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Experimental Study of Applying Natural Zeolite as A Partial Alternative for Cement in Self-Compacting Concrete (SCC)

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ABSTRACT

In recent years, with the increasing demand for modern and environmentally friendly materials, natural pozzolan s can be proved to be such a material and several researchers have focused their research efforts in using it as a partial substitute in the manufacture of concrete and mortar. This study concerns the fresh and hardened properties of self-compacted concrete (SCC) with natural zeolite (NZ). SCC mixtures were prepared by inclusion various amounts of NZ (0–20% by weight of cement) at different water/binder ratios. The fresh properties were investigated by slump flow, visual stability index, T50, V-funnel and L-box. The slump flow and compressive strength changes with hauling time were also considered. The hardened properties were tested for compressive strength, splitting tensile strength, ultrasonic pulse velocity (UPV), initial and final absorption. Results showed that with the inclusion of NZ, SCC can be successfully produced with satisfactory performance in flow ability, passing ability and viscosity. For all mixtures, flowability was lost with hauling time, although the rate of slump flow reduction was higher for mixes with higher amount of NZ. Regarding to hardened properties, the effect of NZ on the compressive and splitting tensile strength of SCC mixtures is generally related to its W/B ratio. Moreover, compressive strength enhancement was seen for mixes with slump flow higher than 550 mm at prolonged mixing time. The UPV measurement shows that the effect of NZ on the UPV values at a high compressive strength are negligible. Compared to control SCC, absorption characteristics of SCC containing NZ significantly decrease with increasing ages.

Keywords:

Self-compacting concrete, Zeolite, Durability, Hardened properties.

1. Introduction

Self-compacted concrete (SCC) is a high flowable concrete which can be placed and compact without any vibration in complex or dense reinforced formworks. In order to achieve such behavior, the main requirements of fresh SCC are filling ability, passing ability and very high segregation resistance. These requirements can mainly be affected by the materials characteristics and the mixes proportions. In the mixture design of SCC, it is usually common to use a low water/powder ratio as well as controlling proportions of coarse aggregates. In addition, it needs to apply high range water reducing (HRWR) admixture to provide adequate flowability, and a large quantity of powder materials and/or viscosity-modifying admixture (VMA) in order to achieve high resistance to segregation. As one of the disadvantages of SCC, high cement requirement and using chemical admixtures leads to increase in material cost of SCC. One alternative procedure to reduce the cost of SCC and probability, producing SCC with better engineering properties is applying inert or pozzolanic/hydraulic additions.

Natural zeolite (NZ) is hydrated alumino-silicates which have been used in construction since ancient time. Similar to pozzolanic additions such as fly ash [1], silica fume [2] and metakaolin [3], NZ contains large quantities of reactive SiO_2 and Al_2O_3. In this respect, a number of studies were attempted to observe the performance of NZ as a mineral additions. Ahmadi and Shekarchi [4] reported that the compressive strength of concrete mixtures with 5, 10, 15 and 20% NZ at water to total cementitious materials ratio of 0.40 were 14%, 16%, 23% and 25% higher than that of the control mixture. Canpolat et al. [5] observed that the inclusion of zeolite up to the level of 15% resulted in an increase in compressive strength at early ages while setting time was decreased when zeolite was substituted. Poon et al. [6] found that the pozzolanic activity of NZ is higher than fly ash and lower than silica fume. Concerning durability aspects, the positive effects of NZ on water penetration, chloride ion penetration, corrosion rate and drying shrinkage of concrete was observed by Najimi et al. [7]. Feng et al. [8] shows at replacement levels of 10% and 15%, the charge passed through NZ concrete reduced to 81% and 61% of the control concrete, respectively which indicated lower chloride ion penetrability. Some researchers have confirmed that undesirable expansion due to alkali silica reaction can be prevented by using NZ [9]. The feasibility of using NZ in high performance concrete was also reported in references. A study by Chan and Ji [10] compared the initial surface absorption and chloride diffusion of high performance concrete with zeolite, silica fume and pulverized fuel ash. They revealed that the zeolite was more effective than pulverized fuel ash but lower than silica fume in increasing the compressive strength, decreasing the initial surface absorption and the chloride diffusion. Feng et al. [11] produced high-strength and high-flowing concrete with compressive strength of about 80 MPa and slump of about 180 to 200 mm. Nonetheless, to the authors' knowledge, the performance of NZ in SCC is not well documented. Uysal and Tanyildizi [12] predicted the compressive strength of SCC containing NZ exposed to high temperature by means of artificial neural network. They concluded that self-compactibility properties provided only when cement was replaced at the proportion of 5% with zeolite by weight. Although, Cioffi et al. [13] produced SCC containing two types of NZ, at a replacement level of 40%, with slump flow values within the range designated for SF1 class SCC [14]. (Therefore, the present study is an effort to characterize the fresh and hardened properties of SCC containing NZ.) As can be observed from previous researches, NZ as partial replacement of Portland cement can enhance mechanical properties and durability of cement and concrete composites. However, due to different chemical and mineralogical composition, contradictory results can also be seen in literatures which necessitate further studies. Therefore, the present study is an effort to characterize the fresh and hardened properties of SCC containing NZ. The usage of NZ becomes more noticeable when considered that NZ is abundantly deposited and can be easily quarried and processed in some region. This may offer a lowered economical unit cost compare to other previously mentioned pozzolanic additions [7].

The experimental investigations were divided in three parts. In the first part, workability of the SCC mixture will be assess by several tests such as slump flow, visual segregation index (VSI), required time of SCC to reach 500 mm length slump-flow diameter (T_{50}), V-funnel and L-box. To simulate the real-world applications, slump flow, VSI and compressive strength will be assessed at different hauling times. Hardened properties will be presented by compressive strength, splitting tensile strength, ultra pulse velocity (UPV), initial (30 min) and final water absorption in the third part of this study.

2. Experimental Program

2.1. Materials

The chemical compositions and physical characteristics of binder materials consisted of Type I Portland cement and NZ are given in Table 1. The fine aggregate was natural river sand and crushed gravel with a nominal maximum size of 12.5 mm was used as coarse aggregate. Polycarboxylic ether based HRWR namely Glenium51 with density between 1.06 and 1.08 g/cm3 (at 20°C) was used to enhance the flowability of the mixtures. In addition, a polysaccharide based VMA in an aqueous solution with a concentration of 20% was used.

Table 1. Chemical composition of Portland cement and NZ.

Chemical composition (%)	Cement	NZ
SiO_2	21.46	68.4
Al_2O_3	5.55	12.5
Fe_2O_3	3.46	1.32
CaO	63.95	1.51
MgO	1.86	1.4
SO_3	1.42	0.45
K_2O	0.54	1.3
Na_2O	0.26	2.2
Physical properties	Cement	NZ
Specific surface (m^2/g)	0.33	0.41
Specific gravity	3.15	2.20

2.2. Mixture Proportion

A total of ten SCC mixes were designed in two groups namely G1 and G2 with W/B ratio of 0.45 and 0.38, respectively. In each group, the reference concrete was only made by Portland cement as binder material. In the remaining mixtures, Portland cement was partially replaced with NZ at four designated contents of 5%, 10%, 15% and 20%. The replacement of NZ in all groups was chosen on the basis of preliminary experimental investigation. In the reference mixes, VMA has been used to achieve proper viscosity and controlling the rheological properties of the concrete mixture. Moreover, the dosage of HRWR was adjusted in all mixes to obtain a suitable flowability without segregation. The proportions of the SCC mixtures are summarized in Table 2.

Table 2. Mix details of NZ concrete.

Mix group	Mix. ID.	Cement	NZ		Water	W/B	Sand	Gravel	HRWR	VMA
		(kg/m^3)	(%)	(kg/m^3)	(kg/m^3)		(kg/m^3)	(kg/m^3)	(kg/m^3)	(kg/m^3)
G1	SCCH	445.0	0	0	198	0.45	915	810	1.28	0.8
	SCCH5	422.8	5	22.2	198	0.45	905	810	2.15	-
	SCCH10	400.5	10	44.5	198	0.45	900	810	3.12	-
	SCCH15	378.3	15	66.7	198	0.45	890	810	4.78	-
	SCCH20	356	20	89	198	0.45	890	800	4.78	-
G2	SCCL	470.0	0	0	179	0.38	937	810	2.85	1.24
	SCCL5	446.5	5	23.5	179	0.38	944	800	3.55	-
	SCCL10	423.0	10	47.0	179	0.38	951	780	4.07	-
	SCCL15	399.5	15	70.5	179	0.38	957	771	5.71	-
	SCCL20	376.0	20	94.0	179	0.38	957	760	8.57	-

Mixing sequence and duration are important issues to produce stable and self-compactable concrete. In order to supply a similar homogeneity and uniformity in all concrete groups, the procedure established by Khayat et al. [15] was used to produce SCC with NZ. In this way, natural coarse and fine aggregates were homogenized for 30 s at normal mixing speed. Thereafter, adding about half of the mixing water into the mixer while mixing goes on for 1min. The mixture was rested for 1 min so that the aggregates could absorb the water in the mixer. Then, cement and NZ were added and mixed for one more minute. The remaining water and HRWR were introduced to the wet mixture, while mixing was going on for 3 min. Finally, after 2 min resting, mixing sequence resumed for additional 2 min. This optimum time is necessary to disperse HRWR.

2.3. Test Procedure

2.3.1. Fresh Concrete Test

In order to evaluate the effects of NZ on the self-compactibility properties of SCC, slump flow, VSI, T_{50}, V-funnel and L-box tests were performed according to the procedure recommended by EFNARC committee [14]. The ability of concrete to deform under its own weight in the absence of obstructions can be characterized by means of slump flow test. According to EFNARC [14], there are typically three slump flow classes for a range of applications which are summarized in table 3. It is not possible to completely assess the fresh characteristic of SCC by using only slump flow test. But, if the slump flow is kept within a desirable range, it is possible to evaluate the requirements of SCC. The SCC mixtures produced with NZ in the present study were designed to have slump flow values between 660 and 750 mm. The visual stability index (VSI) was used in relation to slump flow as the simplest well known method to detect stability. According to this index, self-compactibility of concrete is scaled into four groups between 0 (highly stable) to 3 (highly unstable). After removing the slump cone, the segregation resistance of SCC can be inspected visually by measuring a coarse aggregate pile or the thickness of cement paste extended beyond the coarse aggregate. Generally, a VSI from one (stable matrix) to 0 has been regarded as acceptable. T_{50} or V-funnel times are measured to assess the viscosity of SCC. On the basis of

EFNARC [14], there are two viscosity classes which determined by V-funnel and T_{50} flow times (table 3). The L-box test is utilized to assess passing ability of SCC when flowing through confined or reinforced areas without segregation or blocking. Table 3 presents the passing ability classifications according to EFNARC [14]. It should be noted that three bar L-box height was utilized in this study to simulate more congested reinforcements.

Table 3. Slump flow, viscosity and passing ability classes with respect to EFNARC [14].

Class	Slump flow (mm)	
Slump flow classes		
SF1	550-650	
SF2	660-750	
SF3	760-850	
Class	T_{50} (s)	V-funnel time (s)
Viscosity classes		
VS1/VF1	≤2	≤8
VS2/VF2	>2	9-25
Passing ability classes		
PA1	≥0.8 with two rebar	
PA2	≥0.8 with three rebar	

2.3.2. Tests on SCC with Hauling Time

Generally, immediately after or during mixing, concrete must be transferred from the mixing location to the construction site. Concrete mixture should design efficiently in order to have enough workability and segregation resistance during this transportation. Compared to normal concrete, SCC required further attention due to its low water content relative to the high cementitious materials content.

The elapsed time from the first contact of water and cement to the time when concrete is placed is described as hauling time [16]. The slump flow change with hauling time was measured at 8, 30 and 60 minutes. In addition, resistance to dynamic segregation was also considered to evaluate the flow performance of SCC mixes with hauling time. It should be noted that following the mix preparation, the agitating speed was adjusted to 4 rpm until the desired hauling time was met. This low speed was chosen to simulate the agitation of the ready-mixed concrete in the truck mixer. The procedures a concrete truck follows upon arriving at the job site were also simulated by adjusting the mixer speed to 18 rpm for 1min just prior to slump flow test. Immediately after measuring the slump flow at each hauling time, 100 mm cubes were casted to estimate the 28-days compressive strength changes with hauling time.

2.3.3. Hardened Concrete Test

After the completion of initial fresh concrete tests, the fresh concrete was poured into the moulds. Specimens have been taken out after 24 h and were kept under water curing regime until the testing day. For each mixes, compressive strength was tested on three 100 mm cubes at the age of 3, 7, 14, 28 and 90 days and the mean value were reported as the strength. Before the compression tests, all prepared specimens were evaluated for UPV measurement using a PUNDIT testing device. Additionally, splitting tensile strength was performed at 28 days using 15×30 cm cylindrical specimens. 100 mm cube specimens were also used for absorption test at 28 and 90 days. Firstly, specimens were dried in oven until they attain a constant weight. Thereafter, they were submerged in tap water and the weight gain was determined at regular time intervals. The absorption at 30 min and the final absorption were determined.

3. Results and Discussions

3.1. Fresh Concrete Results

The characterizations of fresh SCC produced with NZ immediately after the mixing process were examined by slump flow, VSI, T50, V-funnel and L-box and results were summarized in Table 4.

Table 4. Fresh concrete test results.

Mix group	Mix. ID.	Slump flow (mm)	T_{50} (sec)	V-funnel (sec)	Blocking ratio
G1	SCCH	670	2.1	6.7	0.93
	SCCH5	660	2.5	6.2	0.87
	SCCH10	680	3.4	8.3	0.91
	SCCH15	685	3.6	9.1	0.85
	SCCH20	665	4.0	10.4	0.82
G2	SCCL	690	2.8	7.8	0.89
	SCCL5	680	2.4	7.9	0.91
	SCCL10	665	3.5	9.1	0.83
	SCCL15	695	3.7	10.5	0.88
	SCCL20	700	4.6	14.7	0.90

3.1.1. Slump Flow and Visual Stability Index

The effects of NZ inclusion on the slump flow values and HRWR contents are presented in Fig. 1. As indicated in this figure, SCC containing NZ with satisfactory slump flow in the range of 660 to 700 mm can be produced by adjusting HRWR content from 1.28 to 8.57 kg/m^3. This figure also indicated that regardless of the W/B ratio, HRWR demand to maintain slump flow in a desired range substantially increased with the increase in NZ content, which is consistent with the finding by Ahmadi and Shekarchi [4] for normal concrete. According to EFNARC (Table 3), all concrete mixtures can be categorized as slump flow class 2 (SF2). The concrete mixture at this class of slump flow is suitable for many normal applications such as walls and columns.

For a given HRWR dosage, slump flow for SCCH15 with 15% NZ was higher than that for SCCH20 with 20% NZ. This shows that the use of NZ decreased the slump flow of SCC which could be due to the higher surface area of NZ particles compared to Portland cement. A similar conclusion was also observed by Feng et al. [2] and Najimi et al. [7] for normal concrete with NZ. However, contradictory results in the literature [4] showed that the replacement levels from 5% to 15% did not affect the slump of NZ concrete as compared with control concrete.

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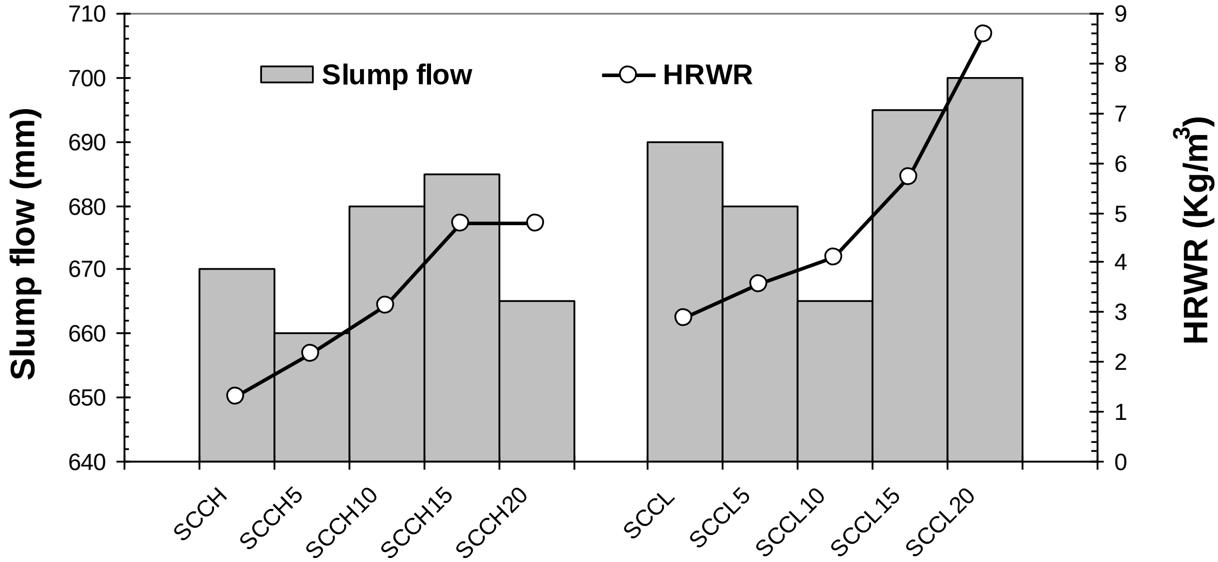

Figure 1. The effect of NZ on the slump flow and HRWR content.

Slump flow values of SCC mixes generally increased with the increase of W/B ratio at the same NZ content (Fig. 1). This may be due to the increase in the lubrication between the fine particles with increasing W/B ratio which resulted in reducing the yielding stress and better flowability. It should be noted that inconsistent trend might be due to the application of higher HRWR for mixtures with lower W/B ratios.

Visual observations during the slump flow test indicated that generally satisfactory VSI within the targeted range of 0 to 1 was attained for all mixes which shows proper stability of all SCC mixes. In addition, uniformity in the distribution of coarse aggregate in the broken split tensile test specimens indicated proper segregation resistance of mixtures.

3.1.2. T_{50} Flow Time

As presented in Table 4, T_{50} flow time for G1 and G2 concrete groups were in the range of 2.12-3.98 s and 2.84-4.67 s, respectively. From this table, all mixtures showed the slump flow time in the range of 2–5 s. At this range of T_{50}, the viscosity is high enough to increase segregation resistance and to limit excessive formwork pressure [17]. T_{50} flow time generally increased with the increase of NZ content and also with the decrease of W/B ratio. Moreover, SCC with NZ did not need any VMA to ensure proper stability, whereas control mixes with W/B ratio of 0.45 and 0.38 have 0.8 and 1.28 kg/m^3 of VMA, respectively. It is well-known from literature [18] that by substituting NZ as a VMA in cement-based grouts, satisfactory rheological properties can be achieved, especially if NZ is used in combination with a superplasticizer.

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3.1.3. V-Funnel Time

The effect of NZ on the V-funnel time at different W/B ratios is shown in Table 4. From this table, V-funnel times for different concrete groups were found to be in the range of 6.2–14.7 s. In a similar trend to that observed for T_{50} flow time, V-funnel times of SCC mixes were mostly increased with the inclusion of NZ. For instance, SCCH had a V-funnel time of 6.7 s which increased to 10.4 s as NZ introduced up to 20% by weight of cement. This result indicates that by using NZ, viscosity of SCC mixtures could be increased. Najim et al. [7] showed that NZ increased the viscosity of fresh normal concrete due to the high surface area of NZ as well as the higher paste volume of the mixtures incorporated NZ in comparison to control concrete. Regarding the effect of W/B ratio, the V-funnel times of G2 concrete group with W/B ratio of 0.38 are about 10–41% higher than that of G1 group with W/B ratio of 0.45, depending on the NZ content.

The viscosity classes of mixtures were illustrated in Fig. 2. According to EFNARC [14], most of concrete mixtures under investigation can be classified as VS2/VF2. This type of concretes can be applied at the ramps and walls/piles with SF2 class slump flow diameter. As presented in Fig. 2, the variation in the T_{50} flow time against the V-funnel times showed that a good correlation can be achieved. An acceptable relationship between T_{50} and V-funnel times has been reported for SCC containing different additions [3, 18].

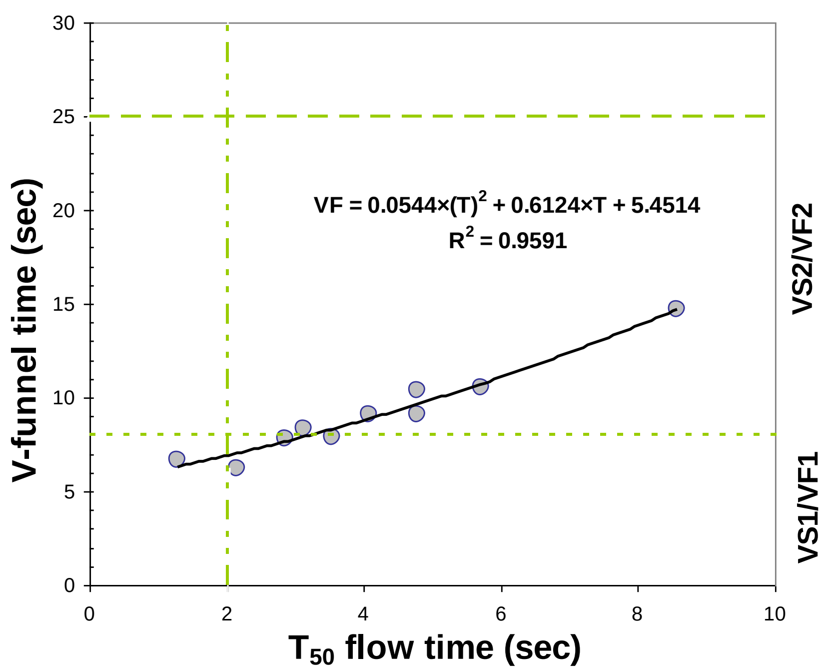

Figure 2. Variation of viscosity classes [14] with T_{50} and V-funnel flow times.

3.1.4. Blocking Ratio

Results obtained from L-box test of SCC mixtures with NZ at different W/B ratios are presented in Table 4. The range found to be from 0.93 to 0.82 without any tendency of blockage. According to the results, the highest blocking ratio was achieved for SCCH and the lowest for SCCH20. As per EFNARC [14], a stable SCC should exhibit a blocking ratio equal to or higher than 0.8. Accordingly, all SCC mixtures prepared in this study showed proper ability to flow through the rebar of the L-box apparatus.

3.1.5. Slump Flow Retention and Visual Stability Index

The effect of NZ at W/B ratio of 0.45 and 0.38 on the flowability loss of SCC mixtures was illustrated in Figs. 3 and 4, respectively. It has been reported that generally, SCC with slump flow value lower than 500 mm cannot completely pass through the highly dense reinforcement [20]. Hence, the slump flow values higher than 500 mm were considered in Figs. 3 and 4. As could be expected, flowability loss was observed for all mixtures with hauling time. This may be due to: (i) the adsorption of superplasticizer on the cement hydrated product, (ii) the stiffness of matrix due to growth of hydration product, (iii) the additional fines brought to the concrete matrix by the grinding of aggregates and (iv) a reduction in the mixing water by evaporation [21-23]. Moreover, the rate of slump flow reduction was higher for mixes with higher amount of NZ. For instance, the slump flow retention of SCCH5 at 60 min of hauling time were found to be 80%, whereas the slump flow retention of 80% were measured at 30 min for SCCH15.

It is well described in literature that different additions have different effects on slump flow losses. While flowability can maintain till about 60 min of hauling time for SCC containing 20% fly ash [24] or 22% limestone powder [25], the results of this study showed that the slump flow of SCC with 20% NZ decreased rapidly over hauling time. This can be explained by the fact that NZ has extremely small pores and channels (varying in size from 3×10^{-4}-4×10^{-4} μm) which can absorb the mixing water over hauling time. Furthermore, it can be inferred that the higher rate of workability loss can be observed for the lower W/B ratio.

The dynamic segregation resistance of SCC mixes with hauling time was also considered through the VSI. Results showed that all mixtures had a VSI of zero, indicating high stability of the SCC mixture.

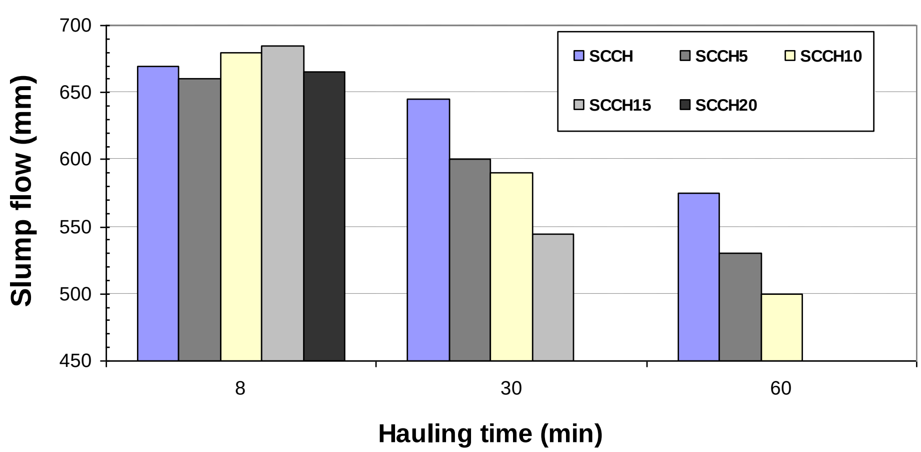

Figure 3. Slump flow vs. hauling time for G1 concrete group.

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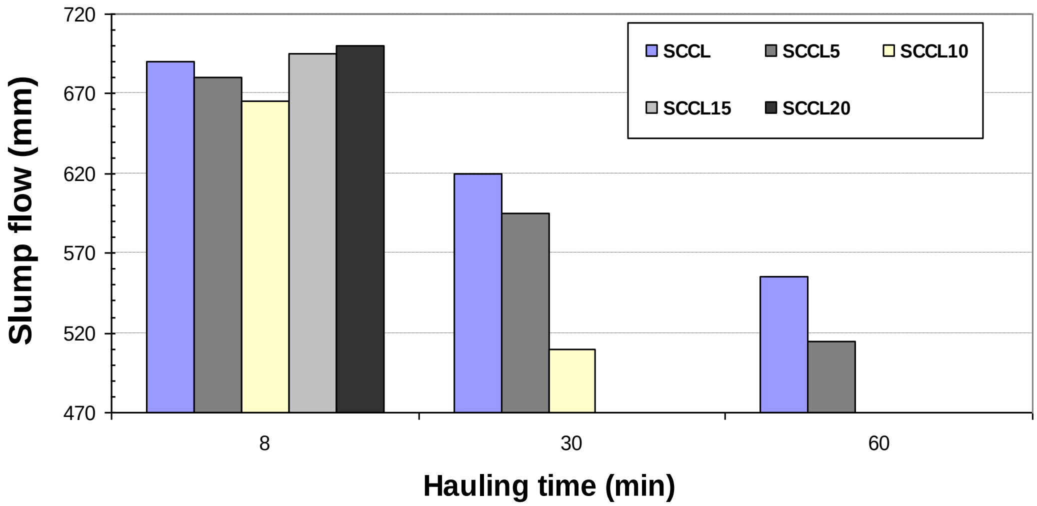

Figure 4. Slump flow vs. hauling time for G2 concrete group.

3.2. Hardened Concrete Results

3.2.1. Compressive Strength

The results of compressive strength of SCC mixtures made with various contents of NZ at different W/B ratios are included in Figs. 5 and 6. From these results, compressive strength for G1 and G2 concrete groups was in the range of 13.2-37.2 MPa and 13.9-53.8 MPa, respectively. As expected, compressive strength enhanced by the age of concrete. However, relatively higher rate of compressive strength development was measured for NZ mixtures at longer ages, mainly owning to the pozzolanic reaction of NZ. For instance, compared with plain concrete, there was a decrease of about 12% in 3-days compressive strength of SCCL15 while this value increased to 3% at the age of 90 days.

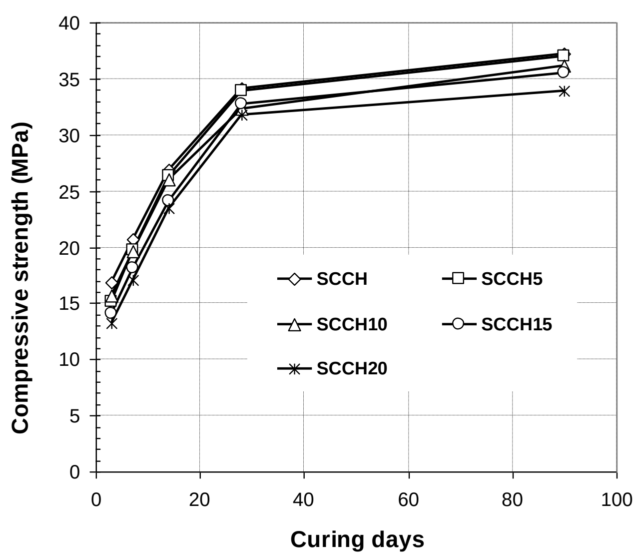

Figure 5. Compressive strength of G1 concrete group.

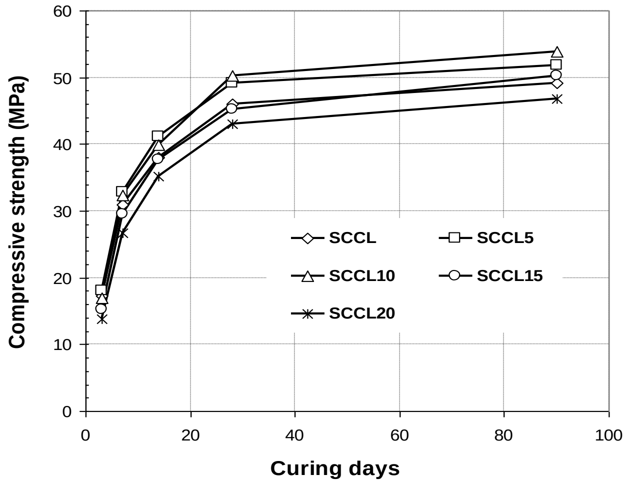

Figure 6. Compressive strength of G2 concrete group.

The effect of NZ on the compressive strength of SCC mixtures is generally related to its W/B ratio. Concerning G1 group with W/B ratio of 0.45, replacement of NZ led to lower compressive strength with respect to the control concrete at all ages while compressive strength improvement up to 9% can be observed when NZ was used in mixes with W/B ratio of 0.38 (G2 group). This indicated that NZ in SCC shows better performance in a lower W/B ratio. The same behavior was also reported for normal concrete or cement paste [6] with NZ. Najimi et al. [7] showed that there was a decrease of 37.9% in the compressive strength of concrete by inclusion of NZ at w/cm ratio of 0.5. However, when compared with their previous study [3], the 0.40 w/cm concrete with NZ shows greater compressive strength than the corresponding plain concrete at all ages. Furthermore, it can be inferred that 5-10% usage of NZ in SCC has the highest strength developments among different NZ inclusion (Figs. 5 and 6).

For mixes with similar NZ content, the compressive strength was found to decrease when W/B ratio was increased. With decreasing W/B ratio, the number of microcracks between aggregate particles and paste, and porosities of the hardened paste generally reduces [14]. Therefore, a higher strength can be obtained.

3.2.2. Compressive Strength with Hauling Time

Figs. 7 and 8 present 28-day compressive strength changes of SCC with NZ in relation to hauling time. It can be observed that concrete mixes mostly show a slight increase in the compressive strength up to 30 min of hauling time. The possible mechanism of the increased compressive strength can be discussed in relation with the vaporization of the mixing water. This can lead to a decrease in W/B ratio with hauling time, and hence increasing compressive strength. However, as the mixing time is elapsed, due to the lack of homogeneity caused by insufficient compaction, the compressive strength increasing trend has been declined. looking at the results more closely (Figs 7 and 8), it can be inferred that generally strength reduction can be observed for mixtures which had a slump flow lower that 550 mm after 30 or 60 min of hauling time when compared with control SCC.

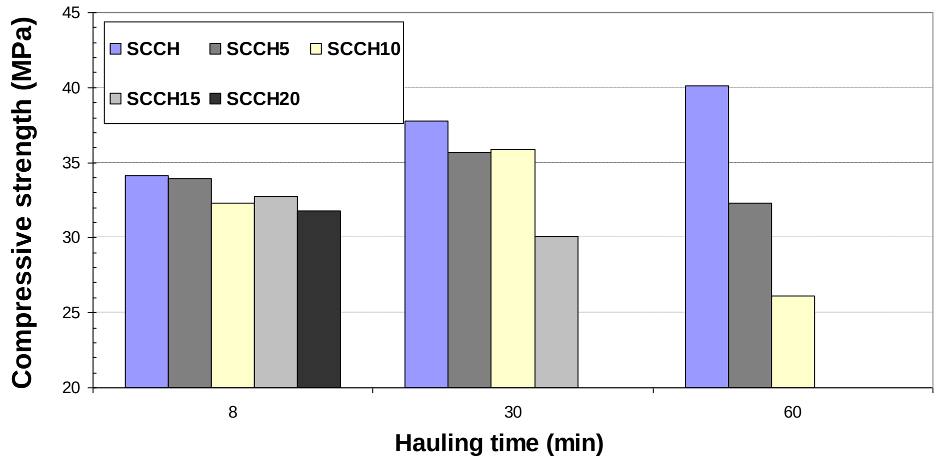

Figure 7. 28-days compressive strength of G1 concrete group over hauling time.

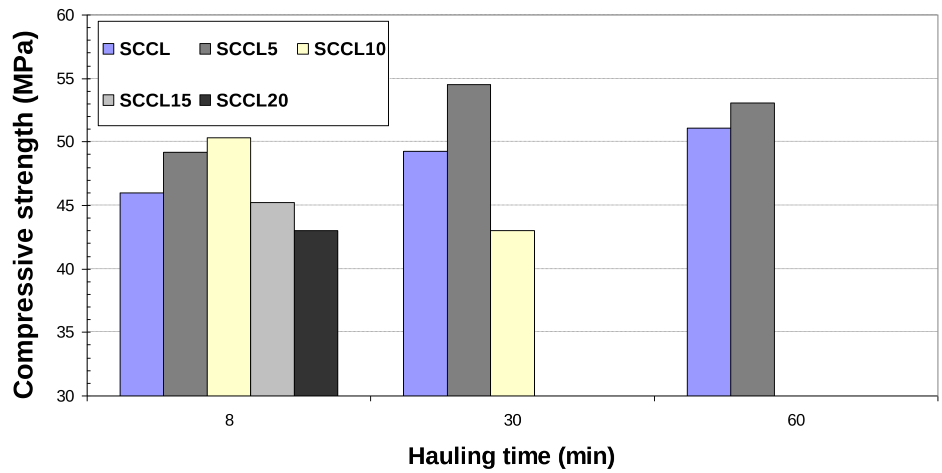

Figure 8. 28-day compressive strength of G2 concrete group over hauling time.

3.2.3. Ultrasonic Pulse Velocity (UPV)

The UPV variation with age for SCC made with different NZ contents and W/B ratios is shown in Fig. 9. The ultrasonic pulse velocity ranged from 3.37 to 3.98 km/s at 3 days, from 3.56 to 4.31 km/s at 7 days, from 3.88 to 4.71 km/s at 14 days, from 4.11 to 4.94 km/s at 28 days and from 4.36 to 5.01 km/s at 90 days. Concrete quality is suggested by Whitehurst [27] as excellent, good, doubtful, poor and very poor for the UPV values of 4500 m/s and above, 3500–4500 m/s, 3000–3500 m/s, 2000–3000 m/s and 2000 m/s and below, respectively. Accordingly, most concrete mixtures were found to have good and excellent quality. It was also found that UPV values tend to increase with the age for all of the SCC mixtures. In a similar trend to that observed for compressive strength, there was a decrease in the UPV values with increasing NZ content for G1 group while the positive effect of 10% NZ on UPV measurement of SCC can be observed for G2 group. The effect of NZ on the UPV was being more significant at later ages.

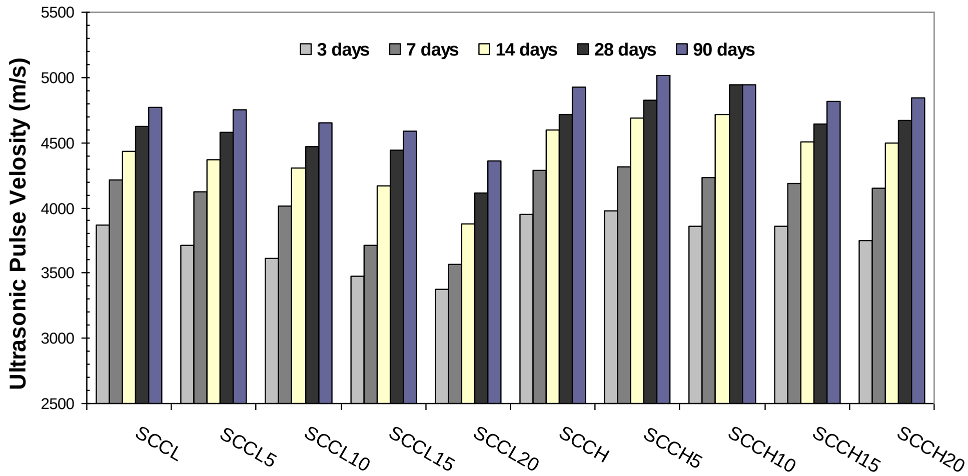

Figure 9. UPV values of SCCs containing NZ.

UPV value is influenced by many variables such as ambient temperature, aggregate type, curing regime, mix proportion and etc. Nonetheless, it is possible to non-destructively monitor the strength of concrete by means of UPV measurement. The relationship between compressive strength and UPV values of SCC with and without NZ were described in Fig. 10. As indicated in this figure, good correlations can be found between UPV and compressive strength, with R2 values equal to 0.91 and 0.97 for control SCC and SCC with NZ, respectively. Moreover, at a high compressive strength the UPV value of mixtures seems to be independent of the NZ content.

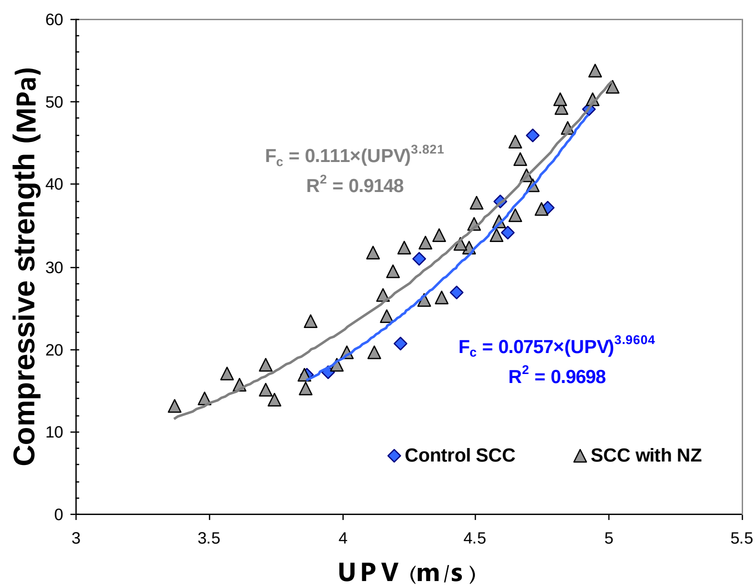

Figure 10. Variation of UPV with compressive strength.

3.2.4. Split Tensile Strength

The variation of compressive strength with splitting tensile strength of SCC containing NZ was studied and results are illustrated in Fig. 11. It should be noted that the 100-mm cube compressive strength was converted to cylindrical strength by applying suitable conversation factor [29]. The splitting tensile strength for G1 and G2 concrete groups was in the range of 2.7-2.29 MPa and 3.09-2.69 MPa, respectively. Splitting tensile strengths of G1 group had the tendency to decrease with an increase in NZ content while at 5% replacement of NZ for G2 group the splitting tensile strength improved as much as 3%. From Fig. 11, it can be observed that the splitting tensile strength increased with increasing in compressive strength. Based on the results at 28 days, the expression $f_t = 0.72 \times (f_c)^{0.38}$ represents the relationship between the compressive strength and splitting tensile strength. This equation provided lower values than those obtained by ACI 318-05 [30] and CEB-FIP [31].

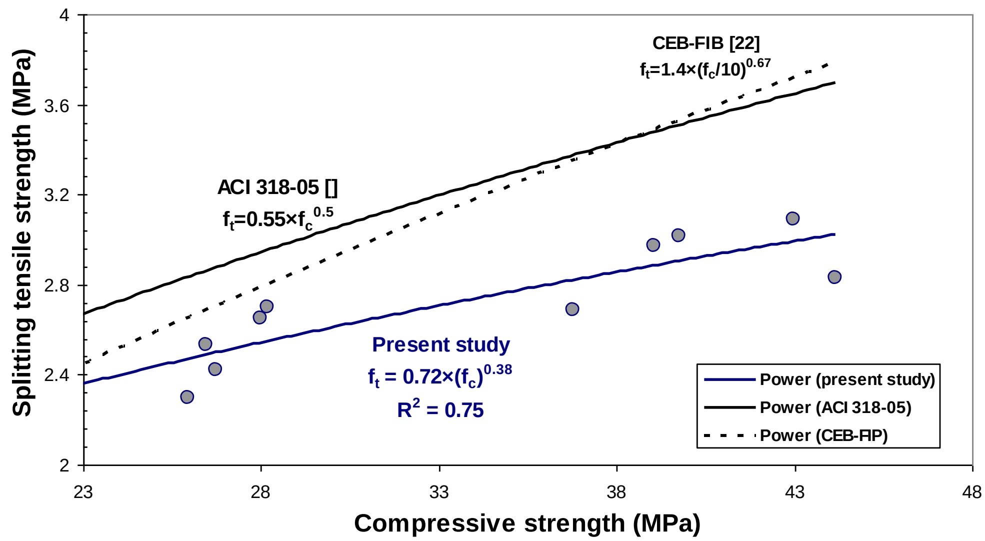

Figure 11. Splitting tensile strength of SCCs at 28-days.

3.2.5. Absorption

Results of initial and final absorptions at the age of 28 and 90 days are summarized in Figs. 12 and 13, respectively. CEB-FIP [32] categorized concrete quality as poor, average and good for initial water absorption values of 5% and above, 3–5% and 0–3%, respectively. All concrete mixtures under investigation showed an initial absorption lower than 3% which can be categorized as ‘‘good’’ concrete quality. Moreover, the final absorption was in the range of 1.74–3.87% at 28 days and in the range of 1.47–3.48% at 90 days. It has been reported that concrete with high quality usually has water absorption lower than 5% [33].

The absorption values of the SCC with NZ were found to be lower than the control SCC at all ages. This is in agreement with the results of Ahmadi and Shekarchi [7] reported that normal vibrated NZ concrete mixtures displayed lower water absorption than the control mixture. The water absorption decreases on control SCC up to 10.2% by increasing ages, whereas this value ranges from 13.8% to 19.2% and from 11.9% to 14.7% for NZ mixtures with W/B ratios of 0.38 and 0.45, respectively. This result shows that the use of NZ significantly decreases the water absorption of SCC with increasing curing ages. This can be explained by the pozzolanic activity of NZ during the prolong curing. Furthermore, the water absorption of SCC mixtures has a decreasing tendency with the decreasing W/B ratio.

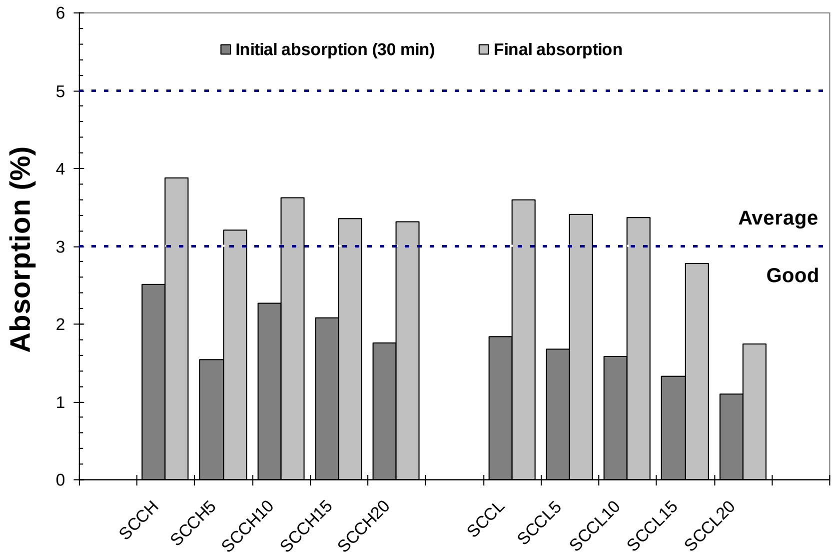

Figure 12. Water absorption of SCC mixtures at 28-days.

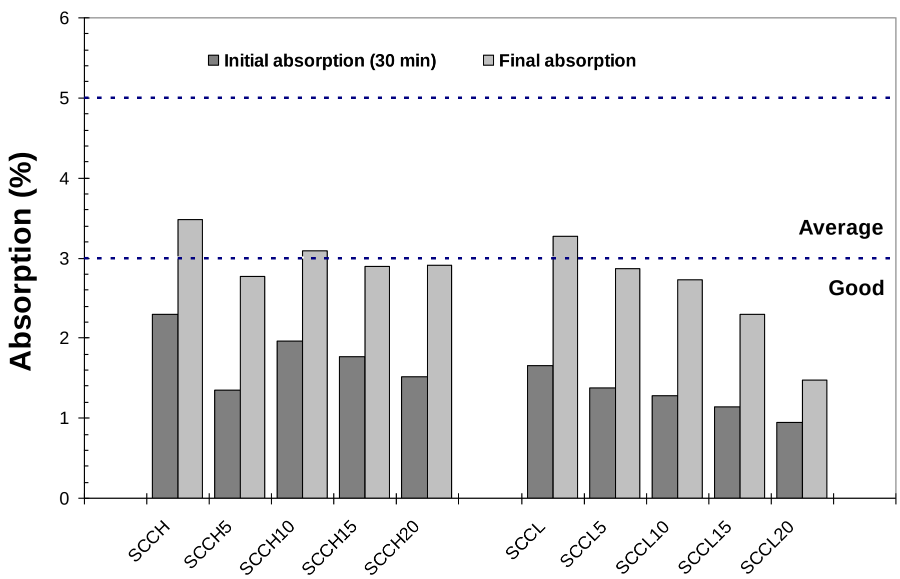

Figure 13. Water absorption of SCC mixtures at 90-days.

4. Conclusions and Discussions

In this paper fresh and hardened properties of SCCs made with NZ at different W/B ratios were evaluated. The following conclusions were drawn according to the results of this study:

1- All of the concrete mixtures had slump flow within the range of 665–700 mm by adjusting HRWR dosage. Accordingly, all mixtures were classified as SF2 which can use in many normal applications. Moreover, it was pointed out that the mixture with the higher content of NZ needs higher HRWR dosage to remain in SF2 class.

2- Increasing NZ content in the formulation of SCC generally results in increasing plastic viscosity which describing by T_{50} and V-funnel flow times. It was also found that V-funnel time can well correlate with the data obtained from T_{50} with a sufficient correlation coefficient of 0.96.

3- The use of NZ in SCC shows a blocking ratio higher than 0.82. This range fulfills the EFNARC recommendation in terms of passing ability.

4- (Results revealed that) NZ inclusion decreases the slump flow retention of the SCC mixtures. Plain SCC maintain its flowability till about 60 min of hauling time while SCC with 20% NZ losses its fluidity relatively quickly over hauling time. This suggests that special care must be taken for transportation and handling of SCC with high content of NZ.

5- Compressive strength of SCC with 10% NZ at W/B ratio of 0.38 was 6% higher than those of plain SCC, while using NZ in SCC at W/B ratio of 0.45 leads to decrease in compressive strength. This showed compressive strength increased with a decrease in W/B ratio (NZ impact for strength increasing is more significant for a lower W/B ratio). Additionally, SCC produced with NZ generally (performed better in strength development) has higher compressive strength development at longer ages than control mixture.

6- At prolonged mixing time, SCC mixtures have lower strength than reference mix; if they slump flow was lower than 550 mm.

7- SCC with NZ mostly has UPV values higher than 3500 m/s which can be categorized as good and excellent concrete quality. Furthermore, at a high compressive strength, the effect of NZ on the UPV values seemed to be negligible.

8- Splitting tensile strength of SCC with NZ showed relatively similar trend to that observed for compressive strength. CEB-FIP and ACI 318-05 relationship overestimated the splitting tensile strength of SCC with NZ.

9- Absorption lower than 3% at 30 min can be achieved for NZ mixes classified as ‘‘good’’ concrete quality. Moreover, NZ significantly decreases the water absorption of SCC as curing ages increases.

10- In general, it seems that 10% NZ can be considered as a suitable replacement regarding to the economic efficiency, fresh and hardened properties of NZ concrete.

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