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FRESH AND HARDENED PROPERTIES OF NANOSILICA AND MICROSILICA CONTAINED SELF-CONSOLIDATING CONCRETES

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ABSTRACT

This study focuses on the effects of colloidal nanosilica (nS) on fresh and key hardened properties of SCCs in comparison with similar replacement values of the commonly used microsilica (mS). Two types of portland cement with low (type V) and moderate (type I) tricalciumaluminates (C3A) and three percentages of cement replacement with nS or mS. Fourteen concrete mixes were evaluated for flow, T50, V- funnel, J-ring and L-box as workability measurements; and compressive strength, splitting tensile strength and chloride resistance as hardened properties. Fresh properties results reveal that with equivalent percentages of cement replacement and super-plasticizer added,colloidal nS shows lower workability measurements compared to that of mS.This observation is consistence for both types of cement used.The use of nS enhanced all concretes compressive strengths compared to mS and controlmixtures. The improvements were a function of nS dosages used. The enhancements in splitting tensile strengths, however, were more pronounced at lower nS dosage of 3%, which reflect the sensitivity of tensile properties to the binder replacement effects. The remarkable improvements in chloride resistance performance for concretes contained nS, correlate with the compressive strength results and indicating for better pore structure characteristics.

Keywords: cement type, colloidal nanosilica, microsilica, self-consolidating concrete.

1. INTRODUCTION

Okamura [1] defined self-consolidating concrete (SCC) as a concrete have the ability to fill and low the formwork in a natural manure, passing through the bar reinforcements and other service extensions and pipes according to its own weight. SCC has received increasing attentions due to its superior fresh properties; it enables to have a uniform level without vibration even in the case of highly congested reinforcements and complicated shapes [2,3]. Among varies supplementary cementitious materials (SCMs), silica fume (SF) is widely agreed as a highly effective in increasing strength and reducing permeability of concrete. Workability difficulties associated with adding of SF to the SCCs are the main drawback of its using. Silica based SCMs are commonly available in a microscale (mS) and proved to be of significant effect on the hardened properties [4]. In the nano-scale however, where the particle size ranged between 100 to 1 nm, nano-silica (nS) is claimed to have a tremendous potential on the produced concrete [5-7].

To investigate the modifications in the microstructure of the matrix related to the use of silica basedSCMs at the hardened state, several variable parameters are need to be monitored simultaneously [8,9]. They are mostly recognized as: mechanical, chemical reaction and pores water parameters [7]. At the early age, the gains in strength with time due to the concrete setting are another possible change in the hydration process of the binder and can have significant effects on the fresh state of the produced concrete[10,11]. Several studies have found that nS can enhance the mechanical properties of the cementitious materials [12-14]. Others have focused on the application of nS to reduce bleeding effects after mixing [1,15,16].

Formations of ettringite and gypsum in abounds quantity in concrete are undesirable due to their expansive behavior which causing tensile expansive stresses inside the pore structures and possiblereduction in the concrete paste stiffness and strength [17,18]. Accordingly, in the case of sulfate attack conditions, the tricalcium aluminate (C3A) content in the cement used is limited to be less than 5% [19]. It is well-established that there is a strong correlation between C3A content and the noticed degradation of concrete paste with time [18,20]. ACI 201.2R [20] recommended to use silica based SCMs to design durable long life concrete. More details about the chemical reactions between cement components and sulfates can be found elsewhere [18, 21, 22].

Recent studies revealed that nS particles may have slight differences from mS particles due to their finer size. Small nanoscale pores can be filled by nS enhancing the strength and durability characteristics of the hardened concretes [12,23]. In addition to this physical effect, nS particles can react with C-S-H crystal produced in the young hydrating cement paste leading to stronger and denser transition zone of the surface around aggregate grains [23].

In the present work, two different types of silica (Microsilica and Colloidal nanosilica) and two types of portland cement (Ordinary Portland cement type I and Sulfate Resistance cement type V) were applied in SCC. The purpose of this study was to investigate the fresh and hardened mechanical properties of SCCs as well as to chloride diffusion. Furthermore, the improvement and packing of the microstructure of the hardened concrete was analyzed by Scanning Electron Microscope (SEM) technique. The findings of this research work provide more insight into the implantation of new nanoscalemineral (i.e. nS) as another option for the more commonly used microsilica. Ultimately, the industrial application of SCC will be promoted towered the using of nanosilica to produce concretes with better strength and durability properties.

2. EXPERIMENTAL PROCEDURE

2.1. Materials and SCC mix proportions

Two types of Commercial Iraqi cements were used, ordinary Portland cement (Type I) with moderate C3A content (7.95%) and sulfate resisting Portland cement (Type V) with low C3A content (2.08%). Both were conformed to ASTM C 150-04[19] and Iraqi Specification No. 5/1984 [24]. It is intended to examine the common types available in the local markets as long as they are conformed to international standards. Their chemical and physical properties are presented in Table-1. Two types of silica were considered, microsilica (mS) MEYCO MS 610 conforming to ASTM C 1240-03[25] supplied by BASF, with density of 2.2 g/cm3 and SiO2 content > 90%. Colloidal nanosilica (nS) produced by Jinan Yinfeng Silicon Products Company, with slight blue and transparence, pH value of 9.55 and density 1.204 g/cm3.

Local natural fine aggregate (FA) and crushed coarse aggregate (CA) were used, they were within the requirements of ASTM C33-13[26] and Iraqi Specification No.45/1984[27]. The specific gravity and bulk density were 2.65 and 1670 kg/m3 for FA, 2.63 and 1685 kg/m3 for CA, respectively. A constant amount of 100 kg/m3 ground limestone powder (LP) was applied as filler for all SCCs mixes. Unique polycarboxylic ether superplasticizer (SP) was added to adjust the workability of the SCC mix, with long lateral chains and specific gravity of 1.07. It conforms to ASTM-C-494 Type F [28].

The ACI 237R-07[29] procedure was followed to design SCC mix. It provides a guideline for proportioning mixtures and makes use of batches as trials mixes and then adjust the proportions based on the fresh and hardened testing results. The mix proportions of the ingredients used in this study are kept constant and only the nS or mS contents were changed as a cement replacement by weight (see Table-2). Fourteen SCCs were prepared accordingly and mixed for 5 min in total using pan mixer of 90 L capacity, following the mixing procedure recommended by [29] and explained in [30].

Table-1. Chemical composition and physical properties of cement and admixtures.

Oxides	**Percent chemical composition** (%)				
	Cement type I	**Cement type V**	**Limestone filler**	**Microsilica**	**Nanosilica**
SiO_2	21.93	21.95	1.02	95.14	30.1
Al_2O_3	4.98	3.76	0.61	0.71	---
CaO	66.11	63.32	65.32	0.92	---
Fe_2O_3	3.10	4.66	0.32	0.46	---
MgO	2.00	2.15	0.31	---	---
SO_3	2.25	1.1	0.12	0.95	---
Loss on ignition	2.39	1.93	31.5	1.41	---
Insoluble material	1.29	0.49		---	---
Lime saturation factor	0.93	0.85		---	---
Physical properties					
Specific gravity	3.12	2.8	2.7	2.2	1.204
Surface area (cm^2/g)	3760	3400	3900	20750	50000

Table-2. Mixture proportions of the investigated concretes.

Mix	Cement kg/m³	mS kg/m³	nS kg/m³	LP kg/m³	FA kg/m³	CA kg/m³	Water L/m³	W/Cem	W/P	SP L/m³
SCC Ref. I	400	0	0	100	850	850	152	0.38	0.3	5
SCC 3% mSI	388	12	0	100	850	850	152	0.38	0.3	5.4
SCC 4.5 % mSI	382	18	0	100	850	850	152	0.38	0.3	5.8
SCC 6% mSI	376	24	0	100	850	850	152	0.38	0.3	6.4
SCC 3% nSI	388	0	12	100	850	850	152	0.38	0.3	11.82
SCC 4.5 % nSI	382	0	18	100	850	850	152	0.38	0.3	15.21
SCC 6% nSI	376	0	24	100	850	850	152	0.38	0.3	18.74
SCC Ref. V	400	0	0	100	850	850	152	0.38	0.3	5
SCC 3% mSV	388	12	0	100	850	850	152	0.38	0.3	5.4
SCC 4.5% mSV	382	18	0	100	850	850	152	0.38	0.3	5.8
SCC 6% mSV	376	24	0	100	850	850	152	0.38	0.3	6.4
SCC 3% nSV	388	0	12	100	850	850	152	0.38	0.3	11.82
SCC 4.5% nSV	382	0	18	100	850	850	152	0.38	0.3	15.21
SCC 6% nSV	376	0	24	100	850	850	152	0.38	0.3	18.74

2.2. Test methods

Concretes fresh properties, such as filling ability, viscosity, and passing ability, were checked using slump flow and T50 cm, V-Funnel and V-Funnel at T5 minutes, J-Ring and L-Box tests, according to relevant ASTM and EFNARC guidelines and standards [31-33].

Mechanical properties including compressive and splitting tensile strengths were assessed at 28 and 90 days. Compressive strength was obtained for cubes 100 mm side length and splitting strength for cylinders 100 mm diameter × 200 mm height [34]. Two days after casting, specimens were demolded and then cured in a water tank following ASTM C 192Mstandard [35] until the age of testing. Dry density of samples was also determined at 28 days. The averages of three specimens were tested for all tests.

According to Querciа*et al.* [5], chloride diffusion test became more reliable for SCC with nano-silica addition compared with other chloride migration tests. In this study, chloride resistance test of concrete at 56 days was carried out following the ASTM C1202 procedure. Two concrete discs of 50 mm thick were cut from the middle of one cylinder of 200 mm height and 100 mm diameter, using diamond saw. The surface of the discs was first dried (left for twohr in air), then the surround surface for each disc, (but not the ends), was paint with acrylic coating and left for I day in air to dry. After that discs were vacuumed into desiccator for 3 h and then water was allowed to drain until full immersion is achieved and left for 24 h. The specimens were then moved to the testing cell which filled with 0.3 M NaOH solution for the positive side and 3% NaCL solution for the negative side of the equipment power supply (Figure-1). The test was started by applying 60 V DC between the cells and continued for a period of 6 h, during that measuring the total charge passed in coulombs which represent the concrete resistance to chloride ion penetration.

Scanning Electron Microscopy (SEM) images were taken for 56 days specimens. A block cube samples of 10×10×10 mm were first cut from the mid-distance of the lower tension fracture zone of tested prisms under flexural using diamond saw [36,37]. Samples were then oven dried for three days in 65 °C and pretreated with gold coating before SEM images taken.

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Figure-1. The concrete chloride resistance test set-up.

3. RESULTS AND DISCUSSIONS

3.1. Fresh concrete properties

The test results of fresh SCC properties are given in Table-3 and Figures 2 to 4. The observed filling ability results indicated for good workability performance for all SCCs mix (slump-flow ranged from 695 to 740 mm; T50 from 2.8 to 3.6 second and V-funnel were ranged from 7.4 to 9.1 second). Passing ability (L-box results ranged between 0.86 and 0.95 and J-ring 695 to 720 mm) were also indicated for acceptable workability measurements. So, for all SCCs, the fresh properties fit in well with EFNARC committee guidelines [33] indicating for a good workability. Concretes with colloidal nanosilica are noticed to be very close to the targeted lower limits of the spread flow. The SP content was changed (as indicated in Table-2) to stay within the limit of fresh tests specified in the European guideline. The percentage of increase in SP content was 0.08, 0.16 and 0.28 for 3, 4.5 and 6% mS respectively; while it was 1.364, 2.042 and 2.748 for 3, 4.5 and 6% nS respectively.

Rate of SP added where ten times more for nS than its counterpart in mS concretes. It can be concluded that the addition of SP dosage is mostly related to the particle grain size rather than percentage of replacement by weight, for the same mineral admixture mixed. This finding is in agreement with other researcher [5,38]. Utilizing of colloidal nS in this study, instead of powder form, does not change this fact. Furthermore, the visual inspection of the produced fresh concretes shows that there is no segregation observed and the coarse aggregate was uniformly distributed (Figure-5). The comparison between concretes contained cement type I, SCC Ref. I with concretes contained cement type V, SCC Ref. V revealed that type of cement has no significant effect on fresh properties as long as the physical properties are comparable for both types of cement used.

Table-3. Concrete properties in fresh and hardened state.

Mix	Properties									
	Slump flow (mm)	**Flow time** (s)	**V-funnel** (s)	**J-ring** (mm)	**L-box H_2/H_1**	**Dry Density** (g/cm^3)	**Compressive Strength** (MPa) **28 days**	**S.D**	**Tensile Splitting Strength** (MPa) **28 days**	**S.D**
SCC Ref. I	740	3.5	8.2	695	0.91	2.38	52.3	1.15	4.12	1.19
SCC 3% mSI	720	3.6	8.5	703	0.90	2.42	55.9	0.95	4.63	1.12
SCC 4.5 % mSI	730	3.2	9.0	696	0.88	2.44	57.8	1.23	4.36	1.26
SCC 6% mSI	725	2.9	7.4	702	0.86	2.46	58.3	1.15	4.11	1.19
SCC 3% nSI	695	3.2	8.5	710	0.92	2.45	63.9	0.96	4.96	1.14
SCC 4.5 % nSI	700	2.9	7.9	698	0.95	2.41	67.8	1.14	4.59	1.18
SCC 6% nSI	705	3.5	8.6	716	0.89	2.40	68.1	1.15	4.21	1.21
SCC Ref. V	735	3.4	8.5	704	0.93	2.39	45.6	1.27	3.91	1.28
SCC 3% mSV	725	3.2	9.1	720	0.91	2.43	50.2	1.35	4.45	1.38
SCC 4.5% mSV	710	2.9	8.8	713	0.88	2.44	55.3	1.14	4.25	1.18
SCC 6% mSV	720	3.0	8.2	699	0.90	2.45	55.8	1.31	4.01	1.35
SCC 3% nSV	700	3.3	7.5	717	0.94	2.47	57.6	1.13	4.81	1.19
SCC 4.5% nSV	695	3.5	8.5	722	0.92	2.42	62.2	1.18	4.65	1.21
SCC 6% nSV	710	2.8	9.0	690	0.91	2.40	63.1	1.25	4.23	1.31

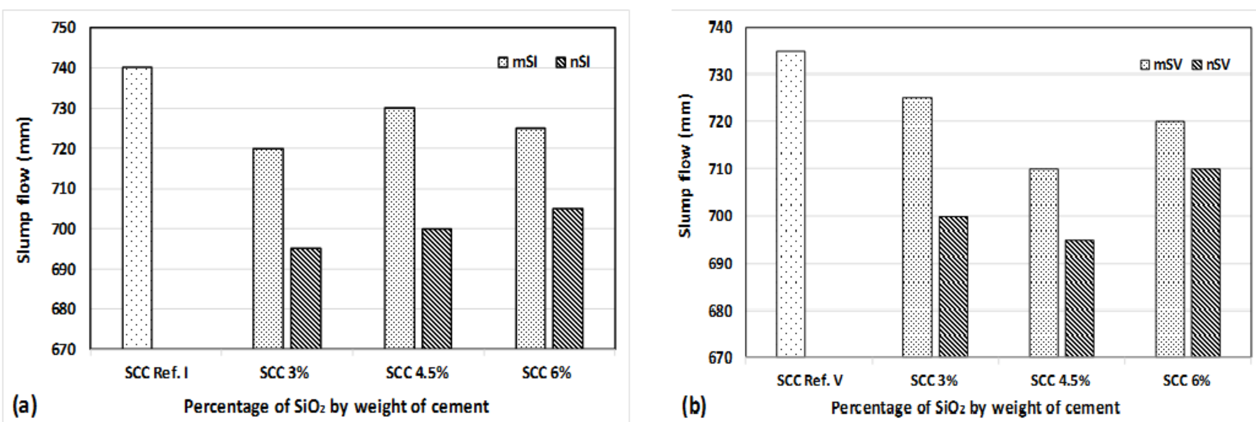

Figure-2. Relation between slump flow and silica percentages for all SCCsmade with a) type I and b) type V cements.

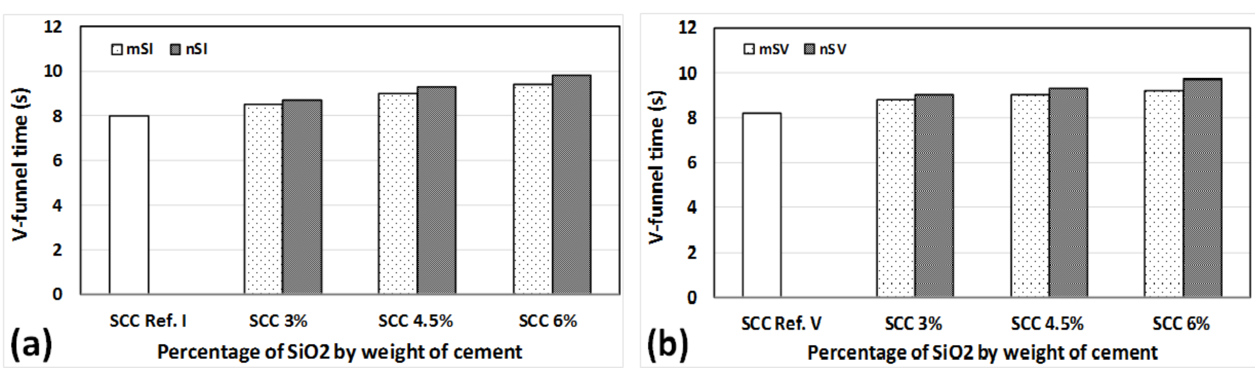

Figure-3. Relation between V-funnel time and silica percentages for all SCCsmade with a) type I and b) type V cements.

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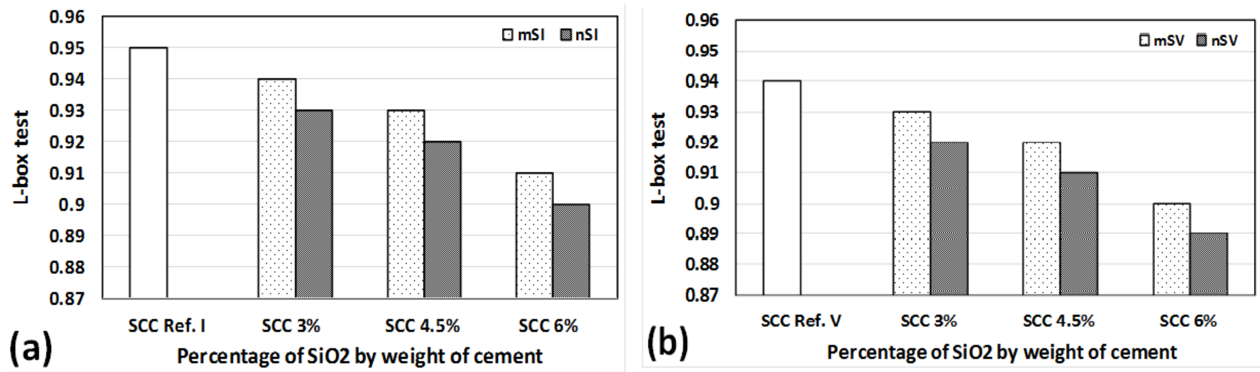

Figure-4. Relation between L-box test results and silica percentagesfor all SCCs made with a) type I and b) type V cements.

Figure-5. Appearance of the produced concrete made with 6% nS.

3.2. Hardened concrete: mechanical properties

3.2.1. Compressive strength

Compressive strength development vs. time is presented in Table-4 for all SCCs mixes.Specimens were tested after 28 and 90 days of standard curing [35]. Although all the SCCs mix proportions were similar even in terms of binder and water/ binder (w/b) ratios, higher compressive strength of nS concretes were observed in comparison with mS concretes, at identical concrete ages (Figure-6). Compared to SCCs produced using type V cement, concrete compressive strength levels of type I cement have significant higher values. On the contrary (Figure-7), the gain in strengths was more pronounced in type V cement concretes which had lower cement grains surface area (Table-1). This is due to lower reference strength level, SCC Ref. V, compared to SCC Ref. I resulted by lower cement grains surface area. The impact of SCM in refining gel pores is, therefore, became more visible in type V cement concretes which have larger cement grains and less possible packing due to their pozzolanic effect [7, 23&39].

After 90 days, the gain in strength difference observed between the two SCCs (i.e. with type I and Type V) broadened, Figure-7b. This suggests that, the two SCCs initially, (at 28 days), exhibited progressive strength gains as a function of SCMs concentration used. This difference becomes more pronounced with time (after 90 days). As evident in the gain in strength behavior of the two concretes in Figure-8, SCCs of type V cement performed better than SCCs of type I, since the ratio of 90 to 28 days of gain in strengths still more than 1 for the former concretes. Due to the identical concrete ingredients between the two SCCs, it is reasonable to assume that at initial ages, chemical hydration of finer cement grains had a more significant effect on the compressive behavior. With time the presence of nano based SCMs become more efficient in reducing the differences between the two concretes and the strength levels become comparable. The long time behavior is, therefore, an aspect recommended for further study. Over time, the lower the silica based SCMs particle size the higher the compressive strength increase.

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Table-4. Concrete properties in hardened state.

Mix description	Properties							
	Compressive strength (MPa)				**Tensile splitting strength** (MPa)			
	28 days		**90 days**		**28 days**		**90 days**	
	fcu	**Increased %**	**fcu**	**Increased %**	**fspt**	**Increased %**	**fspt**	**Increased %**
SCC Ref. I	52.3	0	55.4	0	4.12	0	4.92	0
SCC 3% mSI	55.9	6.14	58.8	6.14	4.63	12.38	5.24	6.50
SCC 4.5 % mSI	57.8	8.84	60.3	8.84	4.36	5.83	5.11	3.86
SCC 6% mSI	58.3	11.01	61.5	11.01	4.14	0.49	4.96	0.81
SCC 3% nSI	63.9	19.31	66.1	19.31	4.96	20.39	5.53	12.40
SCC 4.5 % nSI	67.8	25.81	69.7	25.81	4.59	11.41	5.48	11.38
SCC 6% nSI	68.1	28.52	71.2	28.52	4.21	2.18	5.28	7.32
SCC Ref. V	45.6	0	47.8	0	3.91	0	4.50	0
SCC3% mSV	50.2	11.09	53.1	11.09	4.45	13.81	4.93	9.56
SCC4.5%mSV	55.3	22.38	58.5	22.38	4.25	8.70	4.88	8.44
SCC 6% mSV	55.8	23.22	58.9	23.22	4.01	2.56	4.64	3.11
SCC 3% nSV	57.6	26.57	60.5	26.57	4.81	23.02	5.41	20.22
SCC 4.5% nSV	62.2	38.70	66.3	38.70	4.65	18.93	5.22	16.00
SCC 6% nSV	63.1	41.21	67.5	41.21	4.23	8.18	5.12	13.78

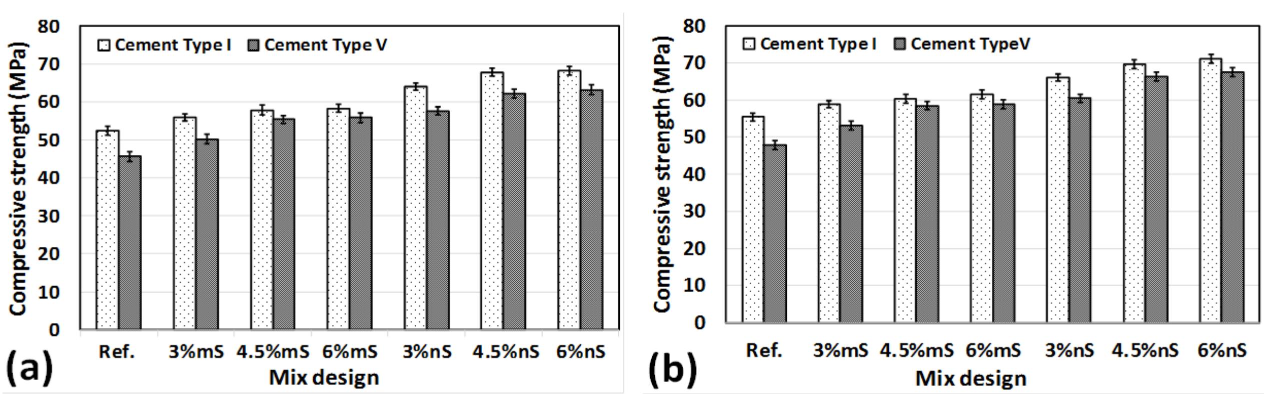

Figure-6. Averages of compressive strengths for SCCs contained mS and nS, (a) at 28 days and (b) at 90 days.

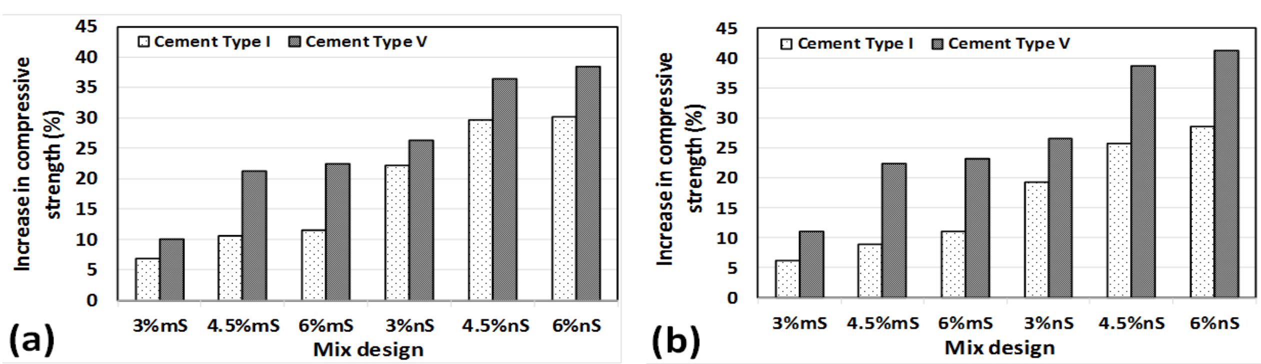

Figure-7. Improvement rates in compressive strengths for SCCs contained mS and nS with respect to control concretes, (a) at 28 days and (b) at 90 days.

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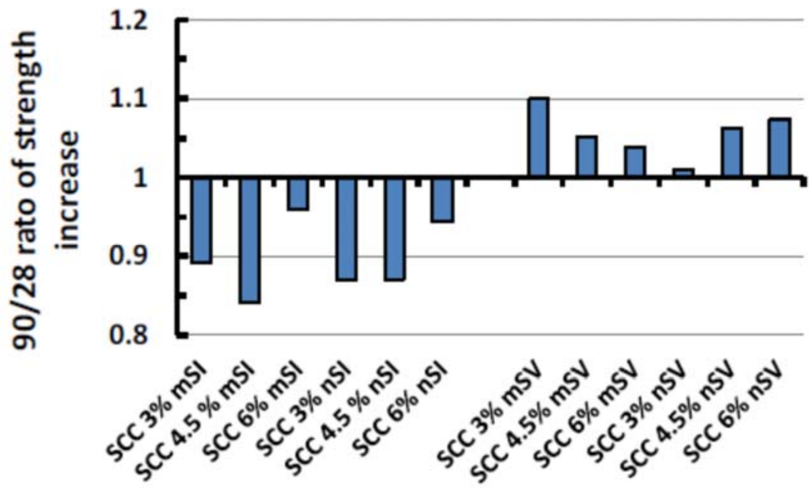

Figure-8. Ratios of increase in strengths (90 d/ 28 d) for SCCs with nS or mS cement replacements.

3.2.2 Splitting tensile strength

Splitting tensile strength results determined at 28 and 90 days are presented in Table-4 and lotted in Figure-9. Results indicated that splitting tensile strength enhanced average of 12.5%, 7.3% and 1.5%; and 21.7%, 15.7% and 5.18% of the control by using 3%, 4.5%, and 6% mS or nS as a cement replacement respectively, at 28 days. To better understand the effect of different dosages of nS and mS on SCCs splitting strength, the obtained results are depicted in Figure-10 in percentage of the control SCC. Despite the fact that both types of silica based SCMs were enhanced the splitting strength, nS concretes perform better than mS at similar dosage. But, unlike compressive strength behavior, the level of splitting strengths reduces as the replacement percentage of nS or mS increased. Among various silica based SCMs dosages used, 3% provided better splitting tensile strength followed by 4.5% then 6%. This descending order does not change even with different cement types or in other age of tests. Other researchers were also investigated the effect of nS or mS on strength and microstructure of cementitious materials. They reported widely varying results ranging from significant strength improvement to strength reduction. However, the researchers have agreed that the improvement in strength is achieved due to: packing ability, pozzolanic reactions and/or nucleation [40]. In compressive behavior, all of these factors are seemed to have significant effects. In the tensile behavior however, the last two factors have more influences. It can be concluded that the impact of using silica based SCMs was varied depending on the mechanical property tested. Replacing of the cement as a binding material with other SCMs is a sensitive case particularly in tensions. While it has been proven that the addition of silica based SCMs is always useful in improving the mechanical properties [5,40,41], the cement replacement is restricted by the substituted percentages. In this study, a cement replacement of 3% led to reach maximum values of splitting strengths, and then decreased as replacement rates increased. Figure-10 also shows that the effect of cement type on splitting tensile strength is similar to that in compressive strength behaviors. The gain in strength was more visible in cement type V which has lower grains surface area.

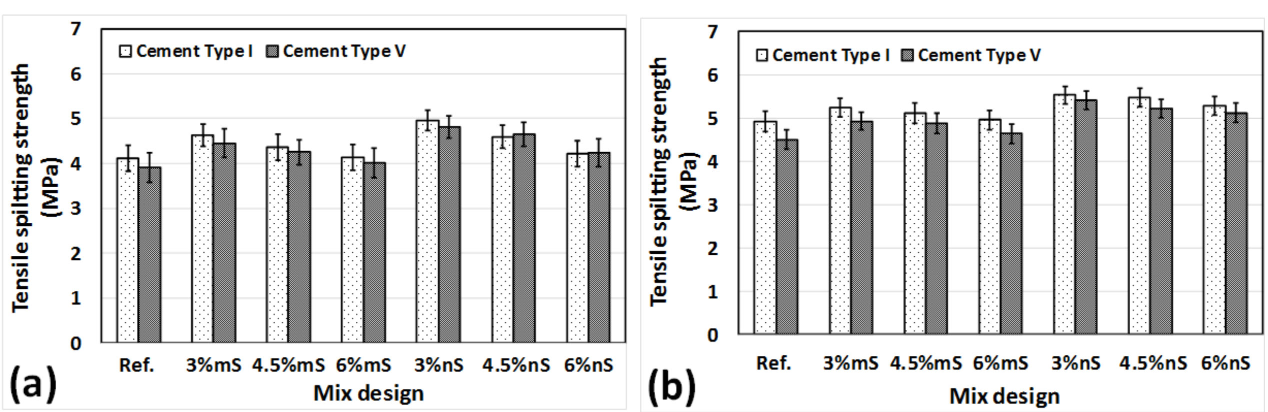

Figure-9. Averages of splitting strengths for SCCs contained mS and nS, (a) at 28 days and (b) at 90 days.

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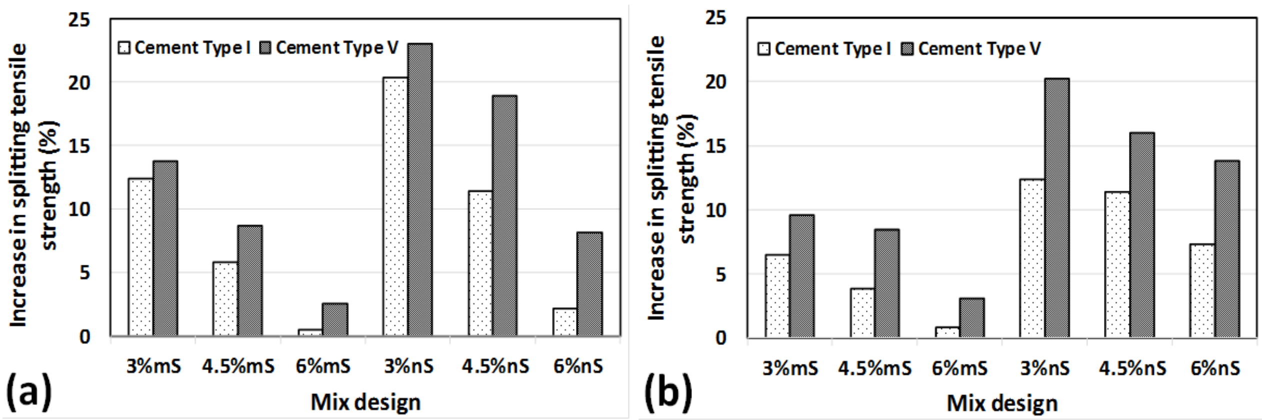

Figure-10. Improvement rates in splitting strengths for SCCs contained mS and nS with respect to control concretes, (a) at 28 days and (b) at 90 days.

3.2.4 Fracture surface observations and microstructural analysis

The SEM micrographs of the SCC samples at 28 days age with and without silica based SCMs are shown in Figures 11 and 12. These micrographs aimed to find possible interpretations of the mechanical properties presented in previous sections. They are conducted on fracture surfaces and may provide qualitative information to explain the obtained compressive and splitting tensile strengths.

As shown in Figures 11 a and b, concretes produced without mS and nS formed visible microcracks even with 100 µm scale (arrows #1). ITZ is defined as the zone (10 to 20 µm long) in the vicinity of the aggregates [5,42]. In this study, reference SCCs have apparent ITZs (indicated by arrows # 2) characterized by relatively poor structure and high amount of air pores. The thin black shadow line surrounding the aggregate grains is proof of that.

As can be seen in Figures 12a to c, the SCCs produced with 6% nS show a more uniform microstructure in comparison with reference concretes shown in Figures 8181 above. When cement composites was no nS or mS, many plate like emerged in fracture surface, which were cement hydration crystals CH or other hydrated cement products and disorderly stacked (Figure-12a, arrow # 4). Increasing nS content from 0% to 6% was associated with the formation of the new distinct shape of flower like crystals distributed in an interwoven shape (Figs. 12a and b), and they are more visible in concretes produced with cement Type I. For concretes produced with cement type V, (i.e. have lower cement grains surface area), and have similar nS content, 6%, the observed fracture surface has fewer flower-like hydration crystals emerged and some of them are even yet to be opened (Figure-12c). The absence of the Ca(OH)2 and the presence of flower like crystals in abounds quantity confirm the nS effect in producing new phases of C-S-H that proved by others [5,43] to have better stiffness and occupying higher volume fraction (up to 38%) compared with control concretes without nS particles. This enhancement in the gel microstructure is correlated with mechanical properties improvement described in preceding sections. It can be suggested that the synergistic effects of using nS particles with cement of higher grains surface area lead to produce newly C-S-H gel due nSpozzolanic reactions that has better properties. This synergistic effect is also enhanced other durability properties which will be discussed in the proceed sections.

3.2.5 Concrete’s ability to resist chloride ion penetration

The resistance of concrete to chloride ion ingress test, following ASTM C1202 [44], is widely used as an accelerated technique to measure the ability of concretes to chloride migration. The charges passed through all SCC specimens in coulombs are measured at 56 days age, and the results are shown in Figures 13 and 14. A lower charge value indicates for better concretes resistance to chloride ion penetration and thus, better permeability.

SCCs contained nS exhibited better performance in chloride resistance which represented in the lower charges passed values in Fig. 13a. Replacing of cement type I with 3%, 4.5%, and 6% mS led to 66.9%, 62.2%, and 51.3% reduction in concrete charges passed values respectively (Figure-14b). The same replacements with cement type V had 65.7%, 52.5%, and 39.6% reduction in concrete charges passed values, respectively (Figure-14a). The progressive enhancement in charged passed as a function of mS replacement indicating that mS replacement up to 6% have beneficial effects which is well correlated with the compressive strength results (Figure-14b).

Similarly to the mS contained SCCs made with cement type V, the nS contained SCCs exhibited better performance in term of charge passed, as shown in Figure-14. The same replacement percentages reduced the charged passed to 7.3%, 4.6%, and 3.1% of the control specimens. These results also revealed that nS contained concretes exhibited very comparable values, indicating that higher replacement percentages are not essentially led to correspondingly beneficial effects. The observed reduction difference between SCCs contained 3% and 6% nS was only 4.2% meaning that 3% nS replacement provided almost the same improvement in charge passed if

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the replacement percentage is doubled. In the case of SCCs made with cement type I, the reductions in charge passed were more pronounced at the same replacement percentages. This behavior could be attributed to the differences in the chemical compositions between the two types of cement used particularly the C3A contents.

For all SCCs, rapid chloride resistances of SCCs produced with the cement type V were better (lower) than those of the cement type I SCCs. Results of cement type I concretes were about 2 times higher than type V concretes at similar mS replacements and about 10 times higher at similar nS replacements. In Iraq and many other neighboring countries, only cements type V are specified, for concrete structure parts below ground level, due to the high percentages of sulfate ion contents in the surrounding soils. In this study, results clearly indicate that the performance of cement type V SCCs were also better than cement type I SCCs in term of chloride resistance following ASTM C1202 procedure. The significant effect of binder type on the chloride resistance of SCCs is also confirmed by other [45].

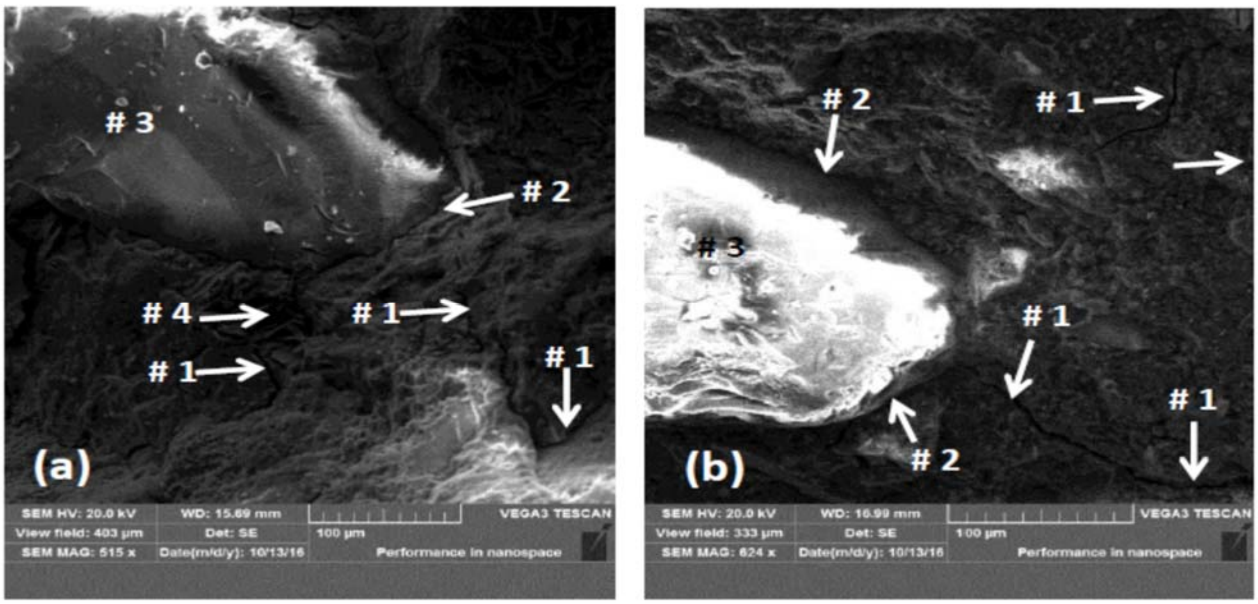

Figure-11. SEM Photomicrographs of the reference SCC mix, (a) cement type I and (b) cement type V. Arrows #1 indicate for microcracks. Arrows #2 indicate for ITZ between sand aggregates and cement paste. #3 indicates for sand aggregates.

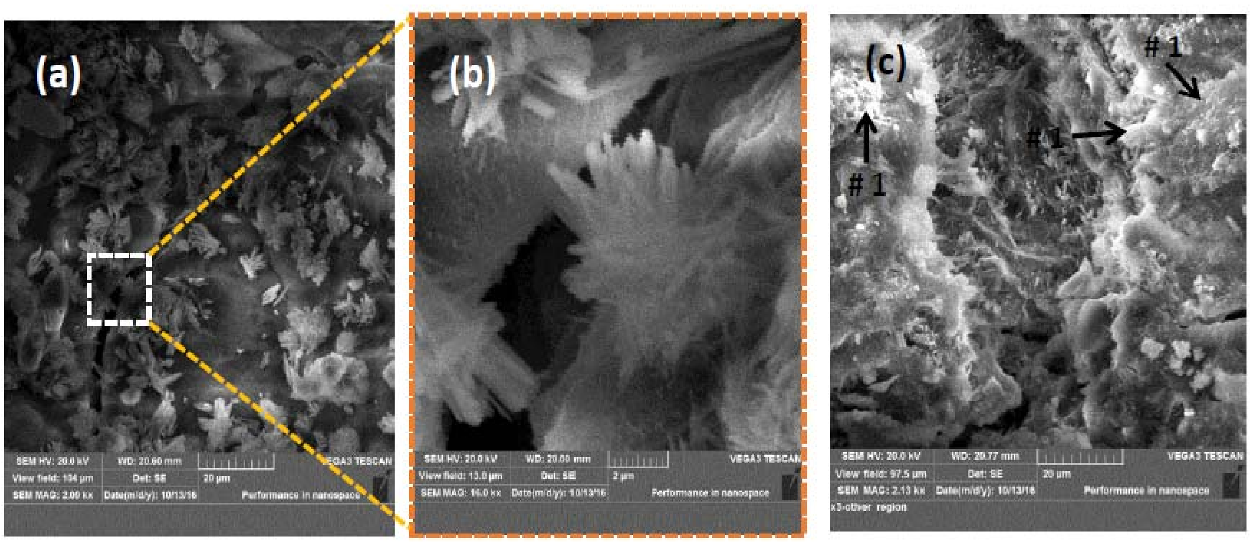

Figure-12. SEM Photomicrographs of the SCC mixes. (a) cement type I and 6% nS, (b) enlargement the white box in the adjacent figure, and (c) cement type V and 6% nS. Arrows #1 indicate for irregular shapes of Ca(OH)2.

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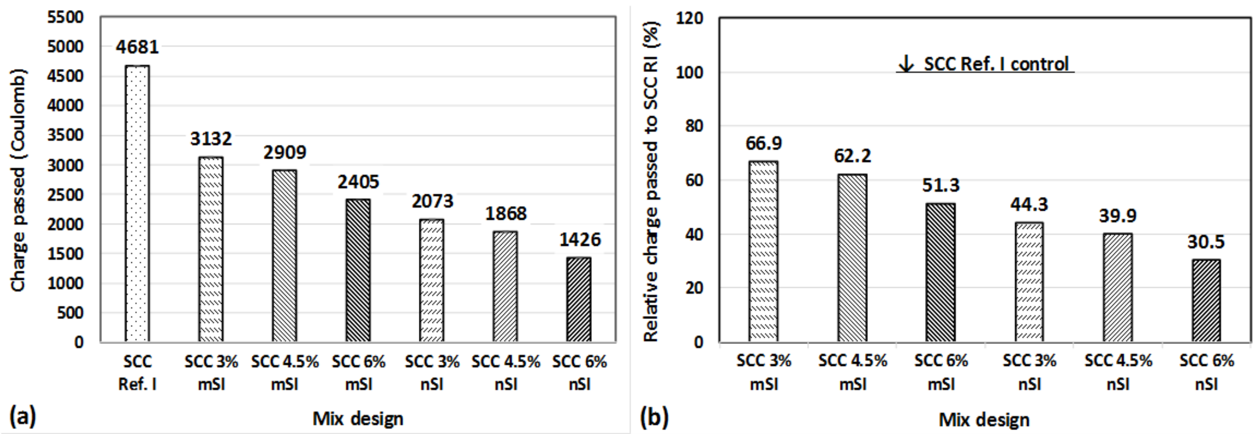

Figure-13. Passed charges for cement type I SCCs contained mS and nS, (a) Average values and (b) Improvement rates with respect to control concrete.

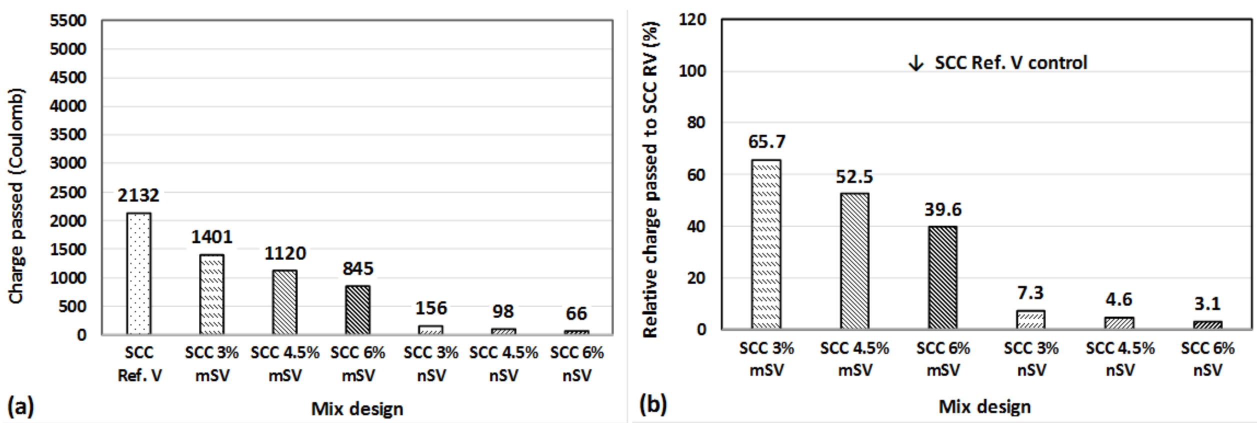

Figure-14. Passed charges for cement type V SCCs contained mS and nS, (a) Average values and (b) Improvement rates with respect to control concrete.

CONCLUSIONS

Based on the experimental results for this comparison investigation to evaluate the fresh and hardened properties of SCCs with different percentages of nS and mS replacements, the following conclusions can be drawn:

a) Using of mS and nS had adverse effects on all workability properties of fresh SCCs. The results confirm the fact that addition of SP dosage is mostly related to the particle grain size rather than percentage of replacement by weight, for the same mineral admixture mixed. Using colloidal nS in this study, instead of powder form used elsewhere, does not change this fact.

b) Despite the high demand of SP for the fresh SCCs made with nS (ten times more than similar mS replacements), no segregations were observed and the coarse aggregate still uniformly distributed. Type of cement used has no significant effect on fresh properties as long as the physical properties are comparable.

c) For concretes made with both types of cement, type I and type V, progressively higher cement percentage replacements from 3% to 6% of mS or nS increased concretes compressive strength levels compared to the control. The enhancement in strength level was a function of the replacement percentages and it was more pronounced in concretes made with cement type I. On the contrary, the gain in strengths was more pronounced in cement type V concretes. The impact of SCM in refining gel pores with time is, therefore, became more visible in type V cement concretes which have larger cement grains and less possible packing due to their pozzolanic effect.

d) Among various silica based SCMs dosages used, 3% provided optimum splitting tensile strength followed by 4.5% then 6%. This descending order does not changed even with different cement types or test ages. Unlike compressive strengths, this behavior shows the sensitivity of splitting tensile strengths to cement replacements.

e) Increasing nS content from 0% to 6% was associated with the formation of the new distinct shape of flower like crystals distributed in an interwoven shape. They are more visible in concretes produced with cement Type I. The absence of the Ca(OH)2 and the presence of flower like crystals in abounds quantity confirm the nS effect in producing new phases of C-S-H. This enhancement is correlated with the mechanical properties improvement.

f) SCCs contained nS exhibited better performance in chloride resistance than SCCs contained mS. Higher levels of nS replacement did not prove to have significant improvement over the lower replacement levels for cement type V concretes. In the case of SCCs made with cement type I, the reductions in charge passed were more pronounced at the same nS replacement levels. This behavior could be attributed to the differences in the chemical compositions between the two types of cement used particularly the C3A contents.

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