Effects of titanium dioxide nanopowder on rheological properties of self compacting concrete

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Abstract: In the present study, rheological, mechanical, thermal and transport properties of self compacting concrete (SCC) with different amount of titanium dioxide (TiO2) nanopowder have been investigated. TiO2 nanopowder up to 5 wt % were partially added to self compacting concrete and various rheological properties of the concrete have been measured. Rheological properties were investigated through slump flow time and diameter, V-Funnel flow time and L-box tests. The results showed that addition of nanopowder can lead to more consistency and homogeneity of the fresh mix and less bleeding and segregation.

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1. Introduction

Self-compacting concrete (SCC) is also considered as a concrete which can be placed and compacted under its own weight with little or no vibration without segregation or bleeding. It is used to facilitate and ensure proper filling and good structural performance of restricted areas and heavily reinforced structural members. It has gained significant importance in recent years because of the advantages it offers [1–4]. Many researchers have used SCC containing admixtures to satisfy the great demand for fines needed for this type of concrete, thereby improving its mechanical, rheological and durability properties in comparison with normal vibrated concrete (NVC). Siddique [5] investigated the properties of SCC made with different amounts of fly ash. El-Dieb [6] studied mechanical and durability properties of ultra high strength-fiber reinforced concrete (UHS-FRC) with self compacting characteristics. According to Fava et al. [7], in SCCs with ground granulated blast furnace slag (GGBFS), strength increase can be achieved. Kulakowski et al. [8] reviewed the silica fume influence on reinforcement corrosion in concrete and the effect of metakaolin on transport properties of concrete were also investigated by Shekarchi et al [9]. There are several works on incorporating nanoparticles into concrete specimens to achieve improved physical and mechanical properties such as using SiO_2 nanoparticles in mortars and cement-based materials [10–12], normal concrete [13,14] and high performance self compacting concrete [15].

Incorporating of TiO_2 nanoparticles has been addressed in some of the works considering the properties of NVCs [16]. The flexural fatigue performance of concrete containing TiO_2 nanoparticles for pavement has experimentally been studied by Li et al. [17]. They showed that the flexural fatigue performance of concretes containing TiO2 nanoparticles is improved significantly and the sensitivity of their fatigue lives to the change of stress is also increased. In addition, the theoretic fatigue lives of concretes containing TiO_2 nanoparticles are enhanced in different extent. With increasing stress level, the enhanced extent of theoretic fatigue number is increased [17]. The abrasion resistance of concrete containing TiO_2 nanoparticles for pavement has been experimentally studied [18]. The abrasion resistance of concretes containing TiO_2 nanoparticles is significantly improved. The enhanced extent of the abrasion resistance of concrete is decreased by increasing the content of TiO_2 nanoparticles [18]. The hydration kinetics of titania-bearing tricalcium silicate phase has been studied [19]. Nano-TiO_2-doped tricalcium silicate (C3S) was obtained by repeated firing of calcium carbonate and quartz in the stoichiometric ratio of 3:1 in the presence of varying amounts of titanium dioxide from 0.5 to 6% by weight. The study revealed that the presence of up to 2% TiO_2 has an inhibiting effect on the rate of hydration of C3S [19].

In this paper, the effects of TiO_2 nanopowder addition into cementitious binder by 1 up to 5 wt% on rheological properties of self compacting concrete have been investigated through slump flow time and diameter, V-Funnel flow time and L-box tests.

2. Materials

An ASTM Type II Portland cement (PC) was used to produce the various SCC mixtures. Table 1 summarizes physical properties and chemical composition of the cement used.

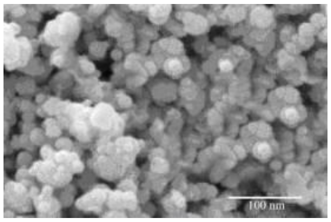

Fig. 1. SEM micrograph of TiO2 nanopowder

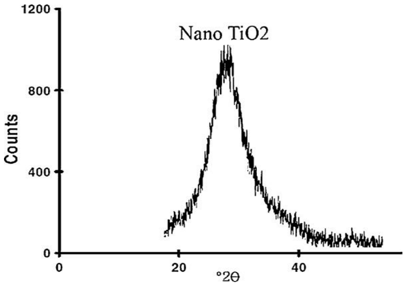

Fig. 2. XRD spectrum of TiO2 nanopowder

Scanning electron microscopy (SEM) micrograph and powder X-ray diffraction (XRD) spectrum of TiO_2 nanopowder are shown in Figs. 1 and 2.

The nanopowder properties are presented in table 2. The coarse aggregate used was limestone gravel with a nominal maximum size of 12.5 mm. As fine aggregate, a mixture of silica aggregate sand and crushed limestone (as filler) was used with a maximum size of 4.75 mm. physical properties of the filler, fine and coarse aggregates are presented in table 3. All aggregates in this research were used in dry form and the aggregates are a mixture of eight particle sizes of fine and coarse aggregates. A polycarboxylic-ether type superplasticizer (SP) with a specific gravity of between 1.06 and 1.08 was employed to achieve the desired workability in all concrete mixtures. Furthermore viscosity modifying agent (VMA) for better stability was used.

Table 1. Chemical composition and physical properties of cement

Chemical analysis (%)	Sio2	Al2O3	Fe2O3	CaO	MgO	SO3	K2O	Na2O	Loss of ignition	Specific gravity	Blaine fineness (cm2/g)
Cement	20<	6<	6<	<50	<5	<3	<1	<1	<3	3.15	3260

Table 2. Properties of TiO2 nanopowder

Diameter (nm)	Surface volume ratio (m^2/g)	Density (g/cm^3)	Purity (%)
15±3	165±17	<0.15	>99.9

Table 3. Sieve analysis and physical properties of the filler, fine and coarse aggregates

Sieve size (mm)	Filler (%passing)	Fine aggregate (%passing)	Coarse aggregate (%passing)
12.5	100	100	97.9
9.5	100	100	79.3
4.75	100	98.38	13.2
2.36	100	76.45	0
1.18	100	46.65	0
0.6	100	39.32	0
0.3	100	15.26	0
0.15	90.9	3.62	0
0.075	33.7	0	0
Bulk density (kg/m^3)		1460	1450
Specific gravity (g/m^3)		2.619	2.6
Absorption (%)	8	2.72	0.4

3. Mix proportions

A total number of 6 concrete mixtures were designed with a constant water/binder (w/b) ratio of 0.38 and total binder content of 450 kg/m^3. Concrete mixtures were prepared with 0, 1, 2, 3, 4 and 5 wt% of cement replacement by TiO_2 nanopowder. The mixture proportions of concrete and binder paste are given in table 4.

Since the SP plays a very important role in the flowability of SCC mixes, a modified mixing procedure was adopted to take the benefit of action of adsorption of molecules of poly-carboxylic ether based SP on the cement particles for all the mixes. SCC mixtures were prepared by mixing the coarse aggregates, fine aggregates and powder materials (cement and nanopowder) in a laboratory drum mixer. The powder material and aggregates were mixed in dry form for 2 minutes. Then half of the water containing the whole amount of Super plasticizer was poured and mixed for 3 minutes. After that, about 1 minute rest was allowed and finally rest of the water containing VMA was added into the mixture and mixed for 1 minute [15].

Table 4. Mix proportions of the concrete specimens

No	Concrete ID	w/b	Cement	Silica fume	Nano TiO2	Filler	Fine aggregate	Coarse aggregate	Sp	VMA
			(kg/m^3)							
1	SCC400	0.38	400	-	-	177	1003	578	2.5	2
2	SCC450	0.38	450	-	-	177	1003	578	2.81	2.25
3	SCC500	0.38	500	-	-	177	1003	578	3.12	2.5
4	SCC400SF10%	0.38	360	40	-	177	1003	578	2.5	2
5	SCC450 SF 10%	0.38	405	45	-	177	1003	578	2.81	2.25
6	SCC500 SF 10%	0.38	450	50	-	177	1003	578	3.12	2.5
7	SCC400NS2%	0.38	392	-	8	177	1003	578	2.5	2
8	SCC450 NS 2%	0.38	441	-	9	177	1003	578	2.81	2.25
9	SCC500 NS 2%	0.38	490	-	10	177	1003	578	3.12	2.5
10	SCC400SF10NS2%	0.38	352	40	8	177	1003	578	2.5	2
11	SCC450SF10NS2%	0.38	396	45	9	177	1003	578	2.81	2.25
12	SCC500SF10NS2%	0.38	440	50	10	177	1003	578	3.12	2.5

4. Tests on fresh concrete

The flow rate of a SCC mixture is influenced by its viscosity. When developing an SCC mixture in the laboratory, a relative measure of viscosity is useful. The time it takes for the outer edge of the concrete to spread and reach a diameter of 20 in. (500 mm) from the time the mold is first raised, based on the procedure described in the slump flow test, provides a relative measure of the unconfined flow rate of the concrete mixture. For similar materials, this time period, termed T_{50}, gives an indication of the viscosity of the SCC mixture [20]. According to Nagataki and Fujiwara [21], the slump flow represents the mean diameter of the mass of concrete after release of a standard slump cone; the diameter is measured in two perpendicular directions. Basic workability requirements for an acceptable SCC are summarized by Khayat [22] as; excellent deformability, good stability, and lower risk of blockage.

Workability properties of SCC mixtures in this study were evaluated through the measurement of slump flow time (T_{50}) to reach a concrete 50 cm spread circle, slump flow diameter (D), V-funnel flow time and L-box blockage ratio according to the ‘‘Specification and Guidelines for SCC” prepared by EFNARC (European Federation for Specialist Construction Chemicals and Concrete Systems) [23].

5. Results and discussion

In this experimental program, rheological properties of SCC-N mixtures were measured by slump flow (D (mm) and T50 (sec)), V-funnel (sec) and L-box tests. Table 5 lists the test results performed on fresh concrete. The slump flow diameters of all mixtures were in the range of 730–800 mm, slump flow times were less than 2.1 s, and the V-funnel flow times (sec) were in the range of 5–6.2 s. The lowest V-funnel flow time as 5 s was measured for the SCC-N0, while the SCC-N5 mixture had the highest flow time as 6.2 s. The L-box height ratios were in the range of 0.79–0.87. Incorporating TiO_2 nanopowder generally made the concretes a little more viscous. Some of the rheological properties of the mixtures were less than the lower limits established by EFNARC [23]; however, all concrete mixtures filled the molds by its own weight without the need for vibration. In addition to the above properties, visual inspection of fresh concrete did not indicate any segregation or considerable bleeding in any of the mixtures containing nanopowder during the slump flow and V funnel; however, a little bleeding was observed in the control specimens without any admixture. The effect of including TiO_2 nanopowder with various volume fractions decreased flowability characteristics a little; nevertheless, the nanopowder improved the consistency of concrete mixtures. Less bleeding and segregation were also observed in the mixtures containing TiO_2 nanopowder.

Table 5. Fresh properties of concrete mixtures

Mix No	Concrete ID	Slump Flow		V funnel flow time	L box
		D (mm)	T50 (sec)	(sec)	H2/H1
1	SCC-N0	800	1.7	5	0.79
2	SCC-N1	790	1.7	5.2	0.8
3	SCC-N2	780	1.8	5.5	0.8
4	SCC-N3	760	2	5.8	0.83
5	SCC-N4	740	2	6	0.85
6	SCC-N5	730	2.1	6.2	0.87

6. Conclusion

The results obtained in this study can be summarized as follows:

- Addition of TiO_2 nanopowder improved the consistency of the SCC-N mixtures and reduced the probability of bleeding and segregation.
- Increase in nanopowder percentage generally improved the rheological properties which could be due to finer particles in the cement past and filler effect of the nanopowder.

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