Oct 28th, 8:00 AM - Oct 29th, 6:00 PM

A parametric study for the structural assessment of multi-ring masonry arches considering influencing factors

Nora AL Anssari
University of Babylon, nora.al-anssari.engh402@student.uobabylon.edu.iq

Abbas AL Ameeri
University of Babylon, abbas.alameeri.eng@uobabylon.edu.iq

Improving the Durability Properties of Concrete by Using Sustainable Materials

Nora AL-Anssari, Abbas AL-Ameeri
College of Engineering,
University of Babylon,
Hillah, Babylon, Iraq.
nora.al-anssari.engh402@student.uobabylon.edu.iq
abbas.alameeri.eng@uobabylon.edu.iq

Abstract

The use of sustainable materials in construction has become essential due to their positive impact on the environment. In this study, binary and ternary blended mixtures of micro silica fume (SF) and nano silicon dioxide (NS) concrete mixes were employed. In order to investigate the impact of these materials on the mechanical properties and to improve the durability of concrete. Two groups of mixtures, binary and ternary blended mixes, were used as well as the control mix. In the first group, micro-SF was replaced with 3.5% and 7% by mass of ordinary Portland cement. Whereas, in a ternary blended group, micro-SF and nano silicon dioxide (NS) were replaced with 3.5% and 1%, respectively, by mass of ordinary Portland cement. A slump test was also performed to assess the fresh concrete properties of the mixes. Compressive and split tensile strengths were evaluated at different curing ages. As well, water absorption test, rapid chloride migration test, and chloride penetration test were carried out to investigate the durability properties. Results show that the replacement of cement by SF in binary blended and ternary blended mixtures reduced the workability of concrete mixes and increased the water demand. On the other hand, a considerable increase in the compressive strength, tensile strength, and durability properties of concrete was recorded. Also, the replacement of cement by 7% SF achieved significant improvements in the mechanical and durability properties of concrete.

1. Introduction

Micro-silica SF and nano-silica NS are pozzolanic materials that have cementitious properties known to improve the parameters of concrete, i.e., strength and durability. Micro- and nano-silica particle sizes are very small, so they can fill the pores or small spaces of concrete easily and effectively [1]**.** The addition of SF to concrete has many advantages, like high strength, durability, and a reduction in cement production [2]. As well, NS can also significantly improve the properties and durability of concrete [3], due to the silica present in these materials requiring the presence of calcium hydroxide to activate it [4]. Calcium hydroxide is released during the hydration of cement and forms additional calcium silicate hydrate (C-S-H). This may improve the durability and mechanical properties of concrete [5]. It is reported that the pozzolanic reaction between silica and calcium hydroxide formed during cement hydration begins to occur after 3 days of hydration [6]. Also, the addition of micro and nano additives can modify the microstructure of concrete as well as densify the cement matrix [7]. The literature reviews concluded that a small addition of these materials to a concrete mix will produce marked changes in both the physical and chemical properties[8]. Different researchers reported that silica fume and nano silicon dioxide are used as partial replacements of OPC in suitable dosages of these materials, and any overdose of these materials might have a negative impact on concrete[4]. Hence, several studies selected 1% NS as the optimum percentage for the incorporation of specimens [9].

Most studies have examined the impact of micro-silica and nano-silica on the characteristics of concrete in a binary blended concrete system and have obtained some remarkable results. However, this experimental study focuses on silica fume in a binary blended concrete system besides silica fume and nano-silica in a ternary blended system to find out the impact of silica fume and nano-silica on durability and strength parameters of concrete, which have been carried out in limited studies and research.

2. Experimental program

2.1 Materials

In this study, micro and nano silica powder were used and appropriately replaced with OPC-CEMI cement (42.5R) by an amount of 3.5% and 7% SF for binary cementitious systems and 3.5%SF with 1%NS for ternary cementitious systems. This type of cement was provided locally in Iraq satisfied with American Standard ASTM C 150 – Type 1[10] .While micro and nano silica was provided by the manufacturer. The main compound compositions of used materials are given in (Table 1).

Table 1 Main compounds composition of OPC, SF and NS.

Composition	**OPC %**	**SF %**	**NS %**
Lime (CaO)	61.52	≤1	0
Silicate (SiO_2)	21.67	94.26	99.5
Alumina (Al_2O_3)	5.33	≤1	0
Iron oxide (Fe_2O_3)	3.31	≤2	0

Magnesia (MgO)	2.97	0	0
Sulfate (SO_3)	2.51	0	0

Natural sand with an apparent specific gravity of 2.6, fineness modulus of 2.41, and absorption of 2.6% was used. Crushed aggregate with an apparent specific gravity of 2.74, absorption of 0.75%, and maximum size (19.5 mm) was also used. Both were conforming to the American Standard ASTM C33/C33M [11]. Also, in this study, a range of water-reducing and super plasticizing admixtures for concrete was utilized and it is commercially called Sika's ViscoCrete 180G which achieves the requirements of (ASTM C-494)/2015 Type F[12] which is considered to be used with Portland cement. It was added by mass of cement in amounts of 1%.

2.2 Mixture proportions and Mixing Procedure

An overall of four mixtures were designed and cast in the laboratory at the water-to-binder ratio (w/b) of 0.45. Mixing water is used for all the mixtures, the mixtures are organized using ordinary Portland cement OPC, silica fume SF and nano-silica NS as partial replacements for cement. The names and mix proportions of mixes are presented in (Table 2) and (Table 3) respectively.

Table 2 The details of mixture proportions.

Mix Notation	Details
SF1	binary blend made with (OPC+3.5% Silica fume)
SF2	binary blend made with (OPC+7% Silica fume)
NS	ternary blend made with (OPC+3.5%Silica fume + nano-silica)

Table 3 The mixing proportions of concrete.

Mix	Content (kg) per m³ of concrete							
	Cement	**w/c**	**Micro**	**Nano**	**Water**	**Sand**	**Gravel**	**SP**
OPC	420	0.45	0	0	189	624	1140	4.2
SF1	405.3	0.45	14.7	0	189	624	1140	4.2
SF2	390.6	0.45	29.4	0	189	624	1140	4.2
NS	401.1	0.45	14.7	4.05	189	624	1140	4.2

2.3 Curing and Testing

The concrete mixtures in this study were cast as specimens and then examined according to standard specifications as follows:

- Slump test of freshly mixed concrete was measured according ASTM C143/C143M [13].
- To obtain the compressive strength and water absorption, cubic specimens (100×100×100) mm were used according to BS EN 12390-3 [14]and ASTM C642 – 13 [15] respectively.
- (200×100) mm, cylinders to obtain the splitting tensile strength test according to ASTM C496/C496M – 11 [16].
- (100×50) mm, a slice of a cylinder to determine rapid chloride migration test RCMT and sorptivity test according to NT-Build 492[17] and ASTM C 1585 [18]respectively.

After the casting process, the specimens were covered with plastic sheets for the first 24 hours at a laboratory temperature of about 25±2°C, then the specimens were removed from the mold and kept in the curing water tanks at 25°C until the test ages.

3 Results and Discussion

3.1 Results of Fresh Properties

In this study, the workability of freshly mixed concrete was measured by using the slump-flow test which is use to denotes the average diameter of the concrete after releasing the standard slump cone, and is one of the important indexes to measure the plasticizing performance of concrete. The results of slump test are presents are presented in Figure 1. The workability of concrete decreased as the replacement by silica increases in all concrete mixtures compared to the control mixture [19],[20]. because the specific surface area of silica particles is larger than that of cement, and it absorbs more water and reduces the slump of concrete[21]. Control concrete mixture made with OPC showed that the value of slump (150 mm), while the slump decreased up to (130 mm) for mix made with 3.5% SF and decreased to (100 mm) for the binary blended mixture made with 7% SF and same for the ternary blended mixture including nano silica NS .This can be attributed to high specific surface of silica fume due to its small particle size, lead to an increase in water demand to maintain mixing and control the concrete workability [22] and this supported the findings.

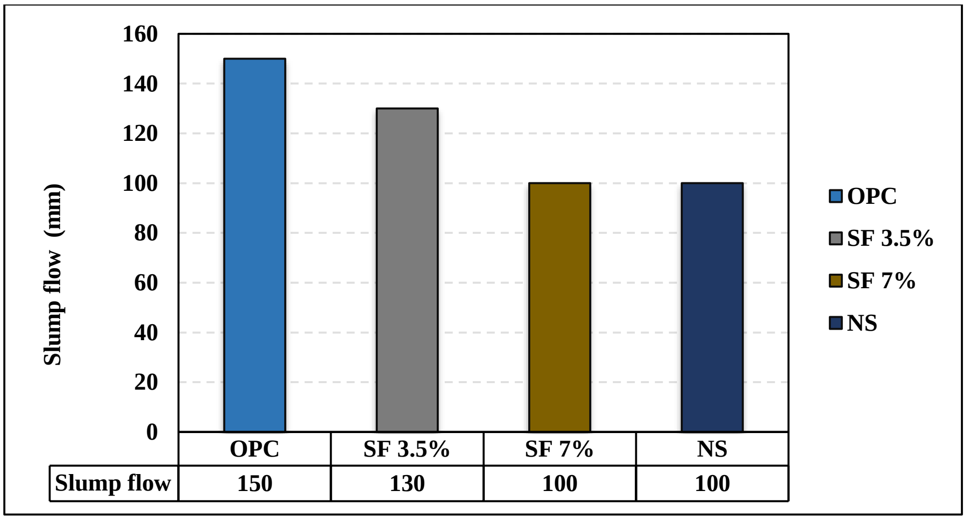


Fig. 1 Reduction of mixtures workability due to replacement of SF and NS.

3.2 Results of Hardened Properties

3.2.1 Compressive Strength

The vast majority of previous research and studies supported the notion that the strength improvement is generally the first property associated with additions of silica to concrete [4],[19]. Figure 2 illustrates the results of compressive strength improvement. The compressive strength of all concrete specimens to the extent that the strength reached a peak at 90 days. However, there is a significant improvement in the compressive strength of concrete because of the high pozzolanic nature of the silica to form more densely packed C-S-H gel and its void-filling ability [23],[24].
For silica fume additions 3.5% and 7% SF in binary blend concrete an early strength improvement of the test was obvious. The highest value of compressive strength (68.88 MPa) was recorded for SF 7% mix at 90 days. It was observed that compressive strength of concrete with 3.5% SF increases by (31.75%, 13.95%, and 13.67%) and for concrete with 7% SF increases by (37.44%, 29.83%, and 31.45%) at 7, 28 and 90 days respectively compared to control concrete, followed by an increase of (6.8%, 9.3%, and 5.8%) for the ternary blend concrete NS at 7, 28 ,90 days respectively. It was also noticed that the addition of nano-silica with 3.5% SF in the ternary mixture induced a drop in compressive strength by (18.93%, 4.09%, and 6.96%) at 7, 28 and 90 days respectively compared to 3.5% SF in the binary mixture The addition of NS into a ternary mixture at a proportion of 1% did not yield results that were significantly different from the control sample. This may be due to decreasing the reactivity of NS [25], which delayed the process of hydration in order to decreased pozzolanic reaction, which led to a reduction in the compression improvement[26].

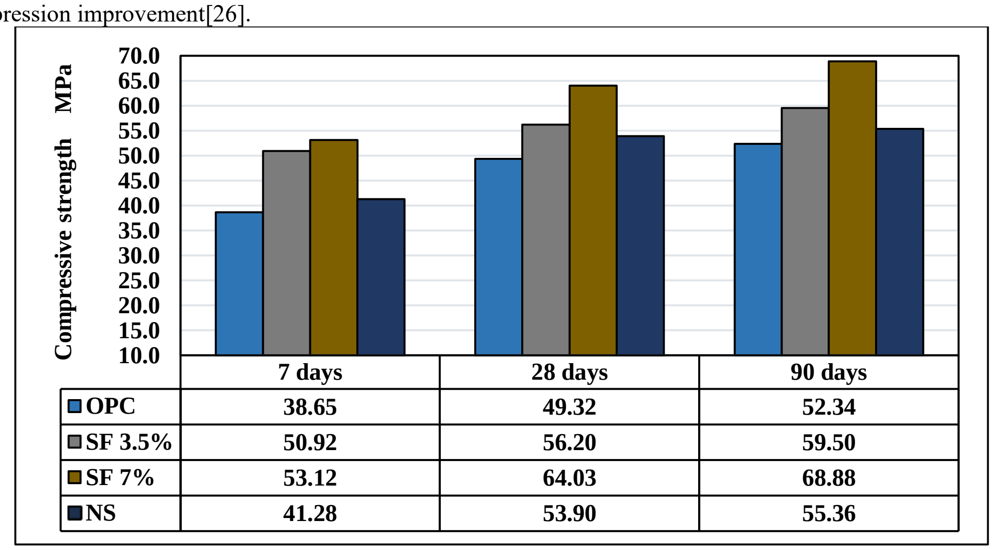
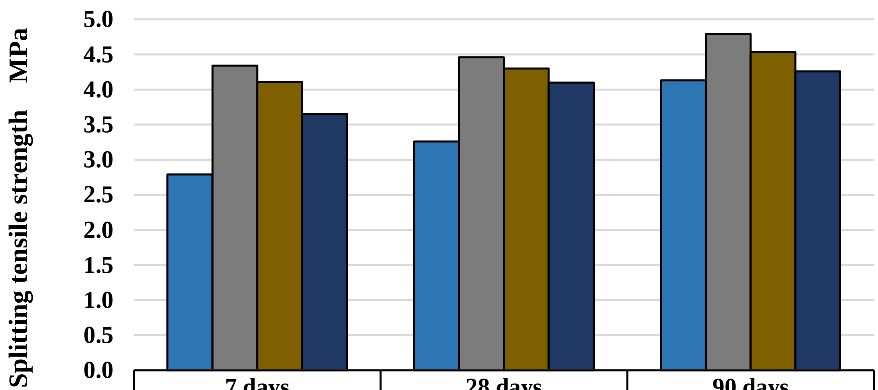


Fig. 2 Improvement of compressive strength of concrete mixtures due to use SF and NS

3.2.2 Splitting Tensile Strength

The experimental studies indicated that improved strength characteristics of concrete can be obtained with the combined use of Nano-Silica and silica fume, due to the overall cohesiveness which enhances the paste-aggregate bond results improving strength properties[24]. As shown in Figure 3, all the specimens showed an increase in the split tensile strength gradually over time. Tensile strength values improved slightly and a value of about 4.79 MPa was recorded at 90 days for SF 3.5% concrete compared to other mixtures. It can be observed that the split tensile strength for the binary blended concrete with 3.5% SF increases by (59.86%, 33.74%, and 15.98%) and for the concrete with 7% SF increases by (47.31%, 31.9%, and 9.68%). Beyond the ternary blended concrete NS, there is an increase of (30.82, 25.77%, and 3.15%) at 7, 28, and 90 days respectively compared to control concrete. The split tensile strength of the specimens included with SF has been found to be higher as compared to the ones included with NS. However, the addition of NS into concrete induced a drop in split tensile strength for the ternary blended concrete by (18.16%, 5.96%, and 11.06%) at 7, 28 and 90 days respectively compared to 3.5% SF in the binary blended mixture, And as a result the strengthening effect of adding silica fume on the splitting tensile strength of concrete was more effective [26]. The Relationship between compressive strength (f_c) of concrete and splitting tensile strength (f_s) is presented in Figure 4.



	7 days	28 days	90 days
OPC	2.79	3.26	4.13
SF 3.5%	4.34	4.46	4.79
SF 7%	4.11	4.30	4.53
NS	3.65	4.10	4.26

Fig. 3 The splitting tensile strength of concrete mixtures.

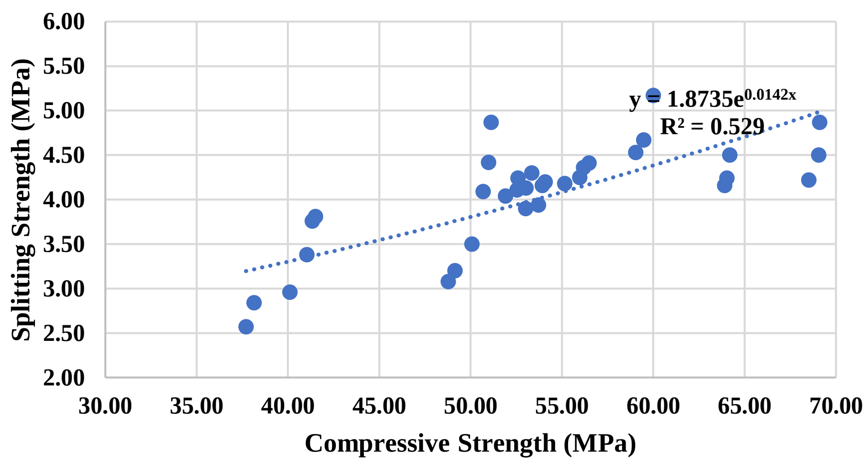
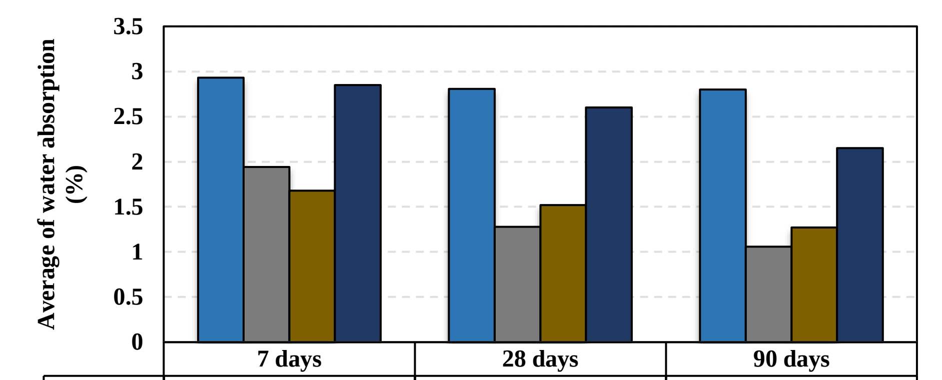


Fig. 4 Relationship between compressive strength (f_c) of concrete and splitting tensile strength (f_s).

3.3 Tests for Durability Performance

3.3.1 Water Absorption Test

Water absorption or called the rate of water absorption which is a measure of the capillary forces exerted by the pore structure causing fluids to be drawn into the body of the material. Based on the experimental results of the test for all concrete mixes, a reduction in saturated water absorption with increase in curing age suggests reduction in permeable voids with prolonged curing. As illustrated in Figure 5, The replacement of silica fume in concrete reduces the water absorption capacity of concrete over age. Also the replacement of NS reduces the water absorption due to the ability to fill any voids in the specimens [27]. It is well understood that lower the rate of water absorption, better is the durability potential of concrete contributed to the interfacial zone in concrete that have improved due to pozzolanic reaction product as well as the filler effect of the micro silica grains [28]. The reduction in water absorption with age refers to gives more resistance of concrete towards water absorption. It's also confirmed from the results that water absorption was goes down with an increase in concrete strength [29]. However there is a valuable correlation between the water absorption test results and other concrete durability indices makes the water absorption test one the most reliable measurements which can be used to evaluate concrete durability performance [30].

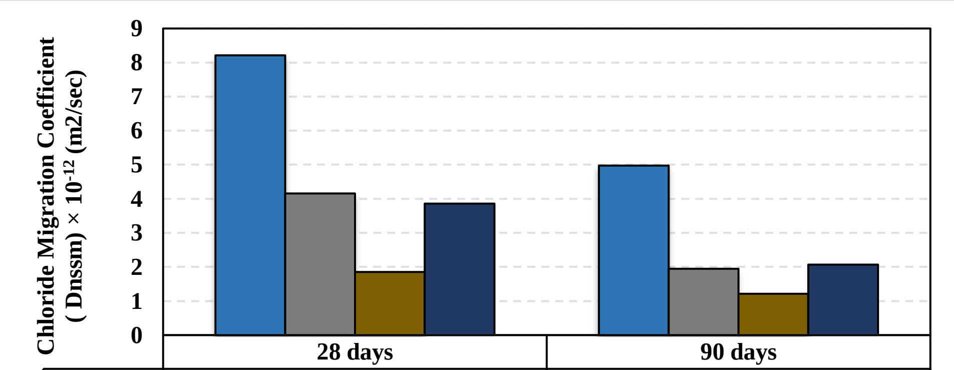


	7 days	28 days	90 days
OPC	2.93	2.807	2.801
SF 3.5%	1.94	1.28	1.06
SF 7%	1.68	1.52	1.27
NS	2.85	2.6	2.15

Fig. 5 The effect of replacement of SF and NS on results of the water absorption test.

3.3.2 Rapid Chloride Migration Test (RCMT).

In this test, short concrete cylinders were used to determine chloride migration coefficient D_{nssm} at 28 and 90 days of age based on the depth of chloride penetration. Figures 7 and 8 show the depths of chloride ion penetration and the findings of D_{nssm} values respectively. The results presented a clear reduction in chloride migration coefficient for all specimens of concrete at 90 days. However, the maximum decrease in D_{nssm} obtained in case of the specimens incorporated with 7% SF. It can be observed that the durability of the concrete can be enhanced by incorporation of pozzolanic materials [9]. For silica fume additions 3.5% and 7% SF in binary blend concrete and for NS in ternary blend concrete decrease reach to (49.33%, 77.47%, and 52.98%,) at 28 day and (60.84%, 75.7%, and 58.43%)) at 90 days compared with control concrete respectively. However, in case of the specimens incorporated with NS increased the resistance against chloride diffusion compared to 3.5% SF, while the maximum decreased obtained with 7% SF. The decrease in RCMT values lead in term to increase durability of these specimens. Also the performance of concrete subjected to aggressive environments suggesting refinement of microstructure leading to improvement in durability and properties of concrete[28]. Also the expansion of silica fume which additionally decreases the diffusion of concrete to chloride particles [8]. This also contributed to generated CSH gel due to the pozzolanic reaction and the filler effect of micro SF and NS particles results in pore reduction in the cement[9].



	28 days	90 days
OPC	8.21	4.98
SF 3.5%	4.16	1.95
SF 7%	1.85	1.21
NS	3.86	2.07

Fig. 7 The effect of replacement of SF and NS on results of rapid chloride migration test.

3.3.3 Chloride Penetration Depth

The samples in this test were subjected to a chloride ion solution made of NaCl for 120 days under particular environmental conditions that included drying and wetting cycles. While a water-proofing coating was applied to the other surfaces, the lower surface next to the rebar was not coated and therefore was exposed to the NaCl solution. This test is based on measure of the depth of chloride penetration, represented by the symbol (x_d) after the short prism is sprayed with a particular concentration of 0.1 N silver nitrate ($AgNO_3$) solution. The reaction between chloride ions (Cl^-) and silver ions (Ag^+) takes place allowing the measurement of chloride penetration depth (x_d) in the prism[31],[32]. Figures 8 displays the results for chloride ion penetration depth (x_d) for all four mixes. As presented the reduction in chloride penetration depth was significant with use of sustainable materials, the reduction was (63.3%, 76.6% and 36.67%) for 3.5%SF, 7% SF and NS respectively as compared with control concrete at 120 days. The similar findings have been reported that silica fume exhibited the lowest value of chloride penetration[33] ,it can be concluded that initiation of chloride attack will be delayed in the presence of silica fume in concrete which increased the ability to resist chloride ion penetration [34]

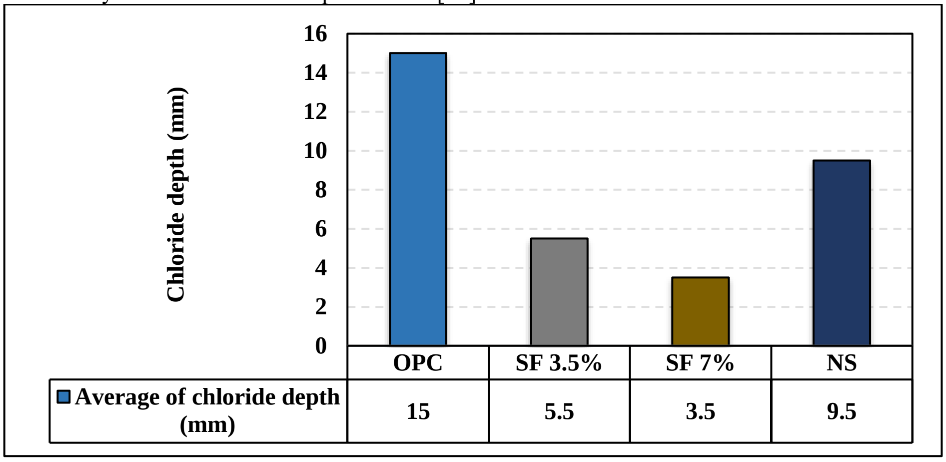


Fig. 8 The effect of replacement of SF and NS on results of chloride penetration depth.

4 Conclusion

The results of the experiment may be used in order to extract the following conclusions:

- Concrete's workability is decreased and water demand increased as a result of silica content replacement.
- The replacement of cement by silica fume and nano-silica causes an increase in compressive and tensile strength of concrete.
- Silica fume seems to have a more pronounced impact on strength and durability of concrete than the nano-silica
- Concrete with higher silica fume content showed positive impact on the durability of concrete, which 7% SF concrete showed the highest resistance to chloride penetration.

This is unequivocal proof that the additional sustainable materials whether nano-silica or micro-silica not only improve the initial pozzolanic reactions; they also serve as filler to create a microstructure that is significantly denser. This study come to the conclusion that understanding the properties of sustainable materials at the nano and microscales can improve the performance of concrete with the incorporation of binary and ternary blends.

References

[1] A. N. Guleria and S. Salhotra, “Effects of silica fume (micro silica or nano silica) on mechanical properties of concrete: A review,” *Int. J. Civ. Eng. Technol.*, vol. 7, no. 4, pp. 345–357, 2016.

[2] N. K. Amudhavalli and J. Mathew, “EFFECT OF S ILICA F UME ON S TRENGTH AND D URABILITY P ARAMETERS OF C ONCRETE,” vol. 3, no. 1, pp. 28–35, 2012.

[3] L. Wang, D. Zheng, S. Zhang, H. Cui, and D. Li, “Effect of nano-SiO2 on the hydration and microstructure of Portland cement,” *Nanomaterials*, vol. 6, no. 12, 2016, doi: 10.3390/nano6120241.

[4] J. Newman, “Advanced concrete technology,” *Elsevier Ltd. All rights Reserv.*, 2003.

[5] S. GR, “Strength development of concrete with rice husk ash,” *Cem. Concr. Compos.*, 2006.

[6] Y. Qing, Z. Zenan, K. Deyu, and C. Rongshen, “Influence of nano-SiO2 addition on properties of hardened cement paste as compared with silica fume,” *Constr. Build. Mater.*, vol. 21, no. 3, pp. 539–545, 2007, doi: 10.1016/j.conbuildmat.2005.09.001.

[7] J. Chakkamalayath, S. Al-Bahar, and A. Joseph, “Nanomechanical and microstructual properties of binary and ternary blended cement paste containing sustainable materials,” no. February 2023, pp. 301–301, 2016, doi: 10.3850/978-981-09-7519-7nbl16-rps-301.

[8] S.Dharanidharan, L.Rajkumar, and B.Karthick, “an Experimental Study on Mechanical Properties of Concrete By,” vol. 4, no. 3, pp. 401–405, 2015.

[9] R. Garg, M. Bansal, and Y. Aggarwal, “Strength, rapid chloride penetration and microstructure study of cement mortar incorporating micro and nano silica,” *Int. J. Electrochem. Sci.*, vol. 11, no. 5, pp. 3697–3713, 2016, doi: 10.20964/110455.

[10] ASTM, “Portland Cement 1,” *ASTM Int.*, vol. 04–02, pp. 1–7, 2011.

[11] ASTM C33/C33M − 18, “Standard Specification for Concrete Aggregates,” 2013, doi: 10.1520/C0033.

[12] ASTM C494, “ASTM C494/C949M-19: Standard specification for chemical admixtures for concrete,” *Astm C494*, no. January, pp. 1–10, 2015.

[13] ASTM C143/C143M, “Standard Test Method for Slump of Hydraulic-Cement Concrete,” *Astm C143*, vol. 04, no. 1, pp. 1–4, 2020, doi: 10.1520/C0143.

[14] E. committe for Stansardization, “Bs-En-12390-3_Compress.Pdf.”

[15] American Society for Testing and Materials, “Standard Test Method for Density, Absorption, and Voids in Hardened Concrete C642-97,” *ASTM Int.*, no. March, pp. 1–3, 1997, doi: 10.1520/C0642-13.5.

[16] ASTM, “Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens1,” *ASTM Int.*, 2011, doi: 10.1520/mnl10913m.

[17] NORDTEST ISSN 0283–7153, “Concrete, mortar and cement-based repair materials: Chloride migration coefficient from non-steady-state migration experiments,” *Measurement*, pp. 1–8, 1999.

[18] Master Builders Solutions, “Water absorption (Sorptivity) Testing of Concrete (ASTM C 1585),” no. 800, p. 44122, [Online]. Available: https://assets.master-builders-solutions.com/en-us/mbs-astm-c1585_06_24_2020.pdf

[19] F. Abubaker and H. Ghanim, "Effect of Silica Fume Addition on The Mechanical Properties of Concrete," no. February, 2022.
[20] L. G. Li, Z. H. Huang, J. Zhu, A. K. H. Kwan, and H. Y. Chen, "Synergistic effects of micro-silica and nano-silica on strength and microstructure of mortar," *Constr. Build. Mater.*, vol. 140, pp. 229–238, 2017, doi: 10.1016/j.conbuildmat.2017.02.115.
[21] N. I. M. Beigi M.H, Berenjian J., Omran O.L., Nik A.S., "An experimental survey on combined effects of fibers and nanosilica on the mechanical, rheological, and durability properties of selfcompacting concrete," *Mater. Des.,* no. 50(50), 1019-1029., 2013.
[22] A. Imam, V. Kumar, and V. Srivastava, "Review study towards effect of Silica Fume on the fresh and hardened properties of concrete," *Adv. Concr. Constr.*, vol. 6, no. 2, pp. 145–157, 2018, doi: 10.12989/acc.2018.6.2.145.
[23] K. N. and Y. V. V.Bhikshma, "'Investigations on mechanical properties of high strength silica fume concrete.,'" *Asian J. Civ. Eng. (building housing)*, pp. 335-346..
[24] B. M. Hanumesh, B. K. Varun, and B. A. Harish, "The Mechanical Properties of Concrete Incorporating Silica Fume as Partial Replacement of Cement," *Int. J. Emerg. Technol. Adv. Eng. 2250-2459, Vol. 5, Issue 9*, vol. 5, no. 9, pp. 3–8, 2015.
[25] K. Khan, W. Ahmad, M. N. Amin, and S. Nazar, "Nano-Silica-Modified Concrete: A Bibliographic Analysis and Comprehensive Review of Material Properties," *Nanomaterials*, vol. 12, no. 12, 2022, doi: 10.3390/nano12121989.
[26] C. Zhuang and Y. Chen, "[Nanotechnology Reviews] The effect of nano-SiO2 on concrete properties_ a review.pdf," pp. 562–572, 2019.
[27] E. Mohseni, B. M. Miyandehi, J. Yang, and M. A. Yazdi, "Single and combined effects of nano-SiO2, nano-Al2O3 and nano-TiO2 on the mechanical, rheological and durability properties of self-compacting mortar containing fly ash," *Constr. Build. Mater.*, vol. 84, pp. 331–340, 2015, doi: 10.1016/j.conbuildmat.2015.03.006.
[28] G. D. Ransinchung, B. Kumar, and V. Kumar, "Assessment of water absorption and chloride ion penetration of pavement quality concrete admixed with wollastonite and microsilica," *Constr. Build. Mater.*, vol. 23, no. 2, pp. 1168–1177, 2009, doi: 10.1016/j.conbuildmat.2008.06.011.
[29] M. . Balakrishna, R. Evans, F. Mohammad, and M. . Rahman, "Water Absorption Capacity of Concrete Cubes with Sorptivity Water," *Int. Res. J. Eng. Technol.*, vol. 7, no. 4, pp. 721–727, 2020.
[30] B. Mohammadi, "Development of Concrete Water Absorption Testing for Quality Control," *Dep. Build. Civil, Environ. Eng.*, no. December, 2013.
[31] X. A. and B. T. He, F., C. Shi, Q. Yuan, "'Calculation of chloride concentration at color change boundary of AgNO3 colorimetric measurement'.," *Cem. Concr. Res. 41(11) 1095-1103.*, 2011.
[32] C. C. and K. Z. He, F., C. Shi, Q. Yuan, "'AgNO3-based colorimetric methods for measurement of chloride penetration in concrete,'" *Constr. Build. Mater. 26(1) 1-8.*, 2012.
[33] V. G. Papadakis, "Effect of supplementary cementing materials on concrete resistance against carbonation and chloride ingress," *Cem. Concr. Res.*, vol. 30, no. 2, pp. 291–299, 2000, doi: 10.1016/S0008-8846(99)00249-5.
[34] S. D. V, T. T. S, and S. Yuvaraj, "Investigation on the Strength and Durability Properties of Concrete with GGBS and Silica fume," no. July, pp. 1–5, 2018.