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Effect of Nanosilica-Wood Ash Mixture on the Mechanical and Microstructural Properties of wood ash Concrete

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***Abstract* -** The South African cement industry is under mounting pressure to reduce carbon dioxide emissions associated with cement and concrete production in line with sustainable development goals. This study investigates the effects of Nanosilica-wood ash mixture on the mechanical and microstructural properties of wood ash cement concrete, with the aim of advancing alternative and sustainable cement production methods. In this research, control concrete sample with Ordinary Portland Cement (OPC), lacking Nanosilica and wood ash is represented as CC. The experimental groups, denoted as Zawa 05-15, utilize South African wood ash as a partial replacement for cement at varying proportions of 5%, 10%, and 15% by weight of cement. The investigation encompasses an analysis of the chemical composition, specific gravity, and particle size distribution of the wood ash, as well as the fine and coarse aggregates used in the concrete mix. The study evaluates the workability, compressive, splitting tensile strength and microstructure of both the plain and composite concrete samples. The findings reveal a noteworthy enhancement in mechanical properties upon the introduction of Nanosilica mixed with wood ash. Moreover, the microstructural characteristics of the concrete are notably improved with the incorporation of Nanosilica mixed with wood ash. Notably, a maximum of 38,8 MPa and 1,3 MPa is attained for both compressive and splitting tensile strength respectively at the 14-day curing period when 15% wood ash is added to the concrete mix. In conclusion, this research establishes that the addition of Nanosilica mixed with wood ash significantly enhances the mechanical and microstructural properties of wood ash cement concrete. The optimum level of wood ash addition for these improvements is determined to be 10% for compressive strength compared to the control sample strength. This research addresses the need to lower carbon emissions in the cement industry in South Africa by utilizing wood ash and Nanosilica in the development of sustainable cement production methods. The findings thus offer more scientific and technically feasible information to further develop sustainable concrete in civil engineering construction.

***Keywords*:** Nanosilica, Wood ash, Concrete, Alternative Cement, Mechanical Properties, Microstructural Properties.

1. Introduction

After 23 years of infrastructure development tracking in Africa, South Africa is by far the largest producer of cement across the African Continent, reaching an estimated production of 15 million metric tons [1]. Its cement consumption per capital is currently at around 63.9 kg, but it is expected to surge to 107.9 kg by 2025 when the global cement consumption is predicted to increase by 6% [2]. This position is justified by placing second in the Africa Infrastructure Development Index [3]. However, the rapid development of the cement industry in the country like any other countries around the world has also brought a series of environmental problems associated with a high amount of CO_2 [4]. By calculation, according to the current level of the cement industry, the production of 1 ton of cement clinker emits about 671kg of carbon dioxide on average [5]. Carbon dioxide emissions from the cement industry account for about 20% of the total carbon dioxide emissions from industrial production in South Africa [6].

In order to expedite the development of alternative cement production for the sustainable goals agenda, the South African cement sector is under intense pressure to cut its carbon dioxide emissions from the manufacturing of cement and concrete.. In order to achieve the goal of low carbon and environmental protection, on one hand [7] while reviewing how green and sustainable the cement industry, came to the conclusion that efforts should not focus on the new technology and equipment alone, but new composite materials should be developed to enhance the environmental sustainability global agenda [7]. Also, the emergence of nanomaterials provides new research directions and research ideas for modified cement-based materials and also provides new development opportunities for realizing national carbon peak and carbon neutralization [8]. With the current development within the nanotechnology space, nanosilica (NS) among others that have been used by a large number of scholars to regulate the microstructure of cement-hardened paste to enhance the mechanical properties and durability of concrete . Its unique volume effect, surface effect, quantum size, and other characteristics have been gradually discovered [9,10], as well as many analytical testing methods, which gradually enables researchers and industry experts to reveal the microstructure of cement-based materials from the nanometre scale.

A review of wood ash shows that its fractional binder substitution in the blend preparation process is beneficial for environmental sustainability. Wood ash has been found to be suitable for use as a filler/partial replacement of cement in high-performance concrete due to its enhanced “ball-bearing” effect given from the spherical shape of WA, thus creating a lubricating effect when concrete is in its plastic state.

Compared with other nanomaterials, NS has been found to possess higher pozzolanic activity and can react with calcium hydroxide ($Ca(OH)_2$ releasing heat to promote hydration [8]. At the same time, NS can effectively refine ($Ca(OH)_2$ crystal and generate calcium silicate hydrate (C-S-H) with strong cementation effect and a large specific surface area, which reduces the content of calcium hydroxide on the surface of aggregate and improves the interface strength between cement paste and aggregate [11-15]. In addition, NS can physically fill the gaps of cementitious materials, capillary pores, and calcium silicate hydrate crystals in concrete, making concrete denser and eventually improve its strength [16-18]. The aim of this research is to investigate the effect of different percentage weight fractions of wood ash mixed with NS on the mechanical and microstructural properties of wood ash concrete with the objectives of determining the effect of NS dispersion on the workability, compressive, tensile strength and morphology of the nanocomposite concrete. It is worth pointing out that this paper is part of a larger research investigating concrete containing NS and wood ash.

2. Materials and Method

Ordinary Portland cement class CEM 1 52.5N conforming to [19] was used in this investigation. The coarse and fine aggregates with compacting bulk density (CBD) were 1557 kg/m^3 and 1846 kg/m^3, respectively. The coarse aggregates of maximum particle size of 22 mm and fine (unwashed crusher sand) of maximum size of 4.75 mm obtained from a local quarry in Johannesburg were used. The particle size analysis of aggregates were conducted in conformity with [20]. The wood ash used were sourced from caterers services situated at Johannesburg. The technical indicators, including particle size distribution, of coarse and fine aggregates are listed in Table 1,2, and 3. The technical indicator for the wood ash used is provided in Table 4. Nanosilica (NS) is in powder form containing 99.9% particle SiO_2 with average diameter ≤150 μm, pore size is 6 nm was used. It’s carbon content is 6,1% while its Nitrogen content is 1,8%. Tap water was used in all mixtures.

Table 1: particle shape according to SANS 5847:2008

Sieve size	Flaky, g	Non-flaky, g
28	0	0
20	61.2	992.5
14	194.8	1142.8
10	58.8	266.4
7.1	7.8	18.1
5	0	3.9
Total	322.6	2423.7
Total sample, g	2746.3	
FI = 100 * (322.6/2746.3) = 11.7%		

Table 2: Sieve Analysis according to SANS 3001-AG1

Fine Aggregate				
Dry Mass	885,3			
Sieve size (mm)	Individual mass retained (g)	Individual percentage retained (%)	Cumulative Percentage retained (%)	Percentage Passing (%)
10	0	0	0	100
7,1	0	0	0	100
5	38,1	4,304	4,304	96
2	229,1	25,878	30,182	70
1	142,9	16,141	46,323	54
0,6	87,1	9,838	56,162	44
0,3	101	11,409	67,570	32
0,15	67,4	7,613	75,184	25
0,075	42,4	4,789	79,973	20
Pan	11,7	1,322	81,294	19
FM				2.8

Table 3: Sieve Analysis According to SANS 3001-AGI

Dry Mass			2846,1		
Sieve size (mm)	Mass of sample retained (g)	Percentage retained (%)	Cumulative Percentage retained (%)	Percentage Passing (%)	SANS 1083:2008 Requirement
28	0,00	0,00	0,00	100	100
20	1551,9	54,5	54,4	45,5	
14	1114,0	39,1	93,7	6,3	0-50
10	150,4	5,3	99,0	1,0	0-28
7,1	15,2	0,5	99,5	0,5	0-25
5,0	4,7	0,2	99,7	0,3	0-9
Pan	4,3	0,2	99,8	0,2	

Table 4: Sieve Analysis of Wood Ash used

Sieve Size [mm]	Mass of Sample Retained [g]	Percentage Retained [%]	Cumm % Retained [%]	Percentage Passing [%]
5	0	0,0	0,0	100
2	8,2	1,6	1,6	98
1	33,5	6,7	8,3	92
0,6	52	10,4	18,7	81
0,3	83,7	16,7	35,5	65
0,15	81,8	16,4	51,8	48
0,075	85,7	17,1	69,0	31
Pan	154,3	30,9	99,8	

2.1 Mixing and Preparation of Concrete Specimens

Portland Cement Concrete (PCC) containing cement, wood ash and NS were prepared. Mixing procedures were carried out in a rotary mixer according to [21]. NS was mixed with water at medium speed. The mixture was allowed to rest for 90 s and then mixed continuously for 1 min at high speed. Details of mix proportions of the cement concrete are given in Table 5.1. The mix proportion for the control sample with OPC (without nanoparticles) is denoted by CC while Zawa 05-15, represent South Africa Wood ash consisting of cement concrete with varying percentage of wood ash at 5%, 10%, and 15% by weight of cement, respectively. The percentage of nanoparticles and other parameters such as fine aggregates, coarse aggregates and remain constant in the Table 5.1

Table 5.1: Mix proportions of cement concrete samples

Sample	Cement (Kg/m3)	Water (Kg/m3)	Coarse Aggregates (Kg/m3)	Fine Aggregates (Kg/m3)	NS(As a % of mixing water (wt%)	Wood Ash (%)	W/C Ratio
CC	385.256	200.333	1112.666	656.3	0	0	0.52
ZAWA 05	355.013	200.333	1112.666	656.3	3.0	30.243	0.52
ZAWA 10	324.771	200.333	1116.222	656.3	3.0	60.485	0.52
ZAWA 15	294.528	200.333	1116.222	656.3	3.0	90.718	0.52

LEGEND:

CC	Control Sample
ZAWA05	SA WA with 5% OPC replacement
ZAWA10	SA WA with 10% OPC replacement
ZAWA15	SA WA with 15% OPC replacement

The water to binder ratio was kept constant at 0.52 of all the mixtures. The fine and coarse aggregates was graded in accordance with [20]. The mix ratio of the concrete samples was designed according to C & CI specifications. The cement consumption in the test group concrete (Zawa 05–15) was calculated according to the reduction rate.

In the process of concrete preparation, under the same water-binder ratio condition, when NS is used as a cementitious materials-reducing admixture for concrete, with the introduction of NS content, a large number of free water in the concrete is absorbed, and the slump of concrete is significantly reduced as shown in the Table 8 below which may make the concrete mixing and vibration insufficient. The slump for each wood ash replacement is represented in Table 5.2 below while maintaining the same water/binder ratio for the whole concrete samples.

Table 5.2: Slump Values

Replacement of OPC by Wood Ash [%]	0	5	10	15
Water/Binder Actual Ratio	0,52	0,52	0,52	0,52
Slump [mm]	75	40	50	30

2.2 Chemical Composition

The wood ash sample in Table 6 contains various elemental oxides. The combined percentages of SiO_2, Al_2O_3, and Fe_2O_3 in the wood ash were found to be 73%, which correlates well to the study by Chowdhury et al. (2015) where the combined percentages were 71.79%. This suggests that the wood ash is a suitable pozzolanic material, meeting the requirements of [22]. Furthermore, Jerath and Hanson (2007) reported that wood ash from bread bakery falls under the category of class F fly ash, as the sum of (SiO_2 + Al_2O_3 + Fe_2O_3) is greater than 70%.

Table 6: Chemical composition of wood ash

Chemical Constituent	SiO_2	AL_2O_3	Fe_2O_3	CaO	MgO	Si_3	Na_2O	K_2O	$CaCo_3$	LOI	LSF	BR	AR
Average Composition	61.8	7.52	3.17	1.77	2.48	1.82	1.09	3.81	6.22	3.05	1.28	4.32	7.05

2.3 Specific Gravity

Table 7 shows the results for the specific gravity of wood ash. The specific gravity of wood ash was found to be 1,92. This result is less than the range of values obtained by (Udoeyo *et al.,* 2006).

Table 7: Specific gravity of wood ash

	Test 1	Test 2
Mass of pycnometer (m_1)[g]	296,9	295,7
Mass of the wood ash	500,2	515,3
Mass of pycnometer and wood ash (m_2) [g]	797,1	811
Mass of pycnometer and water and wood ash (m_4) [g]	1311,9	1620,1
Mass of pycnometer and water (m_d) [g]	1289,9	1289,8
Mass of dry specimen [g]	509,6	513,8
(m_2-m_1) [g]	500,2	515,3
(m_4-m_1) [g]	993	994,1
(m_3-m_2) [g]	514,8	809,1
(m_4-m_1) – (m_3-m_2) [g]	478,2	185
Specific gravity of the particles Gs = (m_2-m_1)/((m_4-m_1) – (m_3-m_2))	1,05	2,79
Mean of specific gravity	1,92	

2.4 Specimen preparation

For each mixture, specimens of 100 x 100 x 100 mm were laminated in accordance with [21]. The test specimens were demoulded after 24 h and then cured in a controlled environment. 24 cubic test specimens were made from each mixture, covering four different ages of 3, 7, and 14 days for both compressive and splitting tensile test respectively.

2.4.1Testing

The concrete samples were prepared in accordance to [22] standards of performance on ordinary fresh concrete to test concrete initial setting time and final setting time. Also, according to [23] Standard for test methods of concrete mechanical properties, the compressive and split tensile specimens of 100 mm x 100 mm x 100 mm concrete were prepared, and both the split and compressive properties were tested at 3, 7, and 14 days using Toni Technic loading frame in accordance with [23] and [24] respectively.

2.4.2 Microstructure Test

Considering the sample curing 14-day specimens, the surface dirt was removed and subject to 40^{o}C drying oven to constant weight. The specimens were grounded in a bowl, and the grinding powder was passed through an 80 µm sieve. The SEM analysis of all concrete mixes was performed on hardened fragments in the form of slices of cement paste using a Zeiss crossbeam 340 scanning electron microscope. Isopropanol was used to dry the fragments of hardened paste using the solvent exchange method. After that, all specimens were examined for changes in morphology and composition.

3. Results and Discussion

The section discussed the results of the experiment

3.1 Effect of NS-Wood Ash on setting time of concrete

Figure 1 shows the effect of Nanosilica mixed with wood ash on the settling time.
The initial setting time of the wood ash cement mortar containing 5% and 10% are higher than the initial setting time of the control sample by 9,4% and 15,7% respectively while the initial setting time of the wood ash concrete containing 15% cement replacement decrease by 40% compared to the control sample as shown in Figure 1. The final setting time of the concrete with wood ash replacement between 5% to 15% shows consistent increase over the control sample by 15,93%, 19,92% and 20,77% respectively. The consistent improvement over the wood ash concrete samples of the final setting times were between 300 and 400 min, respectively as shown in Figure 1 below. The results further revealed that the water demand increases with the increase in wood ash though the Nanosilica content remains constant through the study. The wood ash introduced into the cement increases the carbon content and this increases the water required to achieve a reasonable workability. At the beginning of hydration, calcium hydroxide ($Ca(OH)_2$), the hydration product of cement, reacts with NS, promotes hydration, increases the exothermic rate of cement hydration, reduces the time required for hydration induction period, advances the acceleration period and deceleration period, and thus shortens the setting time of concrete.

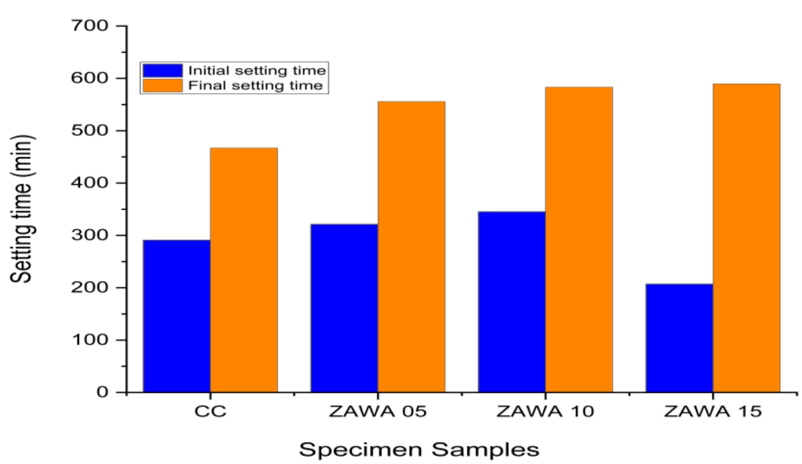

Figure 1. Settling Time of the Samples

3.2 Effect of NS-Wood Ash on Concrete Workability

Slump tests are generally used to check the workability of fresh mix concrete. The slump test was carried out in accordance with [25]. It is shown that the workability decreases with the increase of wood ash with the same dosage of nano-silica as percentage of mixing water in the concrete. The workability of the wood ash concrete mixed with Nanosilica was characterised by a reduction in slump as wood ash content increases. This was caused by the fact that wood ash particles have a greater specific surface area than cement particles due to their smaller size. As a result, these particles absorb more water, which in turn decreases the workability of concrete samples. Figure 2 shows the slump test result, which was carried out to indicate the influence of the addition of WA in dosses of 5%, 10%, and 15% with respect to the weight of the cement. The results of the properties of the concrete in its fresh state as shown in Figure 2, confirmed as the percentage of wood ash are added in higher percentages, reduces the workability even though there is a slight increase of workability between 5% and 10% replacement by 13,4% which further drop by 26,7% at 15% WA replacement. This behaviour may be due to the absorption capacity of this material and the additional volume it occupies, thereby reduces the workability. The test outcome was observed that as the wood ash doses increased, the slump decreased proportionally with respect to that of the control sample concrete. The use of 5%, 10%, and 15% WA reduced the slump by 53,3%, 66,7% and 40% respectively as compared to the control sample.

LEGEND: A= CC, B = ZAWA05, C = ZAWA10, D = ZAWA15

Figure 2: NS-Wood ash Slump Performance

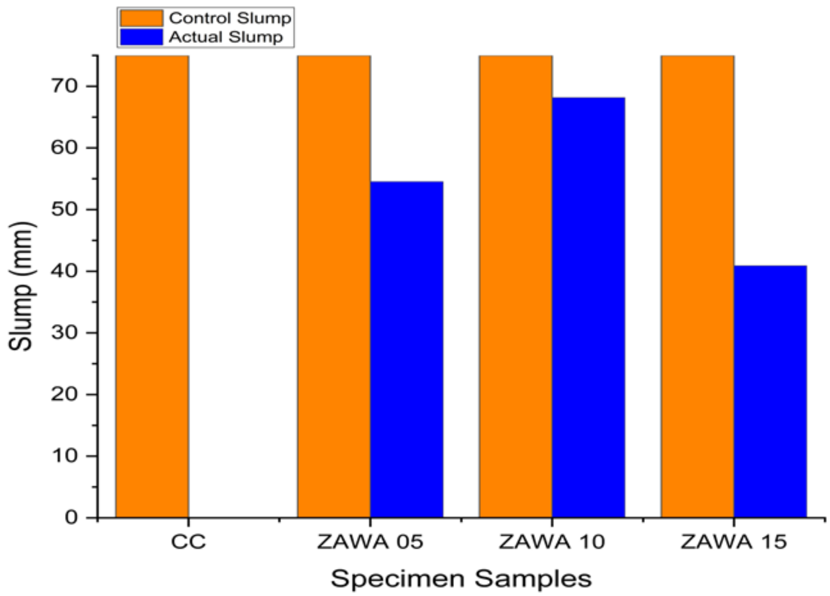

Figure 3: Variation in Slump of NS-Wood Ash Concrete at 14 days

3.3 Effect of NS-Wood Ash on Compressive strength

The compressive strength of hardened concrete is tested in accordance with [24] using cubic samples size (100 mm x 100 mm x 100 mm) using Toni Technik compression testing machine manufactured by Toni Technik Baustoffprefsvsteme GmbH Gustav-Meyer-Alle 25 D-13355 Berlin with a maximum load of 3000 KN. This research is to find the effect of nano-silica ingression on the mechanical properties of wood ash concrete. Table 8 below shows the difference between various mix designs and compressive strength of cube samples at 3, 7, and 14, days respectively.

Compressive strength of 100 mm cubes at 0% replacement of WA is 52,4 MPa at 7 days curing compared to 59,94 MPa at 14 days curing while at 5% replacement of WA, the compressive strength is 40, 7 and 51, 5 MPa respectively at 5% replacement. It is clear from the results that at 5% WA replacement, the compressive strength of NS-Wood ash concrete at 3 days decrease by 9%, 12%, and 18% compared to the control sample. The same pattern could be observed at both 10% and 15% WA replacement as the compressive strength decrease by 22%, 24%, 36% and 14%, 22% and 35% respectively compared to the control concrete sample as shown in Table 8.

In comparison with the research according to [26], the incorporation of 10% wood ash resulted in strength reduction by 26,52% as compared to the outcome of this research resulting in 24% strength reduction. This improvement could be as a result of additional effect of Nanosilica content. This result is consistent with the work of [27] which confirmed that lower doses of wood ash had better characteristics in terms of mechanical properties, although this current study obtained its best characteristics in terms of compressive strength at 5% WA replacement as compared to [28]

Table 8: Compressive Strength test results

MIX %	MIX ID	Weight [kg]			Crushing Load [KN]			Compressive Strength [N/mm^2]		
		3	7	14	3	7	14	3	7	14
0	CC	2431,3	2396,9	2377,6	330,1	523,7	599,4	33,01	52,4	59,94
5	ZAWA5	2433,0	2455,7	2440,6	300,7	407,0	515,2	30,1	40,7	51,5
10	ZAWA10	2335,2	2367,7	2366,0	291,4	400,1	466,6	29,1	40,0	46,7
15	ZAWA15	2353,9	2336,4	2337,9	271,7	335,6	388,1	27,2	33,6	38,8

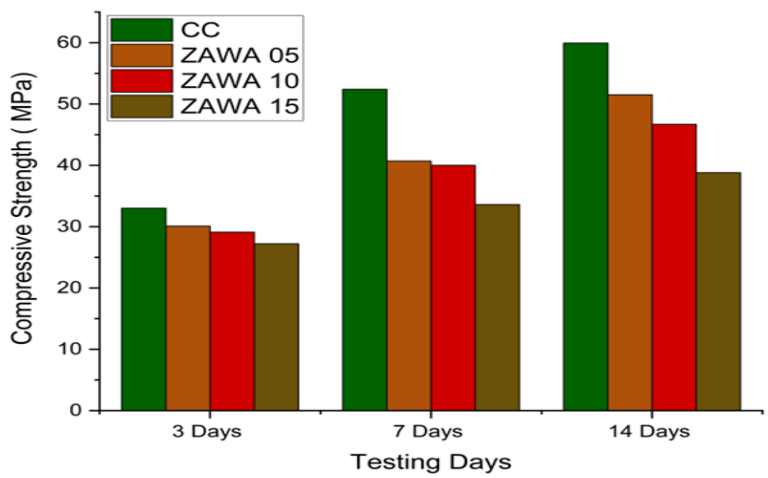

Figure 4: Variation in Compressive Strength of NS-Wood Ash Concrete at 14 days

3.4 Effect of NS-Wood Ash on Splitting Tensile Strength of concrete

Table 9 shows the effect of wood ash incorporating Nanosilica on the splitting tensile strength of the concrete samples. The Table shows the splitting tensile strengths of the samples cured for a period of 3, 7, and 14 days. It is observed that the splitting tensile strength decreases as the day progresses irrespective of the percentage of wood ash replacement at 14 days curing though there is stability in performance between 5% and 10% replacement. Though there is an increase of 7% of split tensile strength of SAWA05 over the control sample at 3 days, there is a further decrease of 21% and 14% for SZAWA10 and SZAWA15 for the same period. Generally speaking, there is an increase pattern applicable to all samples including the control sample concrete. Because of the nano-tiny silica particle size, the amount of water required fluctuated as we increased the amount of it in the concrete [29]. A substance with a greater degree of fineness has a bigger surface, which allows it to absorb more water while being mixed [30]. The slump value decreased when additional wood ash was added to the concrete. Due to the enormous surface area of the nano-silica particles and the unsaturated bonds in nano-silica, a portion of the mixed water (water molecules) pushes towards the surface of the nano-silica particles, forming silanol (Si-OH) groups [23]. As a result, there isn't enough water to maintain the flow of the concrete paste. When nano-silica was properly distributed and de-agglomerated, the presence of free water among the ultra-fine particles enhanced the rolling effects between the particles as there is an increase of tensile strength of 13% for SZAWA05 between 3 to 14 days and 55% for SZAWA10 respectively. There is an initial increase of 25% from 3 to 7 days for SZAWA15 with further decrease of 8% over a period of 11 days. The findings imply that a more uniform nanoparticle dispersion in concrete can potentially improve its use.

Table 9: Split Tensile Strength Test results

MIX %	MIX ID	Weight [kg]			Crushing Load [KN]			Splitting Tensile Strength [N/mm^2]		
		3	7	14	3	7	14	3	7	14
0	CC	2364,6	2423,6	2463,0	49,1	68,1	68,4	1,4	1,9	1,9
5	SZAWA5	2476,0	2458,5	2435,1	52,8	57,7	58,6	1,5	1,6	1,7
10	SZAWA10	2365,2	2338,3	2362,5	38,6	46,8	59,9	1,1	1,3	1,7
15	SZAWA15	2323,3	2335,3	2363,1	41,3	51,3	44,7	1,2	1,5	1,3

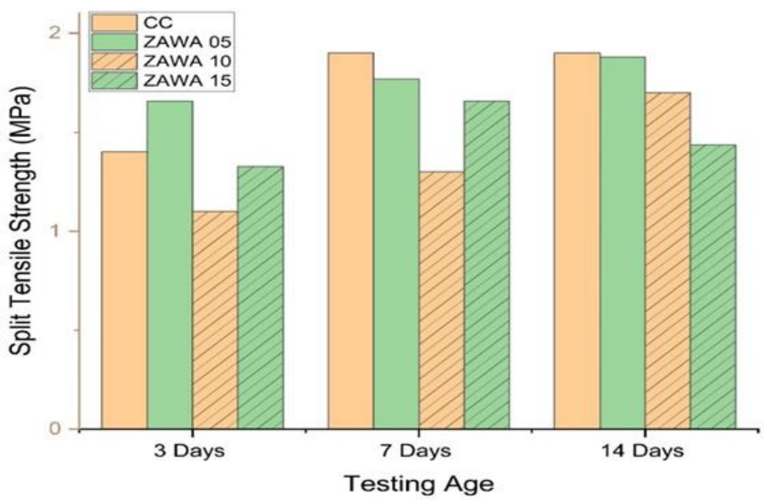

Figure 5. Variation in Split tensile strength of NS-Wood ash concrete at 14 days

3.5 Effect of NS-Wood Ash on the Microstructure of concrete

In Figure 6, it can be found that Nanosilica mixed with wood ash significantly improves the microstructure of concrete. As shown in Figure 6a, the microstructure of the control sample has significant defects, the hydration products are not closely combined with the aggregate, and the Interfacial Transition Zone (ITZ) is weak and there are obvious cracks. By observing Figure 6b (Zawa 05), it can be found that after reducing the amount of cement in concrete by 5 %, the addition of 5% NS-wood ash thus promote the hydration of cement to a certain extent and form denser and regular hydration products. However, there are still cracks and incomplete packages in the interface transition zone. In Figures 6c-d, it can be seen that with the gradual increase of NS-Wood Ash dosage by 10 and 15 %, the microstructure of concrete is significantly improved. The interface transition zone of the Zawa10 specimen is dense, and the hydration products are wrapped together with the aggregate [31-33]. The interface bonding between the slurry and the aggregate is significantly enhanced. Compared with the Zawa10 specimen, the ITZ of the Zawa15 specimen was closer. The hydration products completely wrapped the aggregate, and the hydration products changed from dispersed gel morphology to regular and orderly crystals [34, 35]. The crystals were intertwined to form a uniform and dense structure. This is due to the unique nucleation and filling effect of NS. The specific surface area of NS is large enough to absorb the hydration products. At the same time, C–S–H takes NS as the growth point and gradually grows from flocculent to columnar network structure with a distinct outline to improve the interface structure between cement slurry and aggregate. At the same time, the filling effect of NS can physically fill the gaps of cementitious materials, capillary pores, and calcium silicate hydrate crystals in concrete so that the concrete is denser, and the strength is improved [36, 37].

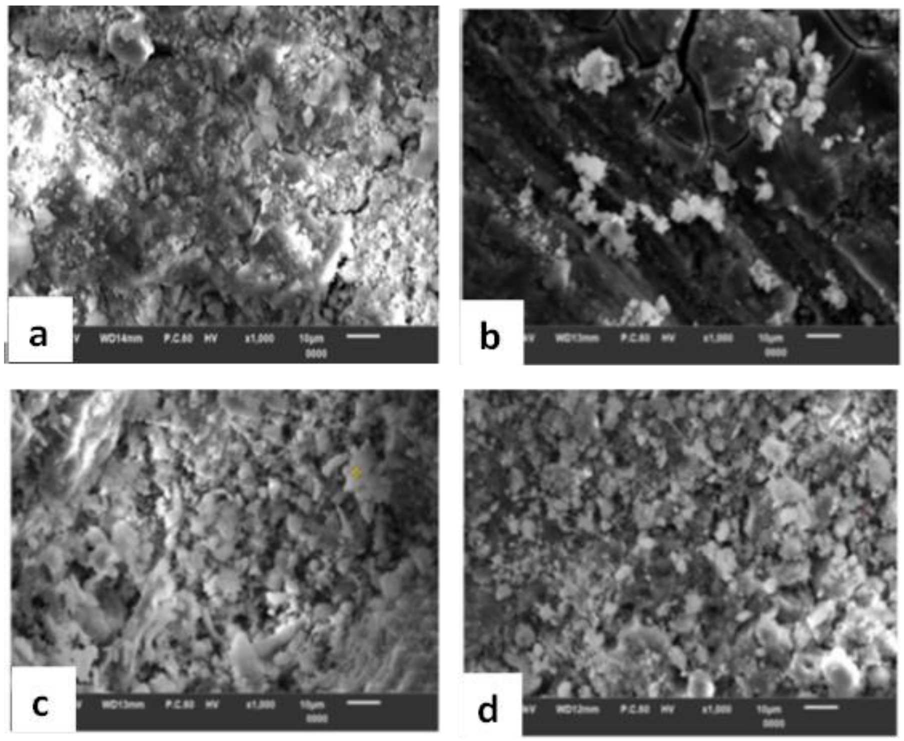

Figure 6a-d Micrographs of the Concretes

4. Conclusions

1. This study is based on the development of a Nanosilica mixed with wood ash obtained from caterers services which is situated at Morake Street, Kagiso 10374, Riverside, Johannesburg, and on the analysis of its physical, chemical and mechanical properties. The objective of the study was to investigate the effect of different percentage weight fractions of Wood ash mixed with NS on the mechanical and microstructural properties of wood ash concrete.
2. The initial setting time of the wood ash cement mortar containing 5% and 10% are higher than the initial setting time of the control sample by 9,4% and 15,7% respectively while the initial setting time of the wood ash concrete containing 15% cement replacement decrease by 40% compared to the control sample. The final setting time of the concrete with wood ash replacement between 5% to 15% shows consistent increase over the control sample by 15,93%, 19,92% and 20,77% respectively. The consistent improvement over the wood ash concrete samples of the final setting times were between 300 and 400 min, respectively.
3. With respect to the workability, the test outcome shows that as the wood ash doses increased, the slump decreased proportionally with respect to that of control sample concrete. The use of 5%, 10%, and 15% WA reduced the slump by 53,3%, 66,7% and 40% respectively as compared to the control sample concrete, even though there is a slight increase of workability between 5% and 10% replacement by 13,4%.

4. The compressive strength results show a slight improvement as against the work of [21] by 2,52% with the incorporation of 10% wood ash, this improvement could be attributed to the additional effect of Nanosilica content. This study also confirmed the notion of addition of lower wood ash doses had better characteristics in terms of mechanical properties, though this current study obtained its best characteristics in terms of compressive strength at 5% WA replacement.
5. The presence of free water among the ultra-fine particles enhanced the rolling effects between the particles as there is an increase of tensile strength of 13% for SZAWA05 between 3 to 14 days and 55% for SZAWA10 respectively. There is an initial increase of 25% from 3 to 7 days for SZAWA15 with further decrease of 8% over a period of 11 days. The findings imply that a more uniform nanoparticle dispersion in concrete can potentially improve its use.
6. The microscopic test results show that reducing the amount of cement in concrete by 15 % and adding Nanosilica mixed with wood ash can promote the formation of more hydration products such as C–S–H gel, which is helpful to form a closer ITZ inside the concrete. In addition, the cumulative pore volume in concrete is reduced, and the pore size is refined to make the internal structure of concrete denser. Finally, improving the mechanical properties and durability of concrete.
7. In general, it was concluded that the present study proved that it is feasible to use wood ash produced from caterers services which is situated at Morake Street, Kagiso 10374, Riverside, Johannesburg as the 14 days compressive strength of 51,5 MPa is higher than the target strength of 50 MPa for high performance concrete. However, the percentage higher than 5% of wood ash influenced the reduction of its properties

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References

[1] Sasu, D.D. Cement Production in Africa. Statista. 2023
[2] Imran, A. 2022 Cement Demand Outlook. World Cement, Emily Thomas 2022
[3] The Africa Infrastructure Development Index (AIDI) Report 2013 available at www.afdb.org
[4] Lilis Noviani, Eko Haryono, Wahyu Supartono. Environmental impact analysis of PCC cement products (Portland Composite Cement) using LCA (Life Cycle Assessment) 2023 *IOP Conf. Series: Earth Environ Science*. 1190 012003
[5] Darren P. AfriSam promotes use of extended cement products to reduce carbon footprint. Engineering News. 2022
[6] Garry T, Concrete industry green gas emissions. *Cement and Concrete Institute.* 2010; 1-60
[7] Johannes, H.P. An Overview of cement production: How "green" and sustainable is the industry? *Environmental Management and Sustainable Development* 2012;1(2) 1-37
[8] Changjiang Liu, Xin Su, Yuyou Wu. Effect of nano-silica as cementitious materials-reducing admixtures on the workability, mechanical properties, and durability of concrete. *Nanotechnology Review* 2021; 10: 1395-1409
[9] Mahani AG, Bazoobandi P, Hosseinian SM, Ziari H. Experimental investigation and multi-objective optimization of fracture properties of asphalt mixtures containing nano-calcium carbonate. *Constr Build Materials*. 2021: 285:122876
[10] Wu ZM, Shi CJ, Khayat KH. Multi-scale investigation of micro-structure-high performance concrete with nano-CaCO3 particles *Cem Concr Cpos*. 2018;86:255-65
[11] Kong DY, Du XF, Wei S, Zhang H, Yang Y, Shah SP. Influence of nano-silica agglomeration on microstructure and properties of the hardened cement-based materials. *Constr Build Mater.* 2012;37:707-15
[12] Said AM, Zeidan MS, Bassuoni MT, Tian Y. Properties on concrete incorporating nano-silica. Constr Build Mater. 2012;36:838-44
[13] Li LG, Zhu J, Huang ZH, Kwan AKH, Li Lj. Combined effects of micro-silica and nano-silica on durability of motar. *Constr Build Mater*. 2017;157:337-47
[14] da Silva Andrade D, da Silva Rego JH, Morais PC, de Mendonca Lopes AN, Rojas MF. Investigation of C-S-H in ternary cement pastes containing Nanosilica and highly reactive supplementary cementitious materials: Microstructure and strength. *Constr Build Mater*. 2019;198:445-55.
[15] Asgari H, Ramezanianpour A, Butt H.J. Effect of water and nano-silica solution on the early stages of cement hydration. Constr Build Mater.2016;129:11-24
[16] Mukharjee BB, Barai SV. Influence of incorporation of colloidal nano-silica on the behaviour of concrete. *Iran Journal Sci Technol-GTrans Civ Eng.* 2020;44(2):657-68.
[17] Balapour M. Joshaghani A, Althoey F. Nano-SiO_2 contribution to mechanical, durability, fresh and microstructural characteristics of concrete: a review. Constr Build Mater. 2018;181:27-41.
[18] Ganesh P, Murthy AR, Kumar SS, Reheman MMS, Iyer NR. Effect of nano-silica on durability and mechanical properties of high-strength concrete. Mag Concr Res. 2016;68(5):229-36.
[19] SANS 50197-1:2013. Cement, Part 1, Composition, specifications and conformity criteria for common cements
[20] SANS 3001-AG1:2014, Civil engineering test methods. Part AG1, Particle size analysis of aggregates by sieving
[21] SANS 5861-1:2006. Concrete tests – Mixing fresh concrete in the laboratory
[22] SANS 1491-2:2005. Portland cement extenders. Part 2, Fly ash
[23] SANS 5861-3:2006. Concrete tests – Making and curing of test specimens
[24] SANS 5863:2006 Concrete tests – compressive strength of hardened concrete
[25] SANS 5862-1:2006. Concrete tests – Consistence of freshly mixed concrete – slump test
[26] Senff L, Labrincha JA, Ferreira VM, Hotza D, Repette WL. Effect of nano-silica on rheology and fresh properties of cement pastes and mortars. Constr Build Mater. 2009;23(7):2487-91.

[27] Kooshafar M, Madani H. An investigation on the influence of nano-silica morphology on the characteristics of cement composites. *J Build Eng*. 2020;30:101293.
[28] Sheetal Verma, Ajit Singh, Rahul Gupta and Dr. Sanjay Sundriyal. The Effect of Wood Ash on the Workability, Water Absorption, Compressive Strength in Cement Mortar. *International Journal for Modern Trends in Science and Technology,* 2023, 9 (04). 368-373. https://doi.org/1046501/IJMTST0904054
[29] Elahi, M., Qazi, A., Yousaf, M., & Akmal, L., (2015). Application of wood ash in the production of concrete. *Science International (Lahore)*, 27(2), 1277-1280.
[30] Juan, A.; Guillermo, A. Luigi, V. Socrates, M. Strength of Concrete using partial addition of residual wood ash with respect to Cement. Strength of Concrete. *Revista Politecnica, Agosto* 2023 52 (1) 2023.
[31] Wu ZM, Shi CJ, Khayat KH. Multi-scale investigation of microstructure, fibre pullout behaviour, and mechanical properties of ultra-high-performance concrete with nano-$CaCO_3$ particles. *Cem Concr Compos*. 2018; 86:255–65.
[32] Li LG, Xiao BF, Fang ZQ, Xiong Z, Chu SH, Kwan AKH. Feasibility of glass/basalt fiber reinforced seawater coral sand mortar for 3D printing. *Addit Manuf*. 2020; 37:101684
[33] Kong DY, Du XF, Wei S, Zhang H, Yang Y, Shah SP. Influence of nano-silica agglomeration on microstructure and properties of the hardened cement-based materials. *Constr Build Mater*. 2012; 37:707–15.
[34] De Larrard, F. Malier, Y. Engineering Properties of Very High-Performance Concretes. *Mater. Struct*. 2018, 20, 85–114. [CrossRef]
[35] Gmira, A.; Pellenq, R.-M.; Rannou, I.; Duclaux, L.; Clinard, C.; Cacciaguerra, T.; Lequeux, N.; Van Damme, H. A Structural Study of Dehydration/Rehydration of Tobermorite, a Model Cement Compound. *Stud. Surf. Sci. Catal*. 2002, 144, 601–608. [CrossRef]
[36] Li, J. Yu, Q. Huang, H. Yin, S. Effects of Ca/Si Ratio, Aluminium and Magnesium on the Carbonation Behavior of CalciumSilicate Hydrate. Materials 2019, 12, 1268. [CrossRef] [PubMed]
[37] Fathi M, Yousefipour A, Farokhy EH. Mechanical and physical properties of expanded polystyrene structural concrete containing Micro-silica and Nano-silica. *Constr Build Mater*. 2017; 136:590–7.
[38] Nunes C, Slizkova Z, Stefanidou M, Nemecek J. Microstructure of lime and lime pozzolana pastes with Nanosilica. *Cem Concr Res*. 2016; 83:152–63