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Experimental Investigation of Self-compacting High Performance Concrete Containing Calcined Kaolin Clay and Nano Lime

Akram Obeed Kadhum [a*], Haider M. Owaid [b]

[a] *Babylon Municipalities Directorate, Babil, Iraq.*

[b] *Department of Civil Engineering, Faculty of Engineering, University of Babylon, Babil, Iraq.*

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Abstract

The aim of this research is to investigate the effect of pozzolanic materials and nano particles on improve the strength characteristic by the properties of a self-compacting high-performance concrete that includes calcined clay with nano lime. In this study, two blends systems are worked on, they are the binary and the ternary systems. For binary mixtures, test samples were prepared from 5% CC, 10% CC, 15% CC and 3% NL by partial replacement of the cement weight. While ternary mixtures, samples were prepared from 5% CC 3% NL, 10% CC 3% NL and 15% CC 3% NL by partial substitution of cement weight. The tests conducted on mixes are fresh tests like slump flow diameter, V-funnel, L-box, and segregation resistance. The compressive strength test was determined at 7, 28 and 56 days. While splitting tensile strength tests at 7 and 28 days from the SCHPC produced in the study. It was concluded that the replacement of CC and NL in SCHPC binary mixes reduced the fresh results enough for SCHPC production and gave a general improvement in the compressive strength and splitting tensile strength properties of the SCHPC mixture. SCHPC with 10% CC partial replacement of cement showed higher values of compressive and splitting tensile strength, compared to the reference mixture of SCHPC for all days, thus it was considered the best. Whereas, the strength of the concrete mixtures in the ternary cement mixtures was better than the strength of the mixing and control mortar systems for the same replacement levels in 7 , 28 and 56 days.

Keywords: Strength; Calcined Clay; Nano Lime; Self-Compacting High Performance Concrete (SCHPC).

1. Introduction

High-Performance Self-Compacting Concrete (SCHPC) is a special type of concrete. It combines the requirements of two types of concrete, namely, self-compacting concrete and high-performance concrete. Self-Compacting Concrete (SCC) is concrete that fills the mold and spreads during heavy reinforcement under the influence of its weight and does not require vibration [1]. Requirements for self-compact concrete include good filling ability, high passing ability, and ability to resist segregation. But it does not include durability and high resistance. Whereas, on the contrary, High Performance Concrete (HPC) is one of its most important requirements, and does not need its ability to filling and passing well [2]. To produce high performance self-compacting concrete, we need cement additives, which are useful for improving resistance, durability and segregation resistance. Also, we need high range water reducers, which are useful for achieving workability and passing ability [3]. The high-performance self-compacting concrete (SCHPC) has a high powder amount and little water content, while it has a lot of fine aggregate and little coarse aggregate compared to normal concrete [4].

* Corresponding author: akramob081@gmail.com

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Self-Compacting High Performance Concrete (SCHPC) differ from conventional concrete in fresh and hardened states which are driven mainly by outstanding material components and combination proportions. This uses many special ingredients such as wide-range water reducing (HRWR) admixture for sufficient flow ability and a high volume of powder materials and/or Viscosity-Modifying Admixture (VMA) to achieve high segregation resistance, in addition to the basic materials used for Normal Vibrated Concrete (NVC). The proportions of component materials in SCHPC often differ materially from those in NVC [5]. In recent times, most of the students went to the field of nanoparticles due to their main effects in the field of concrete on (size, surface, interface, and quantum) [6, 7]. When adding nanomaterials to concrete mixtures, concrete performance and properties will improve due to the addition of nanomaterials. Some studies investigating the effect of adding nanomaterials to concrete are reported.

Özcan and Kaymak (2018) note that when adding metakaolin in different proportions 10%, 15% and 20% as a partial replacement with weight of cement to the self-compacting concrete mixture, the compressive strength will improve at ages 7, 28, 90 and 180 days to comparison with reference mixture [8]. Kumari et al. (2016), attempted to understand the effect of nano $CaCO_3$, nano TiO_2, and (nano TiO_2 + nano $CaCO_3$) upon the properties of the fly ash concrete with contents 0.5, 1, 1.5, 2, 2.5 and 3% by the weight of cement. From durability point of view, 2% substitution of nano particles demonstrated a very good resistance to Cl ion penetration and a high ph value. The workability of fresh concrete showed a decline in the slump value as the percentage of nanoparticles increased, compressive strength decreased with nano $CaCO_3$, while it increased in combination of nano TiO_2 and nano $CaCO_3$ at some percentages [9]. Wang et al. (2016), investigated the influence of nano $CaCO_3$ and nano silica on the hardening of cement-silica fume-fly ash UHSC. Results of the tests manifested that the flow ability of UHSC was decreased by incorporating nano $CaCO_3$ and nano silica content. The compressive strength increased at first then decreased, while the porosity value was vice versa. In regard, the calcium hydroxide content decreases with the increase of nano silica and raises with the nano $CaCO_3$ level increase [10].

Wu et al. (2016) studied nano $CaCO_3$ added to Ultra-High Strength Concrete (UHSC) in different proportions 1.6, 3.2, 4.8 and 6.4% as a partial replacement with cement weight. They observed that the compressive strength and flexural strength of UHSC increased compare to reference mixture at early and later ages. Except 6.4% nano $CaCO_3$ mixture. Whereas the strength decrease compare to the reference mixture [11]. Dadsetan and Bai (2017), investigated the mechanical and microstructural properties of self-compacting concrete (SCC) mixtures containing three Supplementary Cementitious Materials (SCM), namely metakaolin, ground granulated blast-furnace slag and fly ash. For the mixtures, cement was replaced by SCM at different levels 10, 20% for Metakaolin and 10, 20 and 30 % both GGBS and Fly Ash [12].

The mechanical properties were evaluated against a control mixture (without SCM). Metakaolin gave the most enhancing effect as a replacement material to cement on mechanical and microstructural properties of SCC at all ages. Faiz et al. (2017), studied the properties and microstructures of high volume fly ash cement paste incorporating with nano $CaCO_3$ and nano silica particles, nanoidentation results indicated the pozzolanic reaction, where the addition of 2% nano silica and 1% nano $CaCO_3$ increased the volume fraction of C-S-H gel and reduced the porosity [13]. Nanostructure showed that the high strength and high durable concrete can produce lower repair and maintains the requirements for concrete structure. Barkat et al. (2019), studied the effect of adding local metakaolin to the mechanical and rheological performance of self-compacting limestone cement. In this study, two types of cement were used, which are Portland Cement (PC) and Portland limestone cement (PLC), the local calcined clays were added at a temperature of 850 °C for 3 hours in different proportions 5, 10, 15, 20, 25% of the cement weight. The durability properties are porosity and water absorption were studied. Through the results, which showed that the porosity of water for concrete mixtures containing metakaolin at 28 days of age, decreased slightly compared to the reference mixture. The absorption of capillary water for mixtures containing metakaolin is lower compared to the reference mixture at ages 7, 90 days except for the mixture containing 10% metakaolin exposed to a high water absorption. This study achieved its goals through sustainable production SCHPC incorporating calcined pozzolanic materials (CC) and nanoparticles (NL) that could contribute to reducing cement demand, declining CO_2 emission rate, and make durable and eco-friendly SCHPC [14].

2. Materials and Mix Proportions

2.1. Materials

Cement

Type I cement was used in this study locally (Karasta). As its physical and chemical properties were identical to the Iraqi standard specifications (IQS NO.5/1984) [15].

Fine Aggregate

An important factor in producing high-performance self-compacting concrete that is taken into consideration is the amount of fine aggregate, its gradation and the shape of its particles. In this study, natural sand and locally present in

Al-Akhdar area was used as the fineness modulus 2.31 and it falls within the third gradient area according to the Iraqi standard specifications IQS NO.45⁄1984 [16]. Physical properties and sulfate content of fine aggregate as shown in table 1. While the grading of fine aggregate used is shown in Figure 1.

Table 1. Physical properties and sulfate content of fine aggregate

Physical Properties	Test Results	Limits of the Iraqi Specification (IQS NO. 45⁄1984)
Specific gravity	2.65	--
Sulfate content %	0.3	⩽ 0.50 %
Absorption%	1.5	--
Fineness Modulus	2.31	--

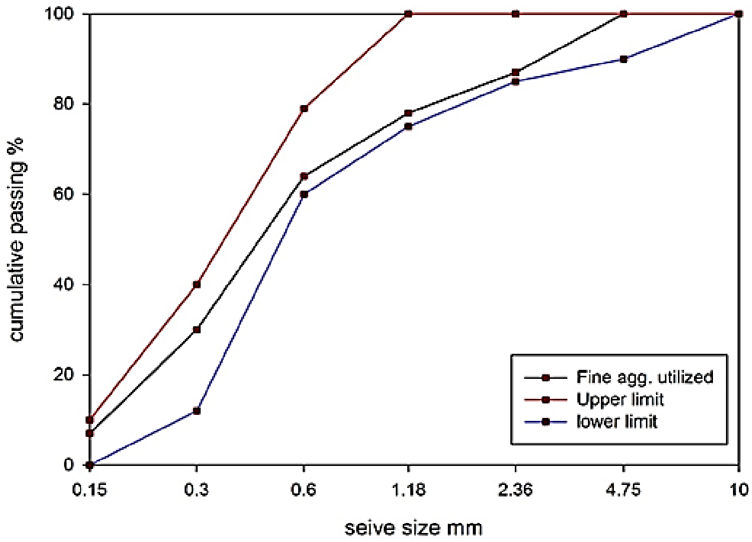

Figure 1. Grading of fine aggregate

Coarse Aggregate

The rounded, washed and locally available gravel was used in Al-Nabaei area with a maximum size 9.5 mm and it was (Specific gravity, absorption and sulfate content) 2.58,0.5% and 0.03%, respectively, and according to the Iraqi standard specifications (IQS NO.45⁄1984)[16]. Figure 2 show the grading of coarse aggregate.

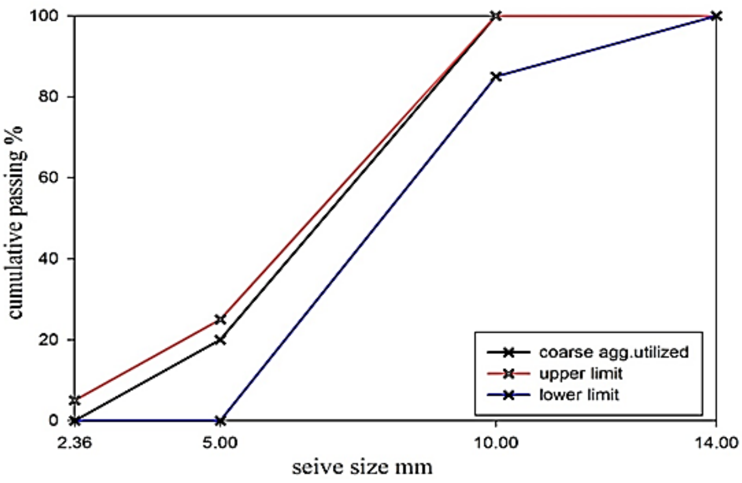

Figure 2. Grading of coarse aggregate

Super Plasticizer

High-range water-reducing additives were used in all concrete mixtures Called (Hyperplast PC200). It satisfies (ASTMC494) [17]. Where it was characterized by a Light yellow Colour, Specific gravity (s.g) 1.05±0.02 and air entrainment typically less than 2%.

Water

In this study, drinking water was used for mixing and curing purposes.

Calcined Clay

The kaolin clays that were used in this research are clays available in the western regions of Iraq. These clays were calcined to a temperature of 800 °C for two hours, to converts it to a pozzolan material named calcined kaolin clay (CC). As shown in Figure 3. Table 2 shows chemical compositions of Calcined Clay (CC). Whereas, the physical properties of (Specific gravity, Fineness m^2/kg and Median particle size (μm)) are 2.59, 1640 and 14.3 respectively.

Table 2. Chemical compositions of calcined clay (CC)

Chemical Composition	Calcined Clay (%)
(SiO2)	54.7
(Al2O3)	37.4
(Fe2O3)	1.72
(CaO)	0.84
(MgO)	0.42
(Na2O)	0.37
(K2O)	0.54
(SO3)	0.13
(P2O5)	0.29
(TiO2)	0.68
Loss on ignition (LOI)	2.91

Figure 3. Calcined clay used in this study

Nano-Lime

The nano-Lime used in this study was prepared by the Sky Spring nano materials company. Commercially available dry nano-$CaCO_3$ powder with a particle size of about 15–40 nm, 97.5% Calcite ($CaCO_3$) content, white colour and a surface area of 40 m^2/g as shown in Figure 4.

Figure 4. Nano-Lime used in this study

2.2. Mix Proportions

In this paper, the European standard (EFNARC, 2005) was used to design concrete mixtures for self-compacting concrete [18]. The content of the raw materials used for concrete mixtures was for total binder content 485 kg/m^3 and constant water/binder (w/b) ratio of 0.36. As for the super plasticizer, it is added in different proportions between 1.6 and 2.0% of weight of cement. Eight mixtures of concrete models were prepared with dimensions of 10× 10×10 cm and 10 diameter × 20 length cm for conducting compressive and splitting tensile strength tests of high-performance self-compacting concrete. The first mixture (Reference-OP) is a reference mixture, four binary mixtures in which the cement was partially replaced with (calcined clays CC, nano lime NL) in different proportions 5% CC, 10% CC, 15% CC and 3% NL from the weight of cement. And three ternary mixture in which the cement was partially replaced with (calcined clays CC and nano lime NL) in different proportions 5% CC 3% NL, 10% CC 3% NL and 15% CC 3% NL from the weight of cement. After the molding process, it was curing 7, 28 and 56 days old. Table 3 and Figure 5 shows mix proportion of concrete mixture and experimental Program of the Research.

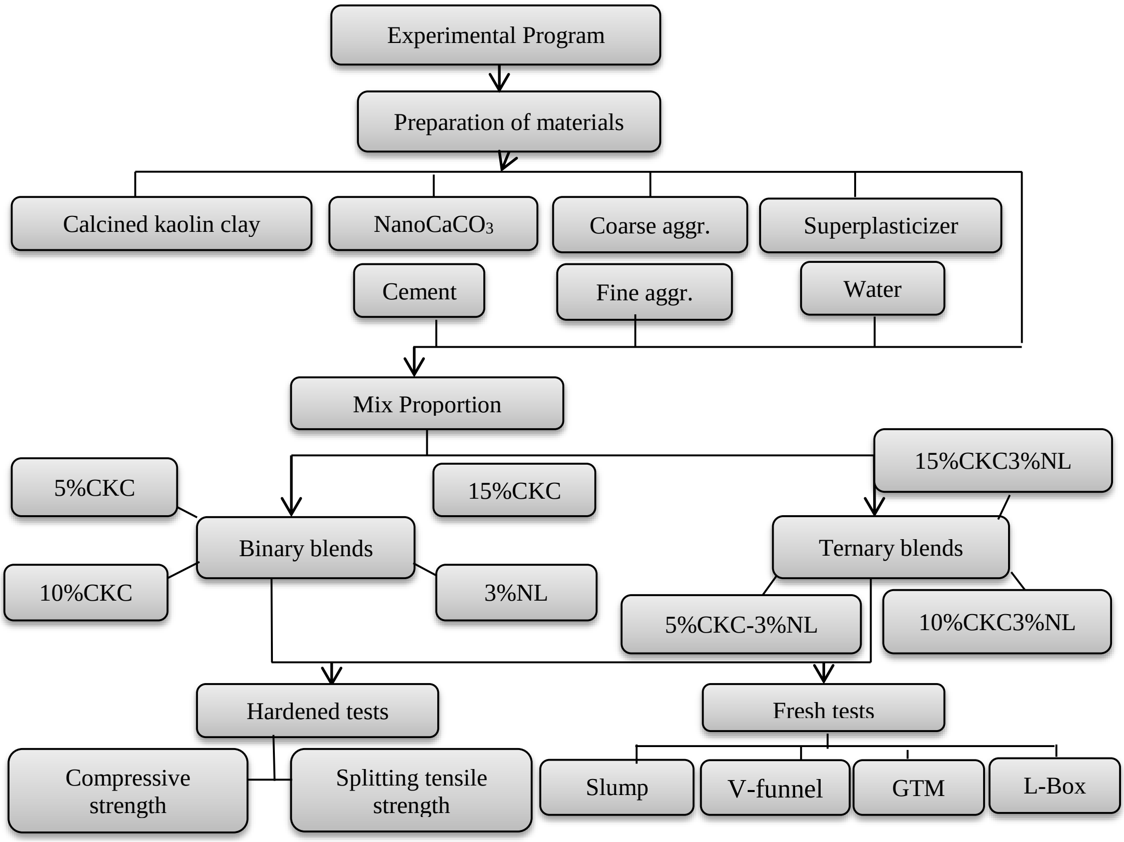

Figure 5. Experimental Program of the research

Table 3. Mix proportion of concrete mixture

Mix notation	Cement kg/m^3	Calcined clay kg/m^3	Nano lime kg/m^3	Fine aggregate kg/m^3	Coarse aggregate kg/m^3	W/b %	Super plasticizer %
Reference-OP	485	----	---	850	862	0.36	1.6
5CC	460.75	24.25	---	850	862	0.36	1.6
10CC	436.5	48.5	---	850	862	0.36	1.6
15CC	412.25	72.75	---	850	862	0.36	1.6
3NL	470.45	---	14.55	850	862	0.36	1.6
5CC 3NL	446.2	24.25	14.55	850	862	0.36	2.0
10CC 3NL	421.95	48.5	14.55	850	862	0.36	2.0
15CC 3NL	397.7	72.75	14.55	850	862	0.36	2.0

2.3. Tests and Curing Regimes

Test of Fresh Properties

Fresh tests for self-compacting high performance concrete (SCHPC) are important tests required to evaluate all the following three workability features of filling ability (flow ability and viscosity), passing ability, and resistance of segregation properties according to the [EFNARC, 2005][18]. However, there is no single test to measure the three characteristics together. In this experimental research, SCHPC's fresh properties were assessed by slump flow diameter, V-funnel, L-box and resistance tests to segregation. The slump flow tool was Abram's cone with a height of 30 cm, a diameter of 10 cm at the peak, and a diameter of 20 cm at the bottom. The slump flow is the diameter average (D_{max} and $d_{perp.}$) to the nearest 10 mm.

The test utilized to evaluate the filling ability SCHPC is the V funnel examine. Whereas, the test procedure and the apparatus used are described in European self-compacting concrete guidelines, 2005. The funnel is filled with concrete from SCC with no pressure applied. Any excess concrete is removed from the top of the funnel using a straight edge. After a waiting period of (10 ± 2) seconds, we open the gate, and at the same time, the stopwatch starts. After that, we look inside the funnel and upon seeing visible areas we stop the watch. Stopwatch reading is reported as streaming time with V-funnel.

L-Box examination can be used to determine SCHPC's passing ability to flow without segregation or blockage in the presence of reinforcing obstructions. As defined in the European self-compacting concrete guidelines, 2005. The vertical portion of the L box is filled with fresh SCC. Let the concrete stay for 1 minute in the vertical section. Concrete will be displayed during this time whether or not it is stable (Segregation). Second, we lift the slide gate and let the concrete flow out into the horizontal portion. Therefore, the height of the L-box was the average of the concrete height at the end of the horizontal portion to the concrete height at the beginning of the same section.

Stability test for sieves can be used to assess resistance of segregation (stability), the equipment and the test protocol as defined in the European guidelines, 2005. Resistance of segregation is the ability of a fresh blend to retain the initial, reasonably consistent distribution of constituent products. Approximately 10 liters of concrete were poured into a bucket, covered to avoid loss of moisture and allowed to settle for around 15 minutes. Then a concrete sample of 4.8 ± 0.2 kg was poured on a sieve of 5 mm with a diameter of 350 mm and left for 2 minutes to enable some mortar to move through and rest on a sieve pan with a weight scale. The segregation index was measured as the ratio of mortar weight compared to the weight on the sieve of the initial sample.

Compressive Strength

According to (BS. 1881: Part 116: 1989) [19] conducted the compressive strength test , Cubes (10×10×10) cm with a loading rate of 18 MPa/minute were tested using a hydraulic compression machine (2000) KN. At each test, an average of three cubes was adopted and tested at 7, 28 and 56 days.

Splitting Tensile Strength

The splitting tensile strength was applied using (ASTM C496-2004) [20] specification cylinders of 10×20 cm. The test involves the measurement of diametric compressive force along the length of a cylindrical concrete specimen at a rate of 1.4 MPa/minute until the failure occurs. At each test the average of two cylinders were taken and tested at 7 and 28 days.

Curing Regimes

Water curing for self-compacting High Performance concrete and is very essential due to the low water cement ratios employed. All of the specimens are demoulded 24 hours after casting and covered with plastic sheeting to preserve its moisture. Specimens are then cured in water at approximately 20 ^{0}C until testing is carried out.

3. Results and Discussion

3.1. Fresh Examination Results

Figures 6 and 7 present slump flow diameter and V funnel flow times, respectively, to show the level of SCHPC viscosity. Figures revealed the size of the slump flow diameter (mm) decreased and the height of the V-funnel flow period in the binary mixes 5CC, 10CC, 15CC and 3NL, by about 3.22, 5.16, 7.1 and 1.93% and 8.57, 18.57, 40 and 4.28% respectively, when compared with the reference mix. For the control concrete the lowest V-funnel flow times of 7.0s were determined whilst the 15CC combination had the maximum flow period of 9.8 s. The concrete generally became more viscous with CC in the binary system. However, utilizing NL substitution beyond 3 percent, the low viscosity rate resulting in low V-funnel flows of SCHPC mixtures. This reason could be due to the shape and size of the calcined kaolin clay particles which are long, hexagonal plates that create obstacles in the fresh mix and increase friction between the particles and also fine particle size of CC and Nanomaterials (NL), which have much larger surface areas that absorb water. The same results were proved by the other researchers [8, 21-23].

Whereas, in the ternary blends mixes 5CC-3NL, 10CC-3NL and 15CC-3NL, It can be observed that the slump flow diameter value declined and height V-funnel flow time, by about 6.45, 7.74 and 10.97% and 17.14, 40 and 62.86% respectively when compared with the reference mixture. The same trend was shown in the state of binary mixes with CC, while in ternary blends of mixtures incorporating CC and NL, the effect of replacement level more appeared. This is due to a result of the synergetic effect of the two reasons explained above. Similar trends were conducted by previous studies [12, 24]. Figure 8 displayed that the binary mixtures (5CC, 10CC, 15CC and 3NL) have lower passing ability compared to the control mixture, by about 2.53, 5.9, 7.38 and 2.21% respectively. The L-Box height ratio value diminished as partial substitution of cement increased. Because the influence of the proportion and fineness of calcined kaolin clay (CC) and nano lime (nano CaCO3), which reduces the ability of passing in the same way to reduce the filling ability. similar results were reported by [22, 25, 26]. But it does not agree with the study [27].

Whereas, it can be observed that this effect increases with the ternary mixtures 5CC-3NL, 10CC-3NL and 15CC-3NL by about 4.22, 7.49 and 10.76% compared to the unblended mixture 100% OPC. this is due to a result of the synergetic effect of the reasons explained above. no blocking or segregation phenomenon were found in the mixes at the time of the test execution. these results are similar to the results study [25]. From the previous works on fresh test of blended SCHPC, it can be observed that the replacement of CKC or NL, from the cement, rises in water demand because of their fineness and reactivity with cement [24, 28]. Figure 9 illustrated the results of the sieve stability test for binary and ternary blends of SCHPCs mixes, it can be seen that the binary mixtures (5CC, 10CC, 15CC and 3NL) have more segregation resistance compare with reference mix, as the percentage of segregation decreases with an increasing percentage of partial replacement. The percentage of decrease was about 13.33, 16.66, 25 and 5.83% for binary mixes above, respectively.

Whereas, ternary mixtures (5CC-3NL, 10CC-3NL, and 15CC-3NL) have a higher segregation resistance compared with reference mixtures and binary mixtures of similar proportions. That is, the segregation ratio decreases further in the ternary mixes about 8.33, 22.5 and 31.66%, respectively. This may be due to impact of surface area increase of the nanoparticles, which leads to increased viscosity, thus increasing the segregation resistance. similar results were with previous findings [29, 12].

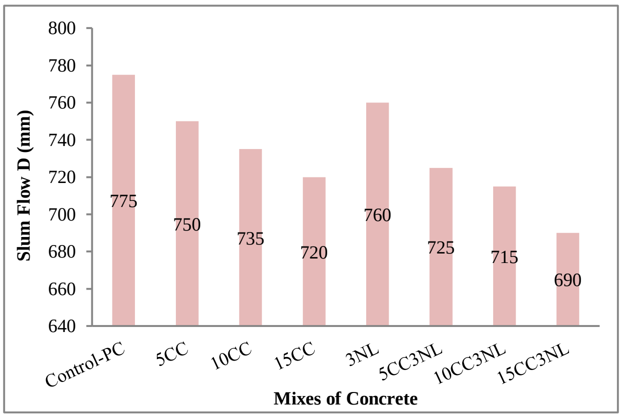

Figure 6. Slump flow diameter test results

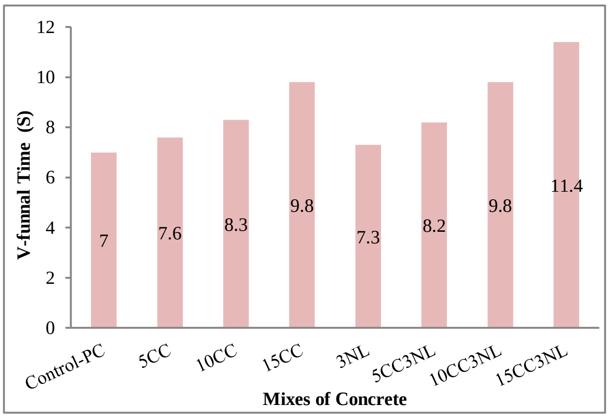

Figure 7. V-funnel time test result

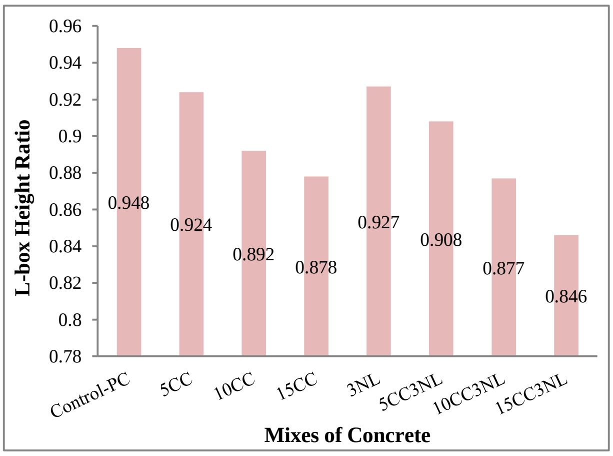

Figure 8. L-Box test results

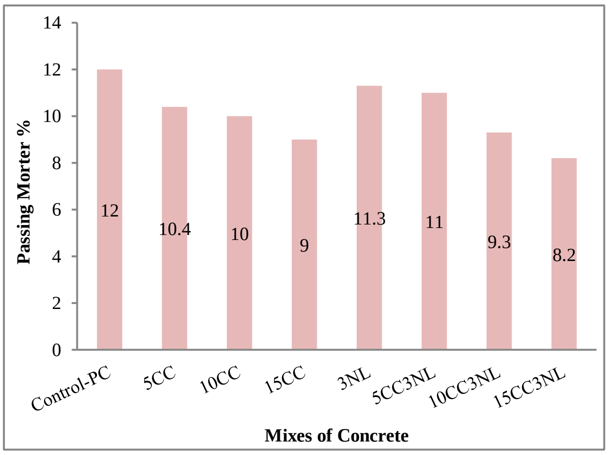

Figure 9. segregation resistance test results

3.2. Compressive Strength

After performing laboratory tests of high-performance self-compacting concrete mixtures in the laboratories of Babylon University/Faculty of Engineering, Department of Civil Engineering, the results shown in Table 4.

Table 4. Compressive strength results

Compressive strength MPa	Mixes							
	Reference-OP	5%CC	10%CC	15%CC	3%NL	5%CC 3%NL	10%CC 3%NL	15%CC 3%NL
7day	42.7	44.2	46.9	46.2	52.7	55.7	57.4	56.8
28day	54.1	57.4	61.2	59.5	64.3	70.3	74.7	72.8
56day	58.1	62.7	67.1	64.7	68.2	74.1	77.3	76.1

We note from the results obtained and shown in Table 4 and Figure 10. is that the compressive strength in the binary mixtures (5%CC, 10%CC, 15%CC and 3%NL), has a higher compressive strength when compared to the values of the reference mixture, where the increase ratio was 3.51, 9.83, 8.19 and 23.41%, 6.1, 13.12, 9.98 and 18.85% and 7.91, 15.49, 11.35 and 17.38% at ages 7, 28 and 56 days, respectively. The reasons are due to the rapid pozzolanic reactions of calcined clay with $Ca(OH)_2$ to formation C-S-H and C-A-H as well as the large surface area of calcined clays compared to the surface area of the cement which also leads to the increase in reactivity. thus, CC plays an important role in improving the bonds between cement paste and aggregate particles due to the formation of a dense microstructure in the ITZ, and it also increases the paste matrix, which could be attributed to both the physical and chemical advantages offered by CC. these results are in agreement with the previous study [8, 11, 25, 30].

Adding 3% nano lime to ternary mixtures 5% CC 3% NL, 10% CC 3% NL and 15% CC 3% NL increases the compressive strength about 30.44, 34.4 and 33%, 29.94, 38, 34.56% and 27.53, 33 and 30.98 for ages 7, 28, 56 days, respectively. As shown in Figure 11. Because lime nanoparticles contribute mainly to accelerating the hydration of early cement because of its high surface area. In addition, the nano lime works to fill in the voids and thus reduces pores and increases strength. these results are in agreement with the previous study [27, 28, 31].

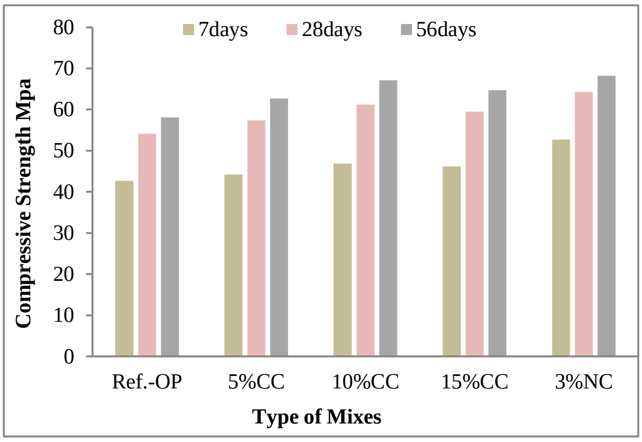

Figure 10. compressive strength values of binary mixes at 7, 28 and 56 days

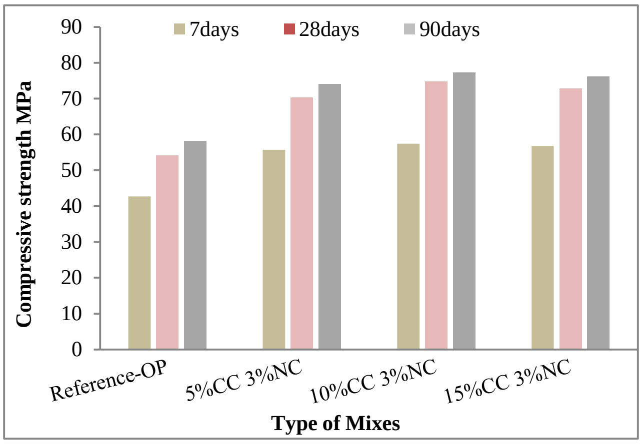

Figure 11. compressive strength values of ternary mixes at 7, 28 and 56 days

3.3. Splitting Tensile Strength

Table 5 and Figure 12 shows that binary mixtures 5% CC, 10% CC, 15% CC and 3% NL have a higher indirect tensile strength when compared with reference mixture values. Where the increase rate was 3.61, 11.74, 9.63 and 22.59% and 6.77, 11.38, 9.44 and 14.04% in ages 7 and 28 days, respectively. The reasons are due to pozzolanic reactions and micro filling ability of CC, which reacts with CH and forms more C-S-H. This process leads to reduce in the porosity of concrete, therefore by improving the microstructure of concrete in ITZ and paste cement matrix tensile strength is increased. Besides, the large surface area of calcined kaolin clay leads to an increase in a reaction as well. these results are in agreement with the previous work [22, 25].

Adding 3% nano-lime to ternary mixtures as a partial substitution of cement weight 5% CC 3% NL, 10% CC 3% NL and 15% CC 3% NL the splitting tensile strength values increase more, by 26.8, 31.62 and 29.81% and 27.84, 33.89 and 29.29 % when compared to the reference mixture, for ages (7 and 28) days, respectively. As shown in Figure 13. Because nanoparticles contribute mainly to accelerating hydration of early cement due to its high surface area. In addition, the lime nanoparticle fills in the voids and thus reduces pores and increases strength. These results are in agreement with the previous work [11, 28].

Table 5. Splitting tensile strength results

Splitting tensile strength MPa	mixes							
	Reference-OP	**5%CC**	**10%CC**	**15%CC**	**3%NL**	**5%CC 3%NL**	**10%CC 3%NL**	**15%CC 3%NL**
7day	3.32	3.44	3.71	3.64	4.07	4.21	4.37	4.31
28day	4.13	4.41	4.6	4.52	4.71	5.28	5.53	5.34

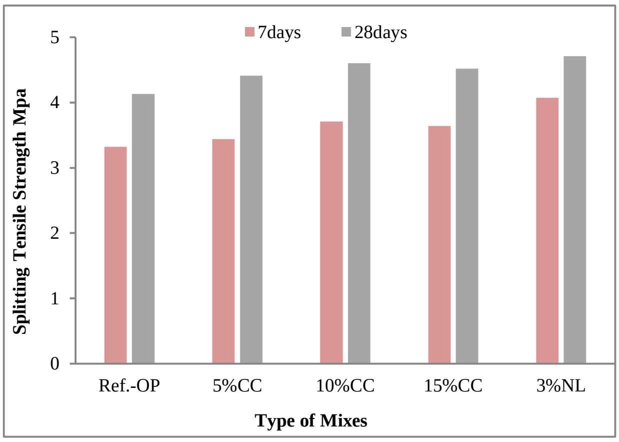

Figure 12. Splitting tensile strength values of binary mixes at 7 and 28 days

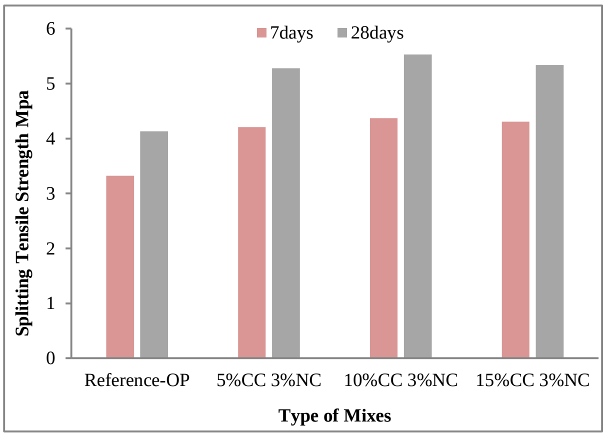

Figure 13. Splitting tensile strength values of ternary mixes at 7 and 28 days

3.4. Relationship between Compressive Strength and Splitting Tensile Strength

The Figure 14 shows the relationship between compressive strength and splitting tensile strength of all self-compacting high performance concrete mixtures. This relationship was found for compressive strength ranging from 42.7 to 74.7 MPa and for splitting tensile strength from 3.32 to 5.53 MPa. The determination coefficient (R^2) for the best fit curve was 0.975, indicating an excellent relationship. This relationship was obtained for both ages (7 and 28 days) from concrete and shown in Equation 1. These results are in agreement with the previous study [23].

$$\mathrm{Fsp} = 0.1237\ \mathrm{fcu}^{0.8797} \tag{3}$$

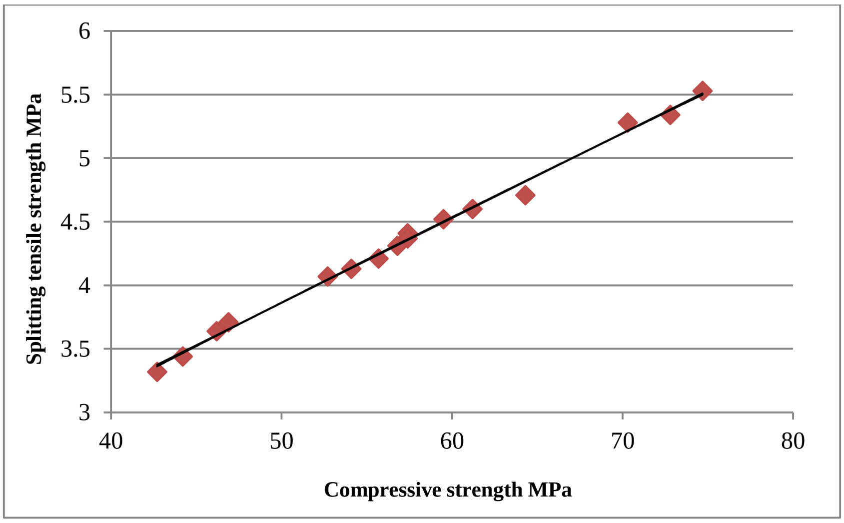

Figure 14. Relationship between compressive strength and splitting tensile strength at various days

6. Conclusion

In the binary blended mixes containing calcined kaolin clay (CC), fresh properties as (Slump flow diameter, L-box height ratio and segregation resistance) decreases with partial replacement of calcined kaolin clay increases. While, V-funnel time increase compared to the reference mixture. Adding 3% dosage of nano $CaCO_3$ to mixture lead to increase the viscosity of SCHPC (i.e. slump flow diameter, L-box height ratio, and segregation resistance) decreases while the V-funnel increases compared to the reference mixture. Fresh properties of ternary blended mixture (have CC and nano-$CaCO_3$ (NL)) more effect than binary mixes. in the binary mixes when adding calcined kaolin clays at rates 5% CC, 10% CC and 15% CC and nano lime at rate 3% NL as a partial replacement of the weight of cement leads to increase in the compressive strength and splitting tensile strength of the high-performance self-compacting concrete mixes in all ages compared to the reference mixture. Through the results of the examination it was found that the optimum percentage for replacing the calcined clay is 10% of the cement weight, as the best results were given. the addition of nano lime 3% of the cement weight in the ternary mixtures improves the compressive strength and splitting tensile strength of the concrete mixtures at all ages. the strength of the ternary mixtures increases when compared with the binary mixtures as well as the reference mixture. In general, Splitting Tensile Strength (STS) of SCHPC mixes appeared relatively the same trend with compressive strength, but the increase was at lower rates compared to that obtained in the compressive strength of SCHPC mixes.

7. Acknowledgements

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8. Conflicts of Interest

The authors declare no conflict of interest.

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