 5%, 10%, and 20% respectively of microsilica.

In test C7-C9, cement was replaced by 1%, 3%, and 5% respectively of nanosilica.

In test C10-C15, cement was replaced by 5%, 10%, 20%, 30%, 40%, and 50% respectively of fly ash (Portland Concrete Association, undated).

3 RESULTS AND DISCUSSION

3.1 Chemical Analysis

According to the chemical analysis (see Table 1), nanosilica and microsilica have a purity of 99.59% and 98.93% respectively. Cement has combined properties of 64.2% C3S, 10.4% C2S, 7.2% C3A, and 9.9% C4AF with fineness of 3450cm2/g. Microsilica has an average particle size of 150µm, and in this case was bought from a local supplier. Nanosilica has an average particle size of 10nm, and in this case was bought from a Chinese supplier.

Table 1. Chemical compositions of cement and Supplementary Cementing Materials.

	SiO_2 (%)	**Al_2O_3 (%)**	**Fe_2O_3 (%)**	**CaO (%)**	**MgO (%)**	**SO_3 (%)**	**K_2O (%)**	**Na_2O (%)**
Cement	20.38	4.79	3.26	64.40	0.98	2.21	0.04	-
Microsilica	98.93	-	0.31	-	0.17	-	-	0.57
Nanosilica	99.59	-	0.33	-	0.06	-	-	-

3.2 Neat Testing

According to test results, neat paste does not indicate any better performance for nanosilica and microsilica. This could be probably due to shrinkage and subsequent cracking of neat cement. Over time, mortar tests have been found to provide a better indication of cement quality, thus tests on neat cement pastes are typically used only for research purposes (Mindess and Young 1981)

3.3 Mortar Testing

According to test M1-M9 results (see Tables 2 and 3), microsilica performs better than nanosilica in all the cases, very similarly to the neat tests. However, when the percentage of nanosilica in the mix is increased, the strength of mortar decreases in all the cases very similar to neat sample tests.

Therefore, concrete tests are needed to see the behavior of nanosilica and microsilica in real applications. Both neat tests and mortar tests may not perform well due to higher finer material in the mix. The surface area of the materials is very high to adhere initially with cement and water slurry in the initial stage.

Table 2: Results of mortar testing of nanosilica without admixtures (EN method).

	Sample Ref.	**Compressive Strength (MPa)**					
		1D	**2D**	**7D**	**28D**	**60D**	**90D**
M1	OPC Reference Test	20.5	29.4	44.5	57.7	60.0	64.0
M2	Nanosilica 2%	20.0	28.6	43.4	56.9	58.1	61.9
M3	Nanosilica 4%	17.1	27.1	42.4	51.7	55.5	58.9
M4	Nanosilica 6%	14.8	22.0	34.5	48.4	50.0	52.8
M5	Nanosilica 8%	11.3	17.5	32.4	36.5	40.6	42.7

Table 3: Results of mortar testing of microsilica without admixtures (EN method).

	Sample Ref.	Compressive Strength (MPa)					
		1D	**2D**	**7D**	**28D**	**60D**	**90D**
M1	OPC Reference Test	20.5	29.4	44.5	57.7	60.0	64.0
M6	Microsilica 2%	20.8	30.4	45.8	59.0	63.9	67.3
M7	Microsilica 4%	21.0	31.2	47.9	62.5	65.4	67.2
M8	Microsilica 6%	20.8	31.4	48.0	65.8	67.1	69.3
M9	Microsilica 8%	20.6	30.2	48.2	66.4	67.5	68.2

3.4 Concrete Testing

Concrete testing with nanosilica (see Table 4 and Figure 1) show that cement can be replaced up to 5% by nanosilica without the concrete losing strength at late ages (i.e., 60 days and 90 days). However, the early strength of concrete is badly affected by nanosilica in all cases. The optimal amount of nanosilica in concrete would be 1-3% considering cost and optimum benefits. The limitation of nanosilica replacement was mainly decided by concrete properties and the high price of material; thus it is not cost-effective to replace higher amount of cement with nanosilica. Most of the literature recommends using 2-3% nanosilica in concrete.

Table 4. Compressive strength of concrete with microsilica.

		7-day compressive strength (MPa)	**28-day compressive strength (MPa)**	**60-day compressive strength (MPa)**	**90-day compressive strength (MPa)**
C1	Controlled Sample	46.3	57.7	59.3	62.1
C2	Microsilica 1%	48.7	57.4	60.2	61.7
C3	Microsilica 3%	50.1	62.2	63.0	63.9
C4	Microsilica 5%	48.9	62.1	63.2	65.1
C5	Microsilica 10%	52.6	57.7	60.4	61.6
C6	Microsilica 20%	49.3	54.0	55.4	58.7

Concrete testing with nanosilica (see Table 5 and Figure 2) shows that cement can be easily replaced by microsilica up to 10% without losing strength of concrete at all ages. The optimal amount of microsilica in concrete would be 3-8%. The main issue when dealing with microsilica is losing workability of concrete mix at higher percentages of microsilica. High-range super plasticizers are always recommended to be used with microsilica. The maximum percentage of possible silica fume for a workable mix was 20% with a maximum recommended amount of super plasticizers. Most of the literature recommends 5-8% microsilica in concrete. Some standards recommend a maximum percentage of microsilica at 11%.

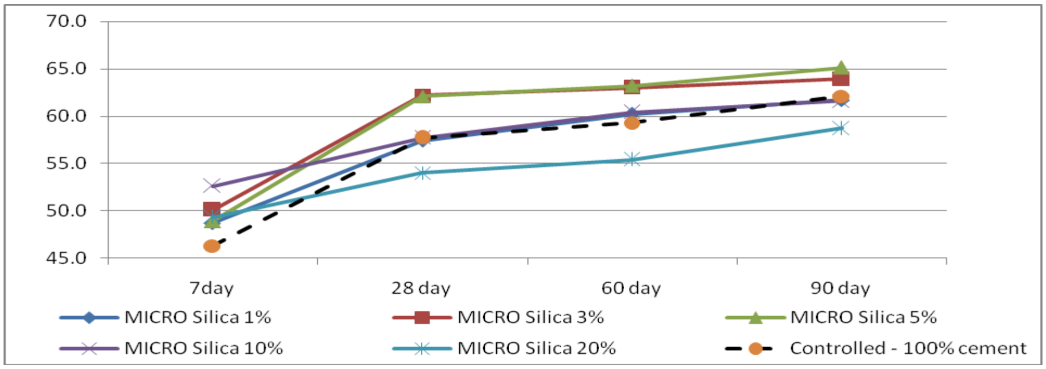

Figure 1. Compressive strength of concrete with microsilica.

Table 5. Compressive strength of concrete with nanosilica.

Test No.	Cement replacement %	7day compressive strength (MPa)	28day compressive strength (MPa)	60day compressive strength (MPa)	90day compressive strength (MPa)
C1	Controlled Sample	46.3	57.7	59.3	62.1
C7	Nanosilica 1%	45.3	60.8	61.7	63.0
C8	Nanosilica 3%	44.6	57.9	60.7	62.6
C9	Nanosilica 5%	41.4	54.6	59.5	63.8

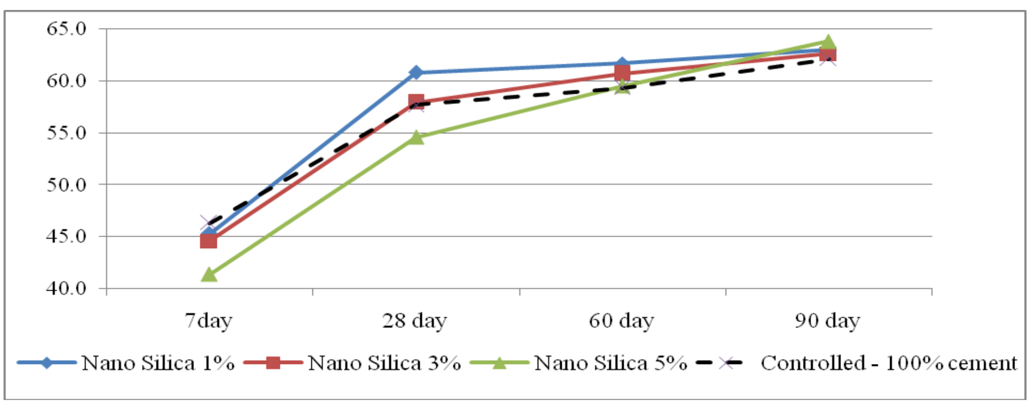

Figure 2. Compressive strength of concrete with nanosilica.

4 CONCLUSIONS

Microsilica with fly ash is used in most of the high-rise building projects in the world to get higher strength and extended durability. However, nanosilica is still new to the construction industry due to its availability and cost. It seems that some cheap materials like fly ash can give results comparative to microsilica and nanosilica in concrete mixes. Thus it is always recommended to consider the possibility of adding cheaper SCM like fly ash (probably up to 20%) before introducing microsilica and nanosilica into the concrete system.

As an example, if we study the mix design of the world tallest building, the Burj Dubai (Baker et al. 2007), the fly ash percentage in the Grade 80 concrete, used for columns and walls at floors 109~126, were as high as 100 kg (18%) with 50 kg (9%) of microsilica. The usage of cement in this mix design was as low as 400 kg, and other materials were sand 830 kg, coarse aggregates (10mm) 847 kg, and admixtures 3%; the water/binder ratio was 0.3. So it is not recommended to only increase the cement content to enhance strength and other properties of concrete. There will always be a better option with blended cement or blended materials with ordinary Portland cement.

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