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Effect of Nano SiO_2 Size on Fresh Properties of Self-Compacting Concretes

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Abstract - Self-compacting concrete (SCC) is one of the most important developments in construction industry. SCC mix design has differences from conventional concrete mix design in order to obtain self-compacting ability. These mixtures necessitates the use of powerful superplasticizers, smaller maximum aggregate size, higher amount of fine materials, and lower water/binder ratio mixtures. Using high amount of fine materials causes a reduction in total coarse aggregate content. This reduction causes changes in elastic properties of hardened concrete. In this study, Nano SiO_2, which is a nano-technological material having enormous specific surface area, was used with the aim of reducing the total fine material amount in the mix design. Therefore, fly ash, which was used as fine material, was reduced gradually. The volumetric emptiness occurred by this reduction was filled with aggregates. Two different sizes of nano SiO_2 with the average particle diameters of 35 nm and 17 nm were used. Five different percentages of nano SiO_2 samples were selected as 0.5%, 1.0%, 1.5%, 2.0% and 2.5%. In order to understand the fresh properties T_{500}, slump flow diameter, V-funnel and sieve segregation tests were performed. The results of these test indicated that the use of nano SiO_2 would be an effective method in order to reduce the total fine material amount of SCC mixtures.

Keywords**:** Self-compacting concrete, Nano SiO_2, Fresh properties

1. Introduction

Self-compacting concrete (SCC) is a special type of high performance concretes which fills all of the corners of formworks without any vibration, resists against segregation and has no blocking around rebars. SCC has perfect deformability but it is very important to balance between deformability and stability [1]. SCC is becoming common in concrete industry and it is growing in worldwide [2]. In order to achieve the proper flowability it is necessary to use a powerful super plasticizer and limiting the coarse aggregate volume [3]. On the other hand, high flowability brings the risk of segregation. It is recommended to use high volume of fine materials or viscosity modifying agents in order to achieve the required stability [4]. According to these designing bases it is obviously seen that the major difference between the SCC and the conventional concrete are the amounts of the components. It is required to use high amount of powder, high amount of superplasticizers, higher amount of fine aggregate content and limited coarse aggregate content [5].

In concrete technology it is generalized that more than 60% of the volume of a conventional concrete is occupied by aggregates. Aggregate content plays an important role on mechanical and hardened properties. In SCC, coarse aggregate content affects also the fresh properties as well as the hardened properties. Characteristic properties of SCC is very sensitive to amount and properties of coarse aggregates [6]. In high strength concretes, the full strength potential of aggregates is being used; therefore the characteristics of coarse aggregates may increase the strength of the concrete [7]. Also the elastic properties of concrete are related to the elastic properties of the constituents, which are paste, aggregates and interfacial transition zone. Due to the large volume fraction occupied in concrete, aggregates have significant effect on elastic modulus of concrete [8]. Researchers have been studying on the role of coarse aggregate on the elastic properties of concrete and it has been observed that coarse aggregates have an important role [9, 10]. In order to understand the effect of coarse aggregate on elastic properties of concrete some researchers has been studied with different aggregates and it is reported that not only the coarse aggregate content but also the quality of the aggregate was affected the elastic properties of concrete [11 – 13].

During the recent years nano science and the nano modification of cement based materials are fast developing research fields [14]. It is believed that nano particles improve the strength of concrete. Nano particles act as super filler materials which improve interfacial transition zone and the bulk properties of concrete. Therefore it would be possible to produce more dense concretes [15]. Additionally, nano particles provide additional chemical reactions in the cement hydration system and it causes more durable and high performance concrete production [16]. Nano SiO2 is one of the most common nano material used in concrete. Researchers has been investigated the effects of nano SiO2 on mechanical [17 – 20], durability [21, 22], rheological [23, 24] and hydration properties of cement based systems [25, 26].

In this study, two different sizes of nano SiO2 was used for reducing the total fine material amount in SCC mix design. Fly ash, which was used as powder, was gradually reduced. This reduction was caused a volumetric emptiness. This volumetric emptiness was filled by aggregates. In order to investigate the fresh properties of nano modified SCC mixtures, slump flow, V funnel and sieve segregation tests were performed. Moreover, visual investigation of mixtures was performed. In this way, it was tried to design nano modified SCCs with low-fine materials.

2. Materials

CEM I 42.5 type ordinary Portland cement used in the study. Fly ash was obtained from Catalagzi thermal power plant in Turkey. Chemical composition and some physical properties of cement and fly ash are given in Table 1. Four different aggregates were used in the study, which are 0-2.5 mm natural sand, 0-4 mm crushed sand, 4-11 mm (CS I) and 11-22 mm crushed stone (CS II). The densities of the aggregates were 2.63, 2.68, 2.69 and 2.69 g/cm3 respectively. Aggregates used in the study have a fineness modulus of 1.65, 2.49, 5.55 and 6.57 respectively. Cembinder 8 and Cembinder 17 by AkzoNobel were used as colloidal nano silicas (CNS) in the study [27]. Based on the information given in Ref. 27, common properties of colloidal nano silicas' are given in Table 2. In Ref. 27, corresponding specific surface area values for 3.5nm, 5nm, 7nm, 9nm and 35nm average particle size nano-silica products are reported. Surface area for 17nm size nano-silica given in Table 2 is estimated by applying exponential extrapolation based on the reported values. Cembinder 8 and 17 have solid content of 50% and 40%, respectively (50% SiO2 and 50% water and %40 SiO2 and %60 water by weight). All the replacement rations given in the study for CNSs denote net nano SiO2 amounts. As super plasticizer, modified polycarboxylate ether polymer based high performance super plasticizer was used.

Table 1: Chemical composition and physical properties of cement and fly ash.

Composition, %:	**SiO_2**	**Al_2O_3**	**Fe_2O_3**	**CaO**	**MgO**	**SO_3**	**Cl^-**	**Density (g/cm^3)**	**Surface area (m^2/g)**
Cement	19.28	5.45	2.79	64.41	2.07	2.76	0.017	3.14	0.337
Fly Ash	58.75	25.24	5.76	1.46	2.22	0.08	0.015	2.00	0.222

Table 2: Properties of colloidal nano SiO_2s.

Property	**Cembinder 8**	**Cembinder 17**
SiO_2 Content, wt%	50	40
Water Content, wt%	50	60
Average Particle Size, nm	35	17
Density, g/cm^3	1.4	1.3
Surface Area, m^2/g	80	160

3. Experimental Study

The mix designs of concretes showing desired SCC characteristics shown in Table 3 and 4 CNS was added to SCC mixture by five different amounts which are 0.5%, 1.0%, 1.5%, 2.0% and 2.5% of total binder by weight. For each CNS percentage, four different fly ash levels were used. For reference mixture 160 kg/m3 fly ash was used and this amount was reduced step by step down to 0 kg/m3. At every step 40 kg/m3 of fly ash was reduced. Volumetric emptiness occurred by the fly as reduction was filled with the addition of aggregates without changing its grain distribution. The volume fractions of aggregates for the reference mixture are 22.0%, 19.0%, 29.5% and 29.5% for CS1, CS2, natural sand and crushed sand, respectively. Total aggregate volume fraction was increased from 59.3% (for reference mixture) to 66.3% (for 0 FA mixtures). Coarse aggregate volume in the reference mixture is 24.3% and it changed up to maximum 27.5% for both 35 nm and 17 nm CNS incorporating mixtures. Average aggregate volume fractions of mixtures are given in Table 5.

Table 3: Mixture designs of SCC mixtures with 35 nm CNS (kg/m^3).

Mix ID	**W/C**	**W/Cm**	**Water**	**Cement**	**FA**	**Nano SiO$_2^*$**	**SP**	**CS I**	**CS II**	**Fine Aggregate**	
										Nt. Sand	**Cr. Sand**
Reference	0.46	0.33	185	400	160	0.0	7.84	351	303	460	469
FA120/S35/0.5	0.46	0.36	185	400	120	2.8	7.84	361	312	473	482
FA120/S/35/1.0						5.6		360	311	472	481
FA120/S/35/1.5						8.4		359	310	470	479
FA120/S35/2.0						11.2		358	309	469	478
FA120/S35/2.5						14.0		356	308	467	476
FA80/S35/0.5	0.46	0.39	185	400	80	2.8	7.84	373	322	488	498
FA80/S/351.0						5.6		371	321	487	496
FA80/S35/1.5						8.4		370	320	485	495
FA80/S35/2.0						11.2		369	319	484	493
FA80/S35/2.5						14.0		368	318	482	491
FA40/S35/1.0	0.46	0.42	185	400	40	5.6	7.84	383	331	502	512
FA40/S/351.5						8.4		382	330	500	510
FA40/S35/2.0						11.2		381	329	499	508
FA40/S35/2.5						14.0		379	328	497	507
FA0/S35/1.5	0.46	0.46	185	400	0	8.4	7.84	393	340	515	525
FA0/S35/2.0						11.2		392	339	514	524
FA0/S35/2.5						14.0		391	338	512	522

W/C: Water to cement ratio, FA: Fly ash, SP: Superplasticizer, CS: Crushed stone, Nt. Sand: Natural sand, Cr. Sand: Crashed sand
*Pure nano silica amounts.

Table 4: Mixture designs of SCC mixtures with 17 nm CNS (kg/m^3).

Mix ID	**W/C**	**W/Cm**	**Water**	**Cement**	**FA**	**Nano SiO$_2^*$**	**SP**	**CS I**	**CS II**	**Fine Aggregate**	
										Nt. Sand	**Cr. Sand.**
Reference	0.46	0.33	185	400	160	0.0	7.84	351	303	460	469
FA120/S17/0.5	0.46	0.36	185	400	120	2.8	7.84	361	312	473	482
FA120/S17/1.0						5.6		360	311	472	481
FA120/S17/1.5						8.4		358	310	470	479
FA80/S17/0.5	0.46	0.39	185	400	80	2.8	7.84	373	322	488	498
FA80/S17/1.0						5.6		371	321	487	496
FA80/S17/1.5						8.4		370	319	485	494
FA40/S17/0.5	0.46	0.42	185	400	40	2.8	7.84	384	332	503	513
FA40/S17/1.0						5.6		383	331	502	511
FA40/S17/1.5						8.4		381	329	500	510
FA0/S17/1.0	0.46	0.46	185	400	0	5.6	7.84	394	340	517	527
FA0/S17/1.5						8.4		393	339	515	525
FA0/S17/2.0						11.2		392	338	513	523

W/C: Water to cement ratio, FA: Fly ash, SP: Superplasticizer, CS: Crushed stone, Nt. Sand: Natural sand, Cr. Sand: Crashed sand
*Pure nano silica amounts.

Table 5: Aggregate volume fractions of SCC mixtures (kg/m^3).

	Aggregate Volume Fraction, %		
Mix Code	**Coarse Aggr.**	**Fine Aggr.**	**Total**
Reference mixture	24.3	35.0	59.3
FA120 mixtures	24.9	35.7	60.6
FA80 mixtures	25.7	36.9	62.6
FA40 mixtures	26.5	38.0	64.5
FA0 mixtures	27.1	39.1	66.3

In fresh state, slump flow tests were performed and T500 time and mean slump flow diameter were measured according to EN 12350-8. V funnel test was performed according to EN 12350-9. In order to measure the segregation resistance of mixtures sieve segregation tests were performed according to EN 12350-11.

4. Results

Results of the T500, slump flow diameter, V funnel and sieve segregation tests are given in Figures 1 and 2 for 35 nm and 17 nm CNS containing mixtures, respectively.

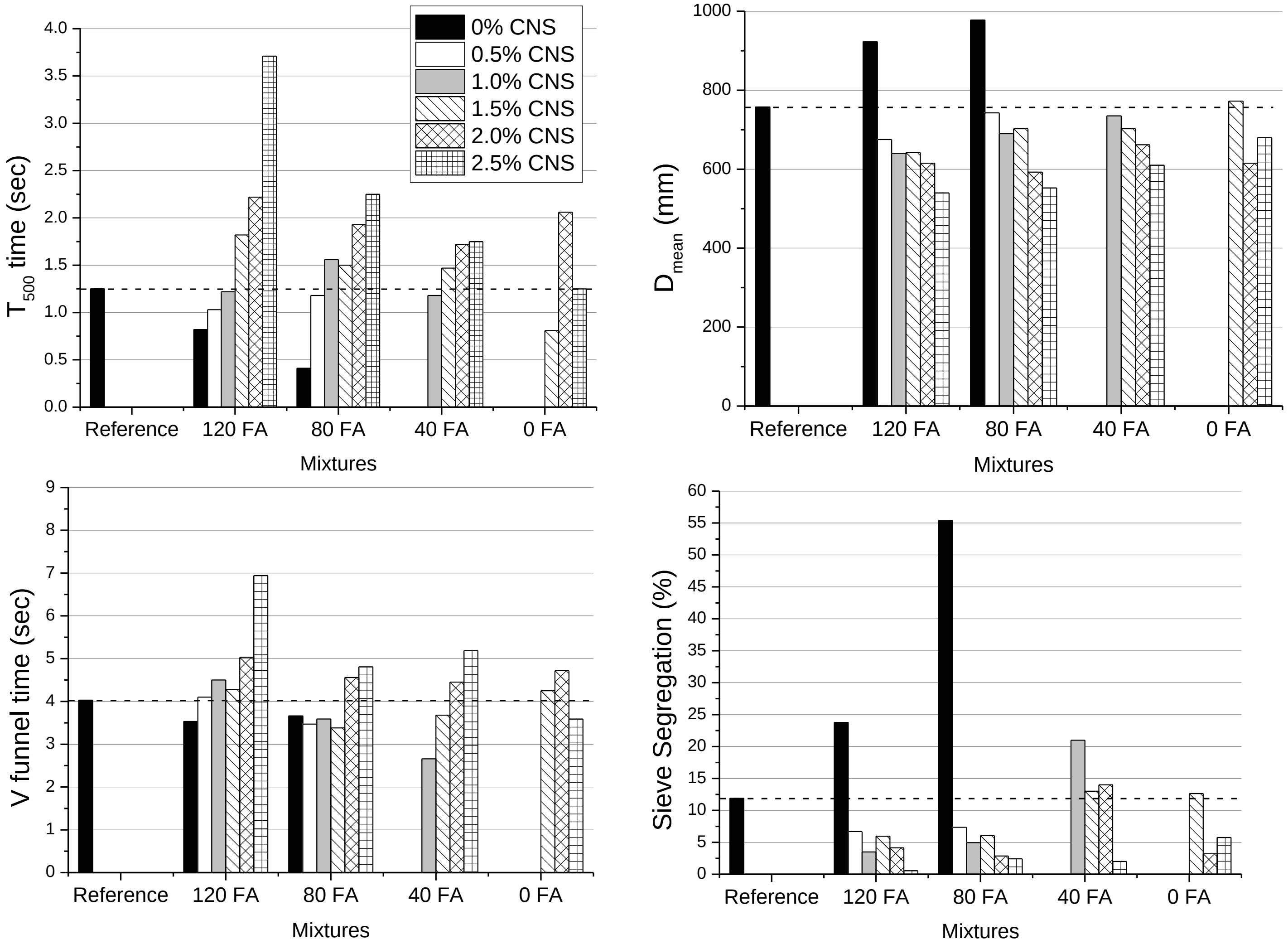


Fig. 1: Results of SCC tests for 35 nm CNS containing mixtures.

According to the results, T_{500} time generally increased with the addition of CNS and decreased with the reduction of fly ash amount. On the other hand, slump flow diameter decreased with the increase of CNS content. In case of 35nm CNS addition up to 1.5%, slump flow time to 500mm increased significantly above the reference mixture and flow diameter drops below it. For example, while reference mixture has a mean diameter of 757mm, by reducing the fly ash content down to 120 kg/m^3, mean diameter increased to 922mm and decreased to 540mm with 2.5% CNS addition. CNS addition smaller than 1.5% for higher levels of fly ash content (80 and 120 kg/m^3), T_{500} times and slump flow diameters are similar to or lower than the reference mixture. On the other hand, for lower levels of fly ash content (40 kg/m^3 and no-fly ash mixtures), SCC mixtures with low CNS content could not exhibit desired flow properties. It can be seen from the Figure 1, for 40 kg/m^3 and no-fly ash mixtures 0%, 0.5% and 1.0% are not shown. These mixtures were accepted as unsuccessful mixtures. V funnel time results show a similarity with the results of T_{500} time.

In can be seen from the sieve segregation results that only 40 kg of fly ash reduction increased the segregation value from 11.9% to 23.8% and only 2.5% CNS addition reduces the segregation value down to 0.6%. As is can be seen from the 40 kg/m^3 and no-fly ash mixtures, reduction in the fly ash content caused segregation. On the other hand, properties of these mixtures were significantly recovered with CNS addition. It can be concluded that the use of CNS is a very effective method in terms of controlling the risk of segregation. It can be also seen from the visual investigations (Fig. 3.).

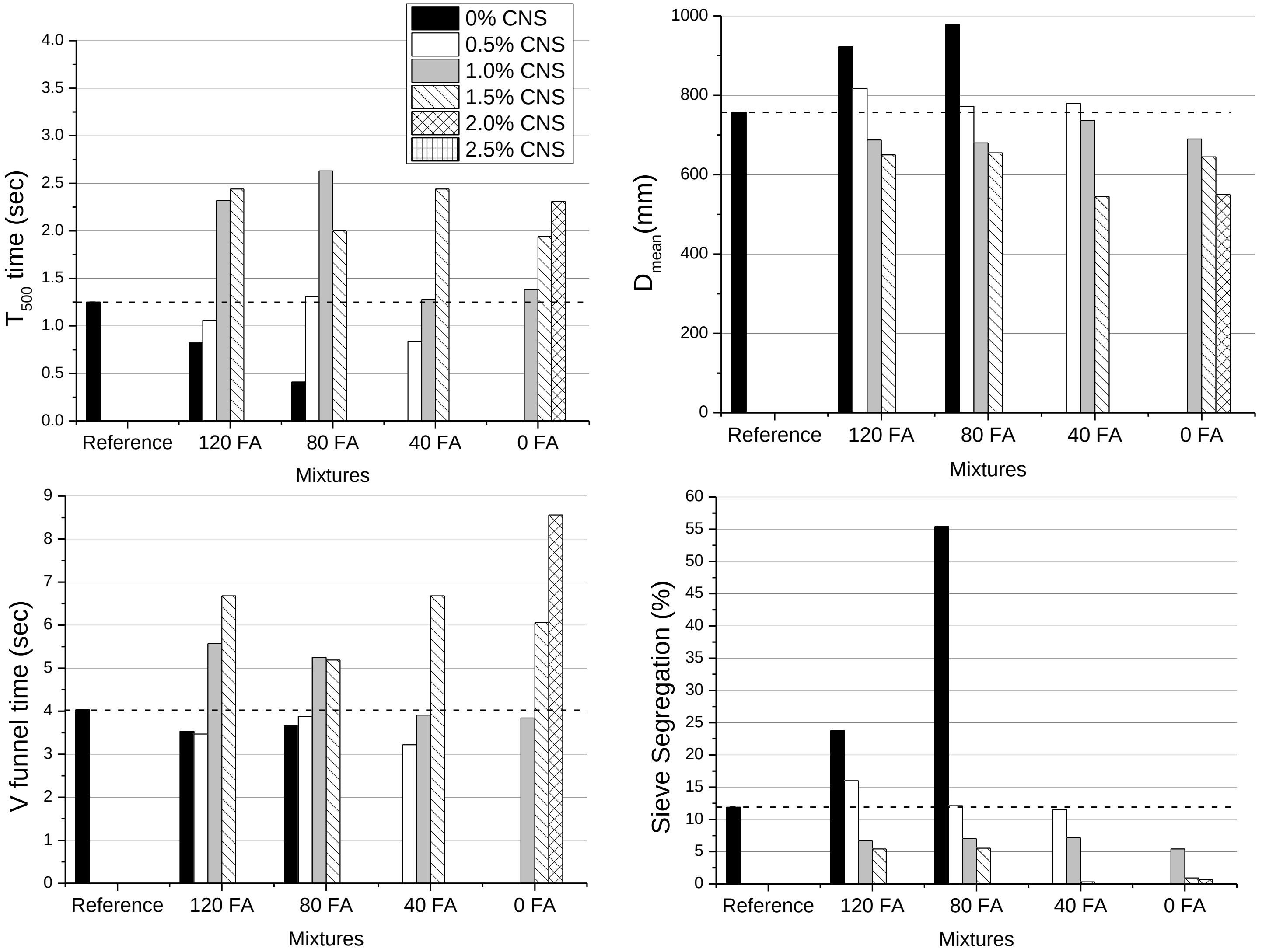
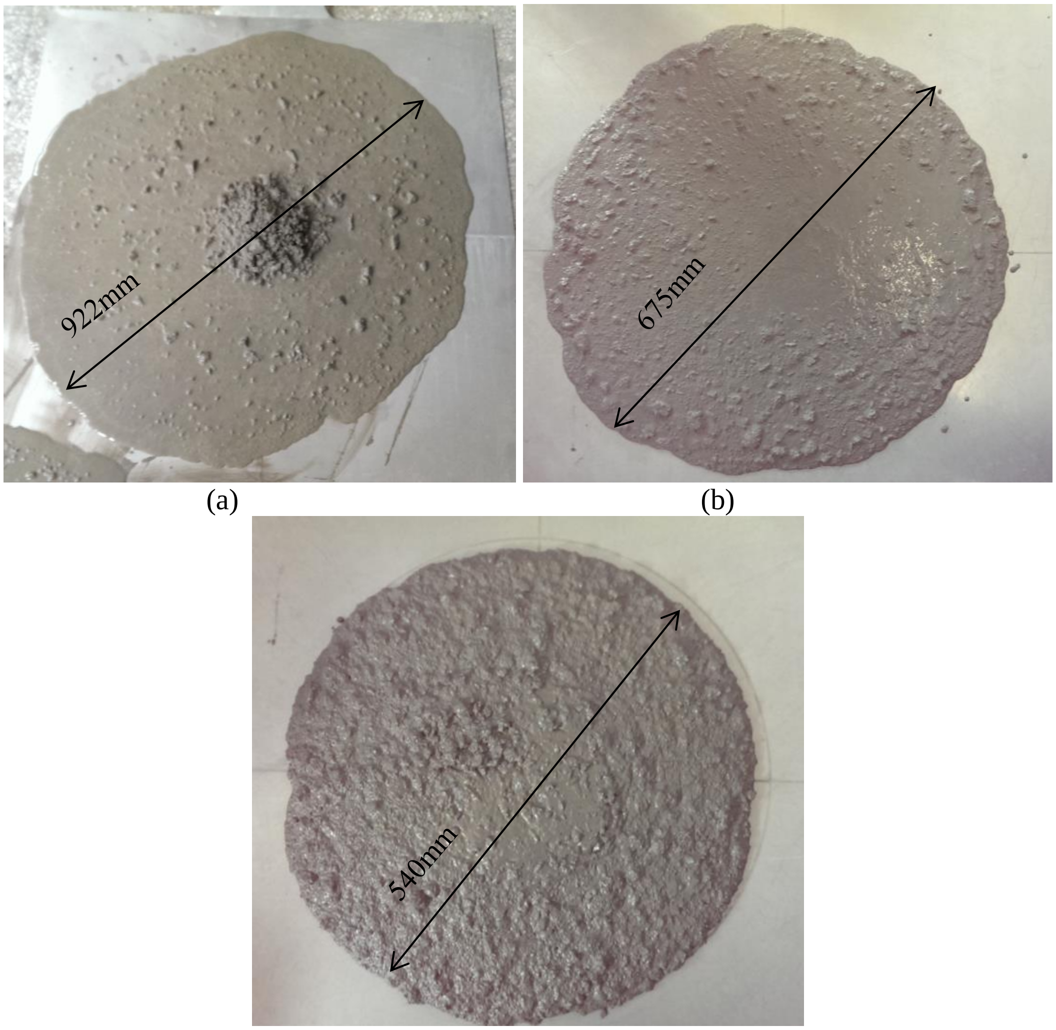


Fig. 2: Results of SCC tests for 17 nm CNS containing mixtures.

In comparison with 35nm CNS added mixtures, in the same levels of CNS addition, 17nm CNS containing mixtures have performed a larger number of unsuccessful mixtures. The decrease in the average particle size of nano SiO2 made difficult to use high amounts of CNS. This result is related to the increased water demand due to the higher specific surface area of 17nm nano SiO2. It was not possible to achieve mixtures with SCC properties using high amounts of 17nm CNS. Therefore, maximum 1.5% of 17nm could be used for 120, 80 and 40 kg/m3 fly ash content mixtures. Only in no-fly ash mixture, it could be possible to use up to 2.0%. As can be seen from the Figure 2, 0.5% CNS addition contributes to the SCC properties in terms of segregation, but in order to obtain more acceptable results from the point of segregation, 1.0% and 1.5% CNS was utilized. For example, for 80 kg/m3 fly ash content mixtures, 0.5% CNS utilization decreases the segregation percentage from 55.4% to 12.1%. In addition to this, the segregation percentage decreases to 7.0% and 5.5% with 1.0% and 1.5% CNS addition, respectively. Over 1.5% of CNS addition, it can be seen that the mixture flow properties started to diverge from the desired SCC properties. For example, mean flow diameter values decreases to 550mm which is the lower limit of SCC according to EFNARC.



(a) (b)

(c)

Fig. 3: Visuals of some SCC mixtures a) FA120/S35/0 –Unsuccessful mix b) FA120/S35/0.5 c) FA120/S35/2.5.

5. Conclusions

The fresh properties of SCC mixtures with 35nm and 17nm CNS in different amounts, with lowered total fine material content and increased coarse aggregates, were investigated. Within the limits of experimental study, the following conclusions can be drawn.

1. In general T_{500} times increased with the increase of CNS content and on contrary slump flow diameters decreased. Also reduction in the fly ash content decreased the flow time of mixtures to 500mm.
2. When 120 kg/m^3 and 80 kg/m^3 fly ash used, 35 nm CNS addition up to 1.5%, T_{500} times and slump flow diameters are similar to or lower than the reference sample. However, when the amount of 35nm CNS increased over 1.5% flow properties has started to diverge from the SCC properties. Especially with 2.5% 35nm CNS addition, flowability properties have been completely lost.
3. In 40 kg/m^3 and no-fly ash mixtures, it was observed that 35nm CNS addition up to 1.0% couldn't contribute to the SCC properties. But when the mean particle size decreased to 17nm, 1.0% and 1.5% amounts were the most successful proportions. With 17nm CNS, the only successful mixture with 2.0% was no-fly ash one. The decrement in the mean particle size and the increase in the specific surface area caused to increment in the number of unsuccessful mixtures. The use of 2.5% 17nm CNS could not be possible due to significant loss of flow.
4. It can be concluded that the use of CNS is a very effective method in controlling the risk of segregation of the SCC mixtures including low-fine materials and higher amount of coarse aggregates. Lowering the average particle size of nano SiO_2, increased the effectiveness. For example, 160 kg/m^3 fly ash can be replaced by 2.24 kg/m^3 of 17nm nano SiO_2 and by this way segregation decreases from 11.9% to 5.4%.

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