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Research paper

The effects of Nano SiO_2 and Silica Fume on the properties of concrete

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Abstract: This study investigates the effects of Nano SiO_2 (NS) and Silica fume (SF) on the mechanical properties and durability of Portland cement concrete. On specimens with varying NS and SF concentrations, compressive strength, flexural strength, abrasion resistance, elastic modulus, and chloride ion penetration were all tested. All specimens were subjected to the proposed method/technique cured at the ages of 3, 7, 28, and 60 days. NS particles were added to cement concrete at various replacements of 0, 0.5, 1.0, 1.5, and 2.0% by the mass of the binder. The water/binder ratio has remained at 0.37 for all mixes. Then, for cement-concrete were prepared 45 MPa (C45) with NS and SF. The specimens confirm the new method effectiveness evaluation were prepared under two different categories: (1) Portland cement replacement with NS of 0%, 0.5%, 1.0%, 1.5%, and 2.0%, by weight for adhesives; (2) Portland cement replacement with NS of 0.5%, 1.0% and each NS content in combination with SF of 5%, 10%, and 15%, respectively, by weight for adhesives. The results indicated that the abrasion resistance and Chloride ion penetration of concrete containing NS and SF are improved. Finally, an analytical model for forecasting the Elastic modulus, flexural strength, and compressive strength of cement concrete was established from obtained data.

Keywords: elastic modulus, Nano SiO_2, compressive strength, flexural strength, abrasion resistance, chloride ion penetration

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1. Introduction

The need for cement concrete, sustainable and ecologically beneficial, is increasing because of the fast development of the infrastructure. Numerous studies used pure nano-silica, which is costly, and hence the application in practice is rare. As a result, the present trend of identifying a widely available, low-cost, silicon-rich source of minerals for use as a concrete addition is worth thought. Nano SiO_2 (NS) has been widely used in catalytic materials, dielectric materials, gas adsorbents, heavy metal ion adsorption, and inorganic carriers throughout the past two decades [1]. Furthermore, most NS materials used in civil engineering were supplied by commercial firms, mainly from China and European nations [2]. Commercial NS has excellent purity and homogeneity since it is manufactured in a factory; nevertheless, it is costly and challenging to utilize in the actual building because it is manufactured in a factory. As a result, the present trend of identifying a widely available, low-cost, silicon-rich source of minerals for use as a concrete additive warrants study and has piqued academic scientists is an engineer's interest.

Rice production in rice-growing regions worldwide, such as China, India, Bangladesh, Brazil, and the Far East, increases daily, resulting in agricultural waste. With an estimated yearly rice production of 42 billion tons, Vietnam is the world's second-largest rice producer. Rice husk is a by-product of rice milling, and rice husk ash (RHA) is produced when rice husk is burned for energy, such as in a steam boiler. Millions of tons of waste RHA [3] were utilized in various sectors, including adsorbents, cement, catalysts, and nanocomposites. RHA is one of the most SiO_2-rich materials, with concentrations ranging from 90% to 98% by volume and a significant amount of amorphous silica (85–95%), making it an appealing source of raw materials for SiO_2 production [4].

In recent years, several researchers have utilized admixtures such as nanoparticles and fibers in cement-based materials to improve the engineering qualities of Portland concrete [5–7]. Several investigations on low-dose NS nanoparticles to substitute cement in concrete mixes to improve concrete quality have shown considerably good results [8]. NS particles exhibit high pozzolanic activity in concrete due to their large specific area and intense activity. Furthermore, NS particles can act as a catalyst for pozzolanic processes, increasing the dissolution of tricalcium silicate and the formation of calcium silicate hydrate (C–S–H) by providing nucleation sites for C–S–H [9]. NS particles were utilized as a partial substitute for cement by Nazari and Riahi [10]. They claimed that an NS concentration of less than 4% by weight may promote the development of C–S–H gel and refine the pore structure of concrete; however, when the NS content increased to more than 4%, the concrete is strength decreased owing to uneven nanoparticle dispersion. In their experiment, Said et al. [11] used colloidal NS and found that mixing nano-silica improved reactivity, strength development, pore structure refinement, and significant densification of the interfacial transition zone. According to certain research, adding 0 to 1.5% nano-silica particles to reinforced concrete with polyvinyl alcohol fibers increased compressive strength, flexural strength, and fracture energies. Furthermore, tensile strength was highest at a concentration of 2.5% nano-silica particles; however, the tensile strength decreased when the concentration was greater than 2.5%. The NS was susceptible to self-desiccation and flocking together, resulting in microfractures and composite strength losses [12]. Zhang et al. [13] examined the effects of NS particles on the mechanical properties, impact resistance, chloride penetration ion, and freezing-thawing resistance of coal fly ash concrete. The compressive, flexural, and splitting tensile strengths of concrete were increased by 15.5%, 27.3%, and 19%, respectively, when NS particles were added at varying amounts of 1%, 2%, 3%, 4%, and 5%, according to binder weight.

The size distribution of particles in ordinary concrete is compared to HPC/HSC concretes and designed concrete nano including NS in the graph below. The particle size distribution of HPC/HSC ranges from millimeters to around 100 nanometers, and it is the outcome of the structural enhancement of hydrated cement stone by integrating silica fume (SF) and other pozzolanic ingredients into traditional concrete. Fig. 1. The fact that NS has a very high surface area increases the range of the particle size distribution of concrete by order of magnitude, demonstrating the extent to which concrete can be nanoengineered at about 5nm. Konstantin Sobolev et al. [14].

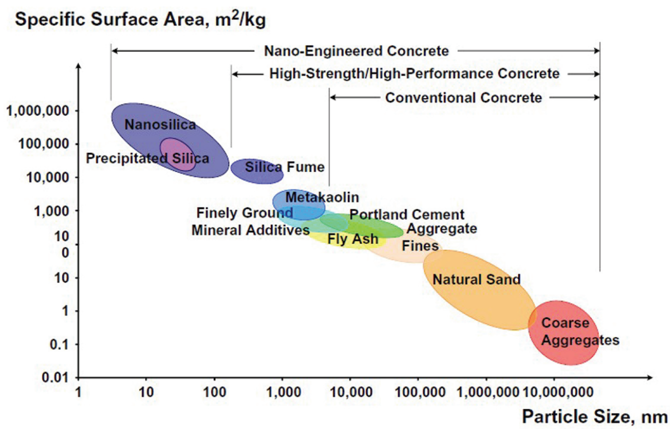

Fig. 1. The particle size and specific surface area scale are related to concrete materials

This study used an NS produced from RHA in Vietnam based on the previously mentioned literature review. Then, an investigation on mechanical and durability properties of cement concrete using various NS and SF contents as mineral admixtures, including Portland cement replacement with NS of 0%, 0.5%, 1.0%, 1.5%, and 2.0%, by weight for adhesives; Portland cement replacement with NS of 0.5%, 1.0% and each NS content in combination with SF of 5%, 10%, and 15%, respectively, by weight for adhesives. For all of the mixtures, the water/binder ratio was held at 0.37. Compressive strength, flexural strength, elastic modulus, abrasion resistance, and chloride ion penetration are among the mechanical and durability parameters of cement concrete that have been documented. The specimens were evaluated for compressive and flexural strengths at 3, 7, 28, and 60 days; elastic modulus was tested at 28 and 60 days. Second, various correlations and experimental coefficients among the acquired data were proposed based on the obtained results generated from this study.

2. Experimental program

2.1. Materials used

2.1.1. Portland Cement Blended (PCB 40) and Silica Fume (SF)

According to ASTM C150/C150M [15], the physical properties and chemical compositions of PCB 40 were determined. The specific gravity of PCB 40 is 3.14. The chemical composition of SF was given by a local commercial firm, and the specific gravity of SF is 2.20 according to ASTM C1240-04 [16]. Table 1 shows the chemical composition and physical properties of PCB 40 and Silica Fume.

Table 1. The chemical composition and physical properties of PCB 40 and SF were used in this study

Chemical composition (%)	PCB 40	SF
Silica (SiO_2)	22.65	95.48
Alumina (Al_2O_3)	5.25	0.20
Ferric oxide (Fe_2O_3)	3.42	0.0063
Calcium oxide (CaO)	65.13	0.13
Magnesium oxide (MgO)	0.06	0.37
Sodium oxide (Na_2O)	0.10	0.28
Potassium oxide (K_2O)	0.72	0.007
Sulphuric anhydride (SO_3)	0.18	0.45
Loss on ignition (LOI)	1.8	0.759
Physical characteristics		
Fineness (Blaine) (m^2/kg)	380	16.000
Specific gravity	3.14	2.20
Initial setting time (min)	120	NA
Final setting time (min)	180	NA
Particle composition		
Retaining on 45 mm sieve (%)	NA	5.93
Compressive strength (N/mm^2)		
1 day	14.5	–
3 days	26.5	–
7 days	33.0	–
28 days	44.0	–

Note: NA means not available.

2.1.2. Fine aggregate

River sand is used as fine aggregate in this investigation. Tables 2–3 and Fig. 2 detail the physical characteristics and sieve analysis, respectively, following ASTM C33 [17] and ASTM C29 [18].

Table 2. Physical properties of river sand

Physical properties of river sand				
Fineness Modulus	Water Absorption (%)	Specific Gravity (g/cm^3)	Bulk dry specific gravity (g/cm^3)	Moisture Content (%)
2.51	0.45	2.64	2.63	2.5

Table 3. Grain size distribution of river sand

Percentage passes of fine aggregates						
Sieve sizes	4.75 mm	2.36 mm	1.18 mm	600 µm	300 µm	150 µm
Percentage passing	95–100	80–100	50–85	25–60	5–30	0–10
Cumulative (%) passed	100	92.85	80.85	58.89	11.07	5.25

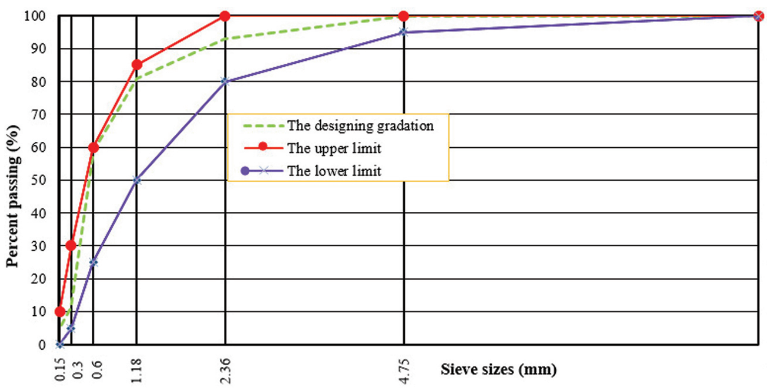

Fig. 2. The grain size distribution of river sand

2.1.3. Coarse aggregate

The coarse aggregate was a crushed stone collected from a local quarry and was originally made of basalt stone. The physical properties of coarse aggregate are presented in Table 4. The grain size distribution of coarse aggregate with a maximum dominant of 19 mm was presented in Table 5 and Fig. 3.

Table 4. The physical property of coarse aggregate

D_{max} (mm)	Water absorption (%)	Specific gravity (g/cm^3)	Bulk unit weight (g/cm^3)	Los Angeles abrasion value (%)	Moisture content (%)
19	0.87	2.72	1.613	24.8	0.48

Table 5. Grain size distribution of coarse aggregate

Percentage passes of coarse aggregate					
Sieve size	25 mm	19 mm	9.5 mm	4.75 mm	2.36 mm
Percentage passing	100	85–100	10–30	0–10	0–5
Cumulative (%) passed	100	92.5	16	8.0	0

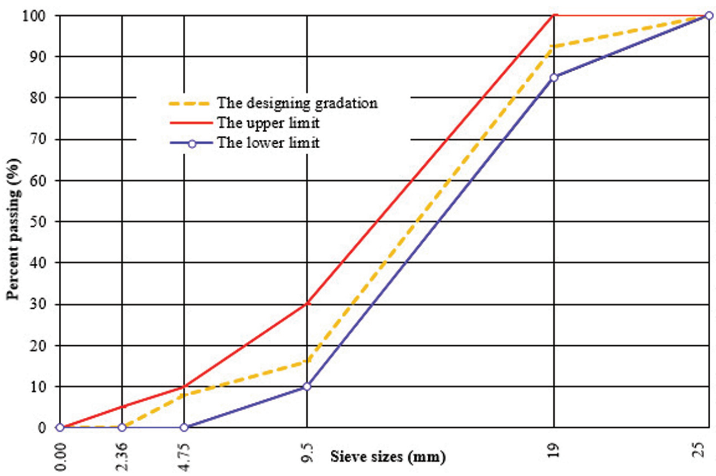

Fig. 3. The grain size distribution of coarse aggregate

2.1.4. NS modulation from RHA

RHA was used to produce NS by the sol-gel technique in southern Vietnam. The physical and chemical characteristics of NS have been assessed by certain procedures. The basic atomic makeup of SiO_2 is Si (28.78%) and O (57.92%), with a Si:O atom ratio of around 1:2, according to EDX spectroscopy data. The XRD findings showed that the NS material was mostly crystalline, with some amorphous SiO_2 mixed with the crystalline SiO_2 phase. BET methods found the specific surface area of nano SiO_2 to be about 258.3 m^2/g. SEM and TEM techniques showed that the NS material made from rice husk ash includes small particles ranging from approximately 10 to 15 nm; SiO_2 is in the form of crystals, made up of numerous microscopic particles that cluster together to create porous SiO_2 blocks. Based on the obtained results, it can be concluded that the NS from RHA could be applied as a suitable application as a binder for building materials, enriching the source of building materials and contributing to the protection of the environment, as seen in Fig. 4.

(a) (b)

Fig. 4. NS modulation from RHA: (a) Rice husk ash sample before preparation; (b) Nano SiO_2

Similar to the findings of previous research [19] the features of NS were derived. Based on the qualities described previously, one of the most important aspects of the NS material manufactured from RHA is its outstanding absorption capabilities. When used as a concrete addition, this aids in the mineralization process, as presented in Table 6.

Table 6. Physical properties of NS made from RHA

Properties	Value
Average particle size (nm)	15 ± 3
Specific surface area (m^2/g)	258.3
Specific gravity (g/cm^3)	2.2
Apparent density (g/l)	52
pH value	3

2.1.5. Water

In line with TCVN 4506:2012 [20], the water used to manufacture cement concrete does not include grease or other organic contaminants.

2.1.6. Superperplasticzer

Sika Viscocrete 3000-20 shines because of its exceptionally high water reduction capacity, which allows for good fluidity while retaining the mixture is optimal adhesion. According to TCVN 8826:2011 [21], this admixture complies with the established criteria for chemical additions for concrete. Sika Viscocrete 3000-20, a 3^{rd} generation polymer-based high-tech superplasticizer with excellent porosity and simple permeability of concrete, was utilized in the experiment.

3. Mix proportions and sample preparation

The concrete strength component was designed using the ACI 211.4R-08 code [22], as follows: The manufacturer's standards were followed during the component-designing phases of concrete using NS. To get the desired slump, the concrete mixture is slump was adjusted.

The ACI specification was used to calculate and design the concrete composition with a specific strength of 45MPa (C45); NS+SF was used in concrete to improve the strength and reduce the cement content. The original binder was made of 100% cement. Then, cement content is replaced by NS, including 0%, 0.5%, 1%, 1.5%, and 2% of the total quantity of the binder. Then, SF was utilized in various ratios in the gradation components, including 0%, 5%, 10%, and 15% of the total quantity of the binder. The water to binder ratio was fixed at 0.37. Table 7 shows the mix proportions of various mixes. The superplasticizer (SP) was gradually added to keep the slump value of the mixtures at 4 ± 1 cm.

Table 7. Mix proportions and quantities for Cement-content

Mix code		In this study		C	S	NS	SF	CA	SP	W/B
		NS (%)	SF(%)	(kg)	(kg)	(kg)	(kg)	(%)	(kg)	
C45	NS0-SF0	–	–	454	625	–	–	1046.5	2.72	0.37
	NS0.5-SF0	0.5	–	451.8	624	2.20	–	1046.5	2.95	
	NS1.0-SF0	1.0	–	449.6	623	4.40	–	1046.5	3.13	
	NS1.5-SF0	1.5	–	447.4	622	6.60	–	1046.5	3.27	
	NS2.0-SF0	2.0	–	445.2	621	8.80	–	1046.5	3.41	
	NS0.5-SF5	0.5	5	429.8	616	2.2	22	1046.5	3.63	
	NS0.5-SF10	0.5	10	407.8	608	2.2	44	1046.5	3.86	
	NS0.5-SF15	0.5	15	385.8	600	2.2	66	1046.5	4.22	
	NS1.0-SF5	1.0	5	427.6	615	4.4	22	1046.5	4.18	
	NS1.0-SF10	1.0	10	405.6	608	4.4	44	1046.5	4.31	
	NS1.0-SF15	1.0	15	383.6	600	4.4	66	1046.5	4.54	

Note: C – Cement; S – Sand; NS –Nano SiO_2; SF – Silica Fume; CA – Coarse aggregates; SP – Superplasticizer; W/B – Water/Binder (Cement + NS + SF).

3.1. The procedure for specimen preparation and testing

NS is difficult to distribute in concrete mixtures due to its large surface area and nanoscale particle size. As shown in Fig. 5, the methods below are experimental mixing processes for producing homogeneous, stable concrete. Mixing the sample consists of seven steps:

Step 1: To equally spread the NS particles, NS was mixed with 60% water and forcefully agitated for two minutes;

Step 2: For three minutes, a mixture of sand, crushed stone, cement, and silica fume were combined;

Step 3: To the sand, crushed stone, and cement mixture, a total of 20% water was added and well mixed for one minute;

Step 4: The NS and 60% water combination from step 1 was added to the Step three mixture and stirred for several minutes;

Step 5: For 3 minutes, the solution containing the remaining 20% water and superplasticizer was mixed into the Step 4 mixture until it was homogeneous;

Step 6: The mixer was turned off for two minutes to allow the superplastic component to react, which improved the outcome;

Step 7: The mixture was constantly blended for 3 minutes to eliminate slumps and ensure homogeneity.

Fig. 5. Sample testing of materials

A 60-liter mixer was utilized to mix the composition. A compressive strength, and a bending test with a specimen of 150×300 mm $(d \times h)$, and $150 \times 150 \times 600$ mm; abrasion resistance with a specimen of $70.7 \times 70.7 \times 70.7$ mm; elastic modulus with a specimen of 150×300 mm $(d \times h)$; and compressive strength, and 100×200 mm cylinders were used for each kind of concrete to evaluate the chloride ion permeability at 28 days. Sand is among the available test specimens. The inside surface of the mold should be smooth, clean, and lubricated before sampling. Samples were compacted using a vibrator with a frequency of 2800÷3000 rpm and an amplitude of 0.35÷0.5 mm. Then, specimens were cured in a room at $25 \pm 2°C$ for a minimum of 24h. Finally, the molds were removed and soaked in water. The compressive and flexural strengths were tested at 3, 7, 28, and 60 days. The elastic modulus was conducted at 28 and 60 days, chloride ion permeability and abrasion resistance were conducted 28 days. All the tests were conducted in triplicate with specimens.

3.2. Compressive and flexural strength tests

Experiments were conducted at the Ho Chi Minh City University of Technology Laboratory of Building Materials LAS-XD 238 Research Center for Industrial Technology and Equipment. The chlorine ion permeability test was conducted at the Construction Materials Laboratory-LAS-XD 143 Southern Institute of Water Resources Research, Vietnam. After molding and curing, compression and flexural tensile strength, elastic modulus, and chloride ion permeability, and abrasion resistance (AR) tests are carried out according to ASTM C39 [23], ASTM C78 [24], ASTM C469 [25], ASTM C1202 [26], and TCVN 3114:1993 [27], respectively. Fig. 6 shows the equipment for testing the chloride ion penetration.

Fig. 6. Chloride ion penetration test

4. Results and discussions

4.1. Mechanical properties of cement concrete with NS and SF

The compressive strength of various mix proportions at 3, 7, 28, and 60 days of curing is shown in Figs. 7–8. NS concentrations of 0%, 0.5%, 1.0%, 1.5%, and 2.0% are used to replace cement. As expected, the compressive strength increased with curing age, with a longer curing duration resulting in a higher compressive strength due to the cementitious-hydrated process continuing. After 7 days of curing, the compressive strength of the selected percentage mixtures reached the goal grades of C45.

Figures 7–8 plot the compressive and flexural strengths with NS contents. The obtained compressive and flexural strengths follow a parabolic curve when the NS content is in a range of 0–2.0%. The compressive and flexural strengths were 54.38–61.26 MPa and 5.21–6.16 MPa, respectively, after 28 days of curing. Looking at the data presented in these figures, when the NS content increased from 0.5 to 1.5%, the strengths considerably rose; however, the strength dropped as the NS percentage increased further. As a result,

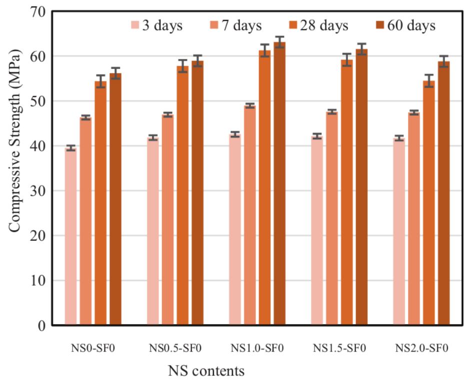

Fig. 7. Compressive strength of Grade C45 Concrete with various NS contents

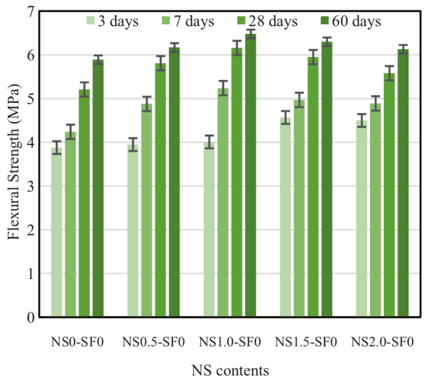

Fig. 8. Flexural strength of Grade C45 with various NS contents

the necessary NS content was identified at 1.0%. These findings were comparable to those published previously by Zhang et al. [28], who investigated the flexural strength of polyvinyl alcohol fiber concentration and NS particles; nevertheless, the optimal NS level was found to be 1.2%. Zhang et al. [13] reported that the NS replacement was in the range of 2–3% and that the compressive strength, splitting tensile strength, and flexural strength in coal fly ash concrete were the greatest. The pozzolanic reaction and nano-filling are two factors that contribute to the increase in cement-content strength. The SF and NS react with $Ca(OH)_2$ to form $CaSiO_3$ significantly improving the mixtures' microstructure. Furthermore, because NS particles are smaller than cement particles, they may significantly improve the characteristics of the interfacial structure. According to Abbasi et al. [29], when NS concentration is more than 1.5%, the large molecular force is beyond the optimal content for NS addition in cementitious composites, which tends to flock and lower strength.

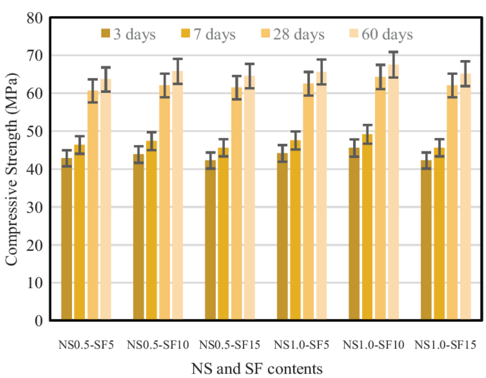

Fig. 9. Compressive strength of Grade C45 using various NS and SF contents

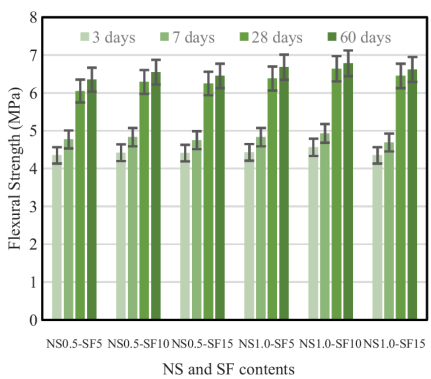

Fig. 10. Flexural strength of Grade C45 various NS and SF contents

Figs. 9–10 show the compressive and flexural strengths of various mix proportions at 3, 7, 28, and 60 days of curing, such as 0.5% NS and 1.0%NS in combination with 0%, 5%, and 10% SF, respectively. At the same curing age and SF concentration, compressive strength containing 1.0% NS is often higher than that of 0.5%. The reason can be explained as combining two types of NS and SF. The SF and the amorphous part of NS react with $Ca(OH)_2$ created by hydration with cement. The reaction that creates CHS ($CaO.H_2O.SiO_2$) gel is more closely linked to the aggregate and, at the same time, reduces the unfavorable $Ca(OH)_2$ content generated during hydration with cement. However, NS fine particles should be filled with the smallest slots, making the cement-mortar and cement-concrete more solid. Combining two additives will reduce hydrothermal heat and thermal stress in cement concrete boards.

4.2. Abrasion resistance of cement concrete

Fig. 11 shows the weight losses corresponding to the abrasion resistance of control cement concrete, cement concrete with SF, and cement concrete with NS, indicating that the abrasion resistance of cement concrete with NS was significantly improved. The abrasion resistance of cement concrete with NS was greater than that of control cement concrete and cement concrete with SF. The explanation for this might be due to the fact that NS cement concrete has a less porous structure (i.e., no visible pores) and so has a denser and more compact texture [30]. The abrasion resistance of concrete treated with NS was similar findings. According to these studies, the inclusion of NS improved the abrasion resistance of cement concrete of all ages. By considering the effect of NS particle size on abrasion resistance which is the main objective of this study, the obtained results showed that the control cement concrete gave the highest weight loss (3.01 kg/m^2) while cement concrete containing NS1.0–SF10 gave the lowest weight loss (25.58% of NS0–SF0) indicating the improvement of abrasion resistance of NS and SF. By increasing the NS ratio, the abrasion resistance of cement concrete was increased. Finally, the relationship between the abrasion resistance in terms of weight loss and the ratio of NS is shown in Fig. 11.

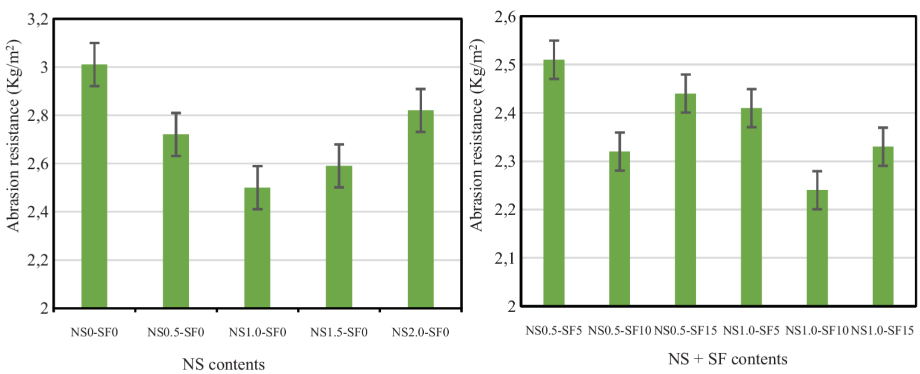

Fig. 11. Abrasion resistance cement concrete Grade C45 using NS and SF contents

4.3. Strength formulation based on analytic data

ACI [31] previously created a predicted-strength model based on Ordinary Portland Cement. As shown in Eq. (4.1), the projected model used compressive strength as a variable to calculate concrete is elastic modulus.

$$E = 4730\left(f_c'\right)^{0.5} \tag{4.1}$$

where E is elastic modulus (MPa); f_c' is compressive strength (MPa).

Based on the experimental data, the correlation between elastic modulus and compressive strength of concrete containing NS and with or without SF can be analytically calculated via Eq. (4.1), which was derived from the Gauss-Newton algorithm using an exponential function and an independent variable. Fig. 12 presents the predicted elastic modulus based on the compressive strength at the age of 28 days. Finally, the predicted equations are shown in Eqs. (4.2–4.3) corresponding cement concrete with NS and SF, as follows:

- For concrete using NS

$$E = 16176\left(f_c'\right)^{0.1907}, \qquad R^2 = 0.9298 \tag{4.2}$$

- For concrete using NS and SF

$$E = 835.49\left(f_c'\right)^{0.91}, \qquad R^2 = 0.824 \tag{4.3}$$

where E is elastic modulus (MPa); f_c' is compressive strength (MPa).

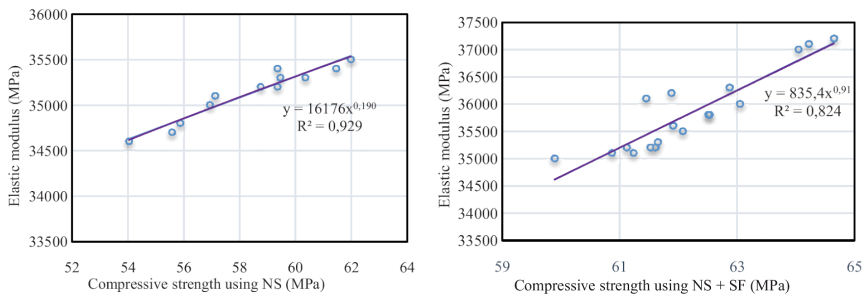

Fig. 12. Elastic modulus with compressive strength of cement concrete using NS and NS + SF contents

Furthermore, in general, the relationship between flexural strength and compressive strength of Portland cement concrete was also established by the Technical report [32] as presented in Eq. (4.4):

$$f_r = 0.393\left(f_c'\right)^{0.66} \tag{4.4}$$

where f_r is flexural strength (MPa); f_c' is compressive strength (MPa).

Similar to elastic modulus, the data of this study were employed to propose the relationship between flexural strength and compressive strength at 28 days. Technical Report algorithm was used to describe the flexural strength based on compressive strength, as shown in Fig. 13 and Eq. (4.5) and Eq. (4.6), as follows:

- For concrete using NS

$$f_r = 0.1393\left(f_c'\right)^{0.92}, \qquad R^2 = 0.9826 \tag{4.5}$$

- For concrete using NS and SF

$$f_r = 0.0191\left(f_c'\right)^{1.4059}, \qquad R^2 = 0.8534 \tag{4.6}$$

where f_r is flexural strength (MPa); f_c' is compressive strength (MPa).

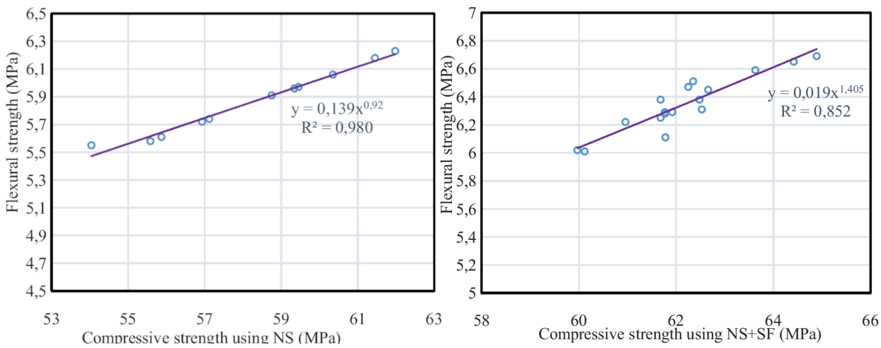

Fig. 13. Flexural strength with compressive strength of cement concrete using NS and NS + SF contents

4.4. Chloride ion penetration

The findings of the permeability of chloride ions with different NS concentrations are shown in Fig. 14. It was discovered that when the amount of NS particles in the concrete rises, the concrete's chloride penetration resistance improves. The data presented in Fig. 14 indicated that the permeability values of chloride ions are in the range of 612–2292 Coulomb at 28 days of testing. The cement concrete Grade C45 using NS containing 2.0% NS had the best anti-chloride ion penetration capabilities of 39.70%, and 1.0% NS containing 10% SF had the best anti-chloride ion penetration capabilities of 73.90%, for 28 days, compared to the control sample. Earlier studies [33] have found a propensity to reduce chloride ion permeability. This result may be explained by the fact that NS is a nanoscale material capable of converting dangerous pores into safe ones and lowering concrete porosity. It can inhibit the creation of concrete pores, refine pore size, and make concrete microstructures denser and more homogenous when added to the concrete as a nanoscale substance with an average particle size smaller than that of cement in concrete. Furthermore, NS in the cement matrix can effectively block or cut off capillaries in the concrete, resulting in tortuosity and more unconnected transport channels, increasing the concrete sample's chloride permeability resistance [8, 13]. As previously indicated, after being introduced to the mixture at higher NS replacement ratios, the NS particles agglomerate and become unable to distribute uniformly in the cement matrix, resulting in a lower chloride ion permeability than that of the concrete with the optimal threshold NS.

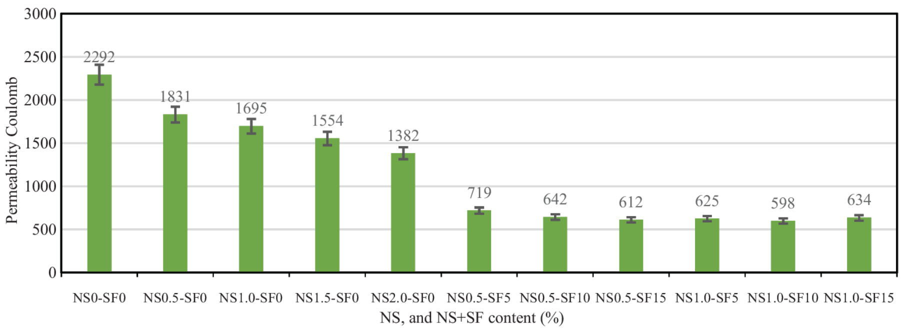

Fig. 14. Permeability of chloride ions with various NS and NS+SF contents at 28 days

5. Conclusions

This paper presents an experimental investigation on additive NS coupled with SF in cement concrete Grade C45. Mechanical characteristics of cement concrete having various NS concentrations. The following conclusions were obtained based on the collected data:

- Without SF, cement concrete containing 1.0%NS significantly enhanced the compressive strength, flexural strength, and elastic modulus. With SF, the largest improvements in compressive strength, flexural strength, and elastic modulus of concrete were obtained at 10% SF and 1.0% NS. The addition of 1.0%NS and 1.0%NS + 10%SF to cement concrete improved its abrasion resistance compared to the control cement concrete.
- The Gauss-Newton method was utilized to obtain some best-fit equations for characterizing the elastic modulus and flexural strength of concrete based on compressive strength in the case of utilizing either NS or NS and SF.
- A modest dosage of NS can considerably increase the chloride penetration resistance of Cement concrete compared to control concrete. Because the NS may break off capillaries in the concrete, causing tortuosity and more unconnected transport channels, the chloride ion permeability was reduced. When the NS replacement amount was about containing 2.0% had the best anti-chloride ion penetration capabilities of 39.70%, and NS1.0% containing 10% SF had the best anti-chloride ion penetration capabilities of 73.90%, for 28 days, compared to the control sample.
- The addition of NS and SF to cement concrete creates a new material form to meet the ever-increasing demand for building materials, economic benefit, reducing environmental pollution produced by waste RHA.

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