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IMPACT OF NANOSIZED SILICA ON THE PHYSICO-MECHANICAL PROPERTIES AND CORROSION PROTECTION OF CONCRETE

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ABSTRACT

Nanomaterials have an important role for enhancingthe concrete properties and inhibition of rebar corrosion in reinforced concrete. Nanosilica (NS) is one of the most effective cementitious materials, which possess high pozzolanic nature. In this work, NS was added in mix design of concrete with different ratios as; 0, 0.5, 1, 1.5, 2and 2.5 % by weight of Portland cement. Physical, mechanical properties (workability, density) were determinedfor the fresh concrete samples. While, compressive strength andmicrostructural properties of the interfacial transition zone (ITZ) between cement pastes and aggregates of concrete were investigatedfor the hardened samples.As well as electrochemical measurements (open circuit potential and linear polarization) were done for the reinforced concrete samples. The results show that, concretes containing NS up to 2% have a higher compressive strength and a denser in interfacial transition zone (ITZ). Also, corrosion inhibition for reinforced concrete increased gradually by increasing NS addition up to 2%.

Keywords: Concrete, nanosilica, corrosion of reinforced concrete

1. INTRODUCTION

Nanotechnology (NT) is defined as the science of studying, examiningand monitoring the behavior and performance of materials at the nano-scale. It is the process of production a material or device with building units at the atomic and molecular scale [1,2]. Nanotechnology covers a wide scope and many disciplines stimulating collaboration among scientists and researchers in sustainable development [3, 4]. These developments have begun to emerge in civil engineering by using NT to improve the properties of cement and concrete [5]. Lotfi et al. studied the properties of cement mortar containing both of nanosilica (NS) and silica fume (SF). They found that the compressive strength values for mortar containing NS particles were higher than that of mortar containing SF at 7 to 28 days [6]. Abd El-Aleem et al. studied hydration characteristics, thermal expansion and microstructure of cement containing NS. They have been reported that, partially substitution of OPC up to 5 mass % NS improves the mechanical and microstructural characteristics in comparison with the neat OPC paste up to 90 days [7]. Prasa da Raoet al. studied the influence of fly ash (FA) and nanosilica (NS) on strength propertiesof concrete. Cement is partially replaced by 20 and 30 % of FA and NS 1.5, 3and 4.5 % by weight. It can be concluded that, with the increase in NS percentage, various strength characteristics of concrete increase up to 3%, with further increase in NS the strength characteristics of concrete are decreased for the given percentages of FA possesses improved properties compared to the controlled concrete [8]. El-Didamony et al. studied the hydration behavior of composite cement containing FA and NS [9]. Tawfik et al. have investigated the influence of nano-particles on mechanical and nondestructive properties of high-performance concrete. The results showed that, both of FA and NS improve the hydration behavior and mechanical properties of the investigated cements. But, NS possesses higher improvement level than FA [10]. Ozyildirim et al. investigated how nano-material improved permeability and strength of concrete and found that, very little amount of NMs like nano silica and nano clay in concrete can improve the compressive strength and permeability of concrete [11]. Mohammed investigated the influence of using different cement blends on the concrete properties incorporating nano materials. There was a significant positive effect of using ternary blends on the different mechanical properties [12]. Isfahaniet al. investigated the effect of replacement different proportions of cement by nano-silica on the compressive strength and durability of hardened concrete with different w/b ratios [13]. Montgomeryet al. studied the effect of replacement different ratios as; 1, 3 and 5 % cement withsilica nano-particles by volume on the compressive strength. The study revealed that, 1% is the optimum cement replacement percentage to increase the compressive strength [14]. Younis and Mustafa improved the performance of recycled aggregate concrete by using nanosilica. The study results show that silica nano-particles can improve the compressive and tensile strength values, reduce the permeability, and also modify the microstructure of recycled aggregate concrete [15]. Several studies have shown that, the addition of NS results in improved compressive, tensile, and flexural strength of concrete [16-18]. Also, the addition of NS in concrete mix design contributes to improve the microstructure of the obtained hardened concrete [19, 20]. Furthermore, there are many researches proved that NS have an important mechanism for inhibition the corrosion of steel rebar in reinforced concrete [21, 22, 23]. The aim of this work was to study the effect of NS addition to concrete mix with different ratios of the cement weight on the physico-mechanical properties and corrosion protection of concrete.

2. MATERIALS AND METHODS

2.1.Materials

Cementitious materials in this study are Portland cement and silica nano-particles. Ordinary Portland cement (type CEM I - 42.5 N) is produced from El- Suez Company (El Suez plant) in Egypt. Silica nano-particles are exported from India. Chemical properties of cement and silica nano-particles are pointed in Table 1. The super-plasticizer (SP) is naphthalene type with 33% solid content and 1.15 g/cm^3 density. The used coarse aggregate is a natural crushed stone of dolomite. It is generated from the quarries and crushers located at Attaqa Mountains (Cairo-Suez Desert Rd.). Steel rebar obtained from Ezz steel Company, Alexandria, Egypt.Its radius is 12mm.

2.2. Methods

2.2.1. Characteristics of raw materials

2.2.1.1. Characteristicsof Portland cement

A. Chemical characteristics of Portland cement

Chemical Characteristics of Portland cement (PC) used were carried out to determine the type and percentage of the major oxides present in it using the following techniques and methods: Themajor oxides of the investigated cement was determined by X-ray florescence (XRF). The test was run using Rh-kα (rubidium) radiation tube at 50 Kvand 50 mA.In the present work, quantitative determination of the major oxides; SiO_2, Al_2O_3, Fe_2O_3, TiO_2, CaO, MgO, Na_2O, K_2O and SO_3 were accomplished bya computerized X-ray fluorescence (Phillips PW 1400 Spectrometer, Holland). Also, a traditional manual method prescribed in ASTM D7348-08 for determination of loss on ignition (LOI) was followed.

B. Physical and mechanical characteristics of Portland cement

The supplied OPC sample was studied in terms of determination the expansion of cement by the LE CHATELIER method (ESS 2421-1993), determination of initial and final setting times of cement paste using Vicat's apparatus (ASTM C191-08) and compressive strength (E.S 2421 part 7 – 2005).

2.2.1.2. Characterization of fine and coarse aggregates

All the physical and chemical properties of fine and coarse aggregates determined according to the Egyptian code for design and construction structures (ECP 203-2001 (2007)).

2.2.1.3.Chemical analysis of mixing water (drinking water)

The chemical composition of the drinking water which is used as mixing water in the concrete specimens preparation are determined according to ECP 203-2001.

2.2.1.4. Characteristics of nanosilica

A. Chemical analysis of nanosilica by (XRF)

The chemical analysis of used nanosilica was determined by X-ray fluorescence (XRF).

B. X-Ray Diffraction (XRD)

The XRD technique was used to determine the mineralogical composition of the investigated material. The used XRD apparatus was X'Pert PRO PW 3040/60 (PANalytical) diffractometer equipped with monochromatic Cu-kα radiation source. The test was run at 40 Kv and 30 mA. A continuous mode was used for collecting data in the 2θ range from5 - 50º ata scanning speed of 2o /min. The acquired data were analyzed using X' pert High Score software including cards of International Center of Diffraction Data.

C. Transmission electron microscopy (TEM)

TEM is one of the useful and widely used tools to determine size and morphology of nano particles. Transmission electron microscopy (TEM) allows a qualitative understanding of the internal structure.TEM specimens were prepared by ultra-sonic materials for 15 minutes before analysis. The test was performed by a JEOL JEM-1230; model Oregon (Japan) at 80 kV.

2.2.1.5.Chemical analysis of steel rebar

The chemical constituents of rebar used in this study are determined by the chemical analysis of rebar according to ASTM E 415-08.

2.2.2. Preparation of concrete samples

For each mix proportion, concrete cubes measuring 100×100×100 mm^{3}for compressive strength test and 150 mm cylinders for water absorption and electrochemical measurements were prepared. In order, SP and water were mixed together in mixer, and then NS particles were added, and mixed for 5 minutes with high speed. Then cement, fine and coarse aggregates were added for three minutes in rotary mixer with low speed to procure a fresh workable mixture of concrete. Finally, fresh concrete were casted in steel molds in three layers and vibrated by using a shaker for consolidation purposeand reduce existing air voids in the matrix of fresh concrete. Specimens were demolded after 24 h and cured in the curing room. Mix proportions of concrete samples listed in Table 1.

2.2.3. Evaluation of concrete samples

2.2.3.1. Workability and density of fresh concrete samples

Slump and density (unit weight)testsweredeterminedaccording to ASTM C143-03 (2003) and ASTM C138 respectively.Density expressed by the following:

$$\mathbf{D = (M_c – M_m) / V_m.}$$

M_c isweight of the measure holding the concrete;M_m is weight of the empty concrete measure and $V_m$is the volume of the measure.

2.2.3.2. Compressive strength of hardened concrete samples

Compressive strength test for hardened concrete samples was carried out by using a 2000 KN compression machine according to ASTM C109 (2011).The hardened cubes were tested at a saturated surface dry condition to avoid of water that fills the pores of the specimens.Compressive strength value of any mix of concrete sample represented as the mean of three readings of compressive strength for three cubes of the same concrete mix.

2.2.3.3. Scanning electron micrograph of concrete samples

Table 1. Mix proportions (kg/m^3 of concrete)

Mix	Cement g/m^3	Dolomite g/m^3	Sand g/m^3	Water g/m^3	Nano Silica g/m^3	S.P.* g/m^3
C	400	1124.8	750.0	160.0	0	6.00
M1	400	1120.6	747.0	160.8	2	6.03
M2	400	1116.4	744.3	161.6	4	6.06
M3	400	1112.2	741.5	162.4	6	6.09
M4	400	1108.0	738.6	163.2	8	6.12
M5	400	1104.0	736.0	164.0	10	6.15

* Super Plasticizer

After determining mechanical properties, the selective crushed specimens were testedby SEM to observe the effect of nanosilica addition on properties of Interfacial Transition Zone (ITZ) between cement paste and aggregates. The scanning electron micrographs were taken using an Inspect S machine (FEI Company, Holland). The microscope can examine the microstructure of the fractured composites at accelerating voltage of 200 V to 30 KV and power zoom magnification up to 300000 xs.

2.3.3.4. Corrosion resistance measurements

Concrete cylinders were immersed in 3.5% NaCl as aggressive medium for 28 days, then corrosion parameters measured by Potentiostat instrument as shown in Fig. 1.

Fig. 1. Potentiostat

A. Open circuit potential (OCP)

In this work, this technique is used formeasuringthe scope of steel rebar susceptibility to react with an environment. Where concrete represented as an electrolyte and reinforcement will enhance a potential dependent on the concrete environment.For reinforcement concrete structures, OCPtechnique is depending on measurement the corrosion potential of steel rebar (working electrode) with respect to a standard reference electrode such as standard calomel electrode (SCE).

B. Linear polarization (polarization resistance) technique

This technique determines the effect of Ns addition content on the corrosion of steel rebar through measuring the corrosion rate.

3. RESULTS AND DISCUSSIONS

3.1. Characteristics of raw materials

3.1.1. Characteristics of Portland cement

3.1.1.1. Chemical composition of Portland cement

Table 2. Chemical composition of Ordinary Portland cement (OPC)

Oxide	Result (%)	ESS 4576-1/2013
SiO_2	20.79	
Al_2O_3	4.01	
Fe_2O_3	3.08	
Cao	62.17	
MgO	2.69	
SO_3	2.69	<3.50
L.O.I	3.94	<5.00
Na_2O	0.18	
K_20	0.07	
Total	99.91	
Insoluble residue	1.21	<5.00
Cl^-	0.05	≤0.10 %
Na_2O Eq.	0.22	≤0.6 %
LSF	0.92	
C_3A	5.42	

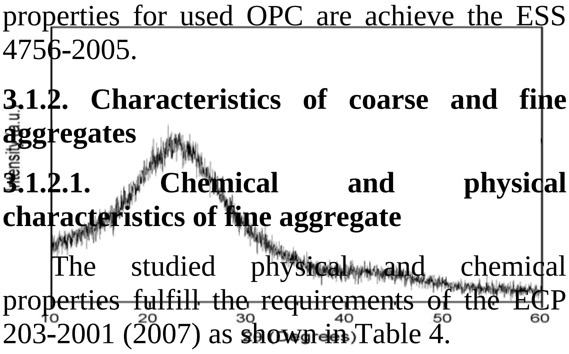
3.1.1.2. Physical and mechanical properties of the used Portland cement

The physical and mechanical properties of Ordinary Portland Cement used in this study are illustrated in Table 3. It is noticed that the

Table 3.Results of the physical and mechanical properties of the used OPC.

Item	Test	Test value	ESS limits
Physical properties	Le Chatelier expansion	1.2 mm	<10 mm
	Initial setting time	150 min.	>45 min.
	Final setting time	190 minutes	---
Mechanical properties	Compressive strength (N/mm^2)		
	2 Days	20.00	>10
	7 Days	23.00	>16
	28 Days	50.00	42.5 X ≤ 62.50

results of all physical and mechanical properties for used OPC are achieve the ESS 4756-2005.



3.1.2. Characteristics of coarse and fine aggregates

3.1.2.1. Chemical and physical characteristics of fine aggregate

The studied physical and chemical properties fulfill the requirements of the ECP 203-2001 (2007) as shown in Table 4.

3.1.2.2. Chemical and physical characteristics of coarse aggregate

Table 5 show the chemical and physical characteristics results of coarse aggregate used in this study. The chemical and physical characteristics results of coarse aggregate comply with ESS.

3.1.3. Chemical properties of mixing water (drinking water)

The chemical composition of the drinking water, which is used as mixing water in the concrete specimen's preparation shows that, it is clear and free from salts and conformable for using in such purpose. Excessive impurities in mixing water not only may affect setting times and concrete strength, but also may cause efflorescence, staining, corrosion of reinforcement, volume instability, and reduced durability. All the studied parameters match the limits of ECP 203-2001. The test results are mentioned in Table 6.

3.1.4. Characteristics of nanosilica

3.1.4.1. Chemical analysis of nano silica by XRF

Table 7. shows XRF results of NS. It is found that the SiO_2 content represents 94. 50 %.

B. X-Ray Diffraction(XRD)

Table 4. Chemical and physical characteristics of fine aggregate

Item	Test	Test value	ESS limits
Physical properties	Specific gravity	2.65	N.D*
	Bulk density (ton/m^3)	1.65	N.D*
	Clay and other fine materials by volume (%)	2.09	<3.00
Chemical properties	Chlorides (%)	0.023	<0.06
	Sulfate (%)	0.028	<0.40
	Organic impurities	Non	No organic impurities in sample

Table 5. Chemical and physical characteristics of coarse aggregate

Item	Test	Value	ESS limits
Physical properties	Specific gravity	2.75	2.50-2.75
	Bulk density (ton/m^3)	1.63	N.D
	Clay and other fine materials by weight (%)	0.22	<3.00
	Water absorption (%)	2.47	2.50
Chemical properties	Chlorides (%)	0.022	<0.04
	Sulfates (%)	0.012	<0.40

Table 6. Results of the chemical properties of the used mixing water

Item	Test	Test value	ESS limits mg/L
Chemical properties	Chlorides as Cl^- (ppm)	36.00	<500.00
	Sulfates as SO_3 (ppm)	75.00	<300.00
	Total soluble salts (ppm)	387.00	<2000.00

Table 7.XRF results of nanosilica

Item	Na_2O	MgO	Al_2O_3	SiO_2	SO_3	Cl	CaO	Fe_2O_3	LOI
Value %	0.87	0.18	0.33	94. 50	0.16	0.69	0.33	0.08	3.37

Fig. 2. XRD pattern of nanosilica

From Fig.2, by applying X-Ray Diffraction test (XRD), it was found that the used nanosilica was in amorphous phase. Where, Fig. 2showed strong broad peaks between 20^{o} and 30^{o} (2è). These peaks indicated characteristic of amorphous SiO_2, which has suitable specific surface regarding its dissimilar structure, and is used as concrete admixture.

C. Transmission electron microscopy (TEM)

Fig. 3 shows TEM image of nanosilicasample. The TEM image shows the grain size of the nanosilica ranging between 9-16 nm.

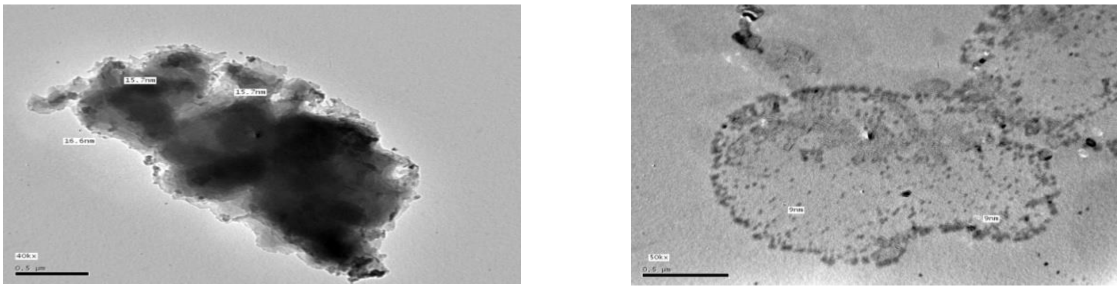
3.1.5. Chemical constituents of steel rebar

Table 8 shows the Chemical constituent results ofthe used rebar. It is found that the Fe constituent is 98.20.

3.2. Evaluation of concrete samples

3.2.1. Workability and Density of the prepared concrete samples

Slump and density values for each mix proportion are listed in table (8). These values recorded for fresh concrete specimens.



(a) **(b)**

Fig. 3. TEM of naosilica

Table 8. Chemical constituents of steel rebar used

Constituents	Wt (%)	Limits	Constituents	Wt (%)	Limits	Constituents	Wt (%)	Limit
C	0.247	--	Cu	0.317	--	Zn	<0.0020	--
Si	0.202	--	Co	0.014	--	As	0.015	--
Mn	0.75	--	Ti	<0.0010	--	Bi	<0.0020	--
P	0.019	Not more than 0.060	Nb	<0.0030	--	Ca	0.0005	--
S	0.043	Not more than 0.060	V	0.0062	--	Ce	<0.0030	--
Cr	0.078	--	W	<0.010	--	Zr	0.0040	--
Ni	0.063	--	Pb	<0.0030	--	La	<0.0010	--
Mo	0.016	--	B	0.0010	--	Fe	98.20	--
Al	<0.0010	--	Sn	0.018	--	-		--

Table 9.Workabilityand density of prepared concrete samples

Mix	Slump, mm	Density (unit weight), g/cm^3
C	100	2.53
M1	80	2.48
M2	65	2.47
M3	50	2.45
M4	45	2.42
M5	40	2.38

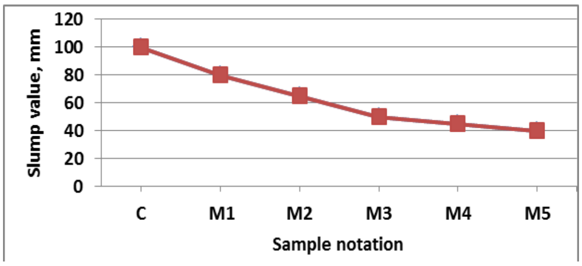


Fig. 4. Slump test results of concrete samples

Table 9 shows slump test results of fresh concrete mixtures for each mix proportion. It is noticed that; the slump values decreased by increasing NS content in the concrete mixture as shown in Fig.4. This is due to extremely high specific surface area of silica nano-particles,which is accompanied by absorption of large part of water in the concrete mixture [24]. Accordingly, by increasing the nanosilica content in the concrete mixture, resulting in more absorption of water and consequently more loss in the slump [25, 26].

3.2.2. Compressive strength of cured concrete samples

Table10. Compressive strength of cured concrete samples

Mix	Average of compressive strength, Mpa		
	3 days	7days	28 days
C	20.0	30.3	52.2
M1	18.7	27.6	55.0
M2	19.0	26.3	57.3
M3	17.9	25.8	59.8
M4	18.8	30.6	64.2
M5	16.7	28.7	60.3

The compressive strength of the cured concrete specimens was tested for different time periods of curing as 3, 7 and 28 days. After curing periods, concrete cubes were crushed at the specified time to determine the strength values. The average compressive values are shown in Table 10.

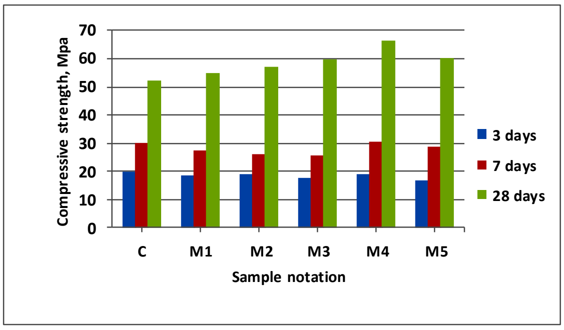


Fig. 5. Compressive strength of cured concrete samples

Table 9 shows the compressive strength results for concrete specimens at different ages of curing. It is noticed that, nanosilica improved compressive strength of concrete, and M4 specimen recorded the maximum strength value at 28 days. Also Fig5 show compressive strength increases with increasing of nanosilica content up to 2%. This can be attributed to the following mechanism:

Due to the reaction of water and cement in the concrete mixture,large amounts of calcium hydroxide $Ca(OH)_2$ are formed in the interfacial transition zone (ITZ) between aggregates and cement pastes matrix. These crystals of $Ca(OH)_2$negatively affected on the strength of concrete as observed in the following equations:

2C3S + 11H2O → C-S-H + 2$Ca(OH)_2$ (1)

2C2S + 9H2O → C-S-H + $Ca(OH)_2$ (2)

A chemical reaction occurred between silica nano particles and $Ca(OH)_2$ producing calcium silicate hydrate (C-S-H) condensed gel. This reactionknown as pozzolanic reaction and expressed by the following equation:

2SiO2 + 3$Ca(OH)_2$ → 3CaO.2SiO_2.H2O (3)

As a result of this pozzolanic reaction, the amounts of $Ca(OH)_2$ are consumedin the production of C-S-H gel that isfilling the empty spaces in the interfacial transition zone (ITZ) resulting in enhancement strength and consequently durability of concrete improved [27, 28]. Moreover, the strength enhancement of the prepared concretes may be attributed to the reduced porosity and improvement microstructure of the concrete due to the addition of the nano-particles of SiO_2 [15]. In several researches, it was observed that, the compressive strength increased as a result using of nanosilica but at different dosage [29-32].Also, it is noticed that, increasing the addition of nanosilica more than 2% in mix proportion of concrete, the compressive strength not increased.This is becauseof theagglomeration that occurred during the process of mixing andconsequently cannot fill the pores in the concrete [28, 33].

3.3.3. Scanning electron microscope(SEM)

The SEM micrographs (at magnification 5000) for the specimens are shown below from Fig6 to Fig.11.

Figs. 6 to 11 indicate the results of the SEM test. These figures show the results of the examination of concrete matrix microstructure from samples C, M1, M2, M3, M4 and M5. It can be noticed that, as the nanosilicaamount in mix design increases, the concrete matrix becomes denser in the interfacial transition zone, which can be a result of a severe pozzolanic characteristic of silica nanostructures and formation of the dense gel of Calcium-Silicate -Hydrate on one side, and high micro-filling characteristic of these particles on the other side.

3.3.5. Corrosion

The sample M4 was low performance, so it was excluded in corrosion inhibition tests.

3.3.5.1. Open circuit potential (OCP)

The addition of NS affects the corrosion behavior of steel rebar that impeded in concrete samples of C, M1, M2, M3 and M4 that immersed in 0.5 M NaCl solution for 28 days was investigated by potential-time (OCP) curve measurement for 30 minutes as shown in Fig12.

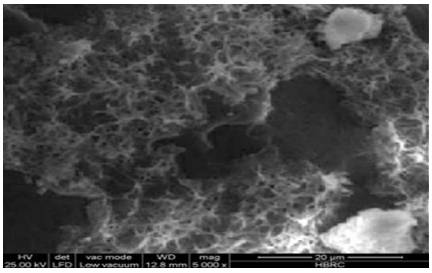


Fig. 6. SEM of C

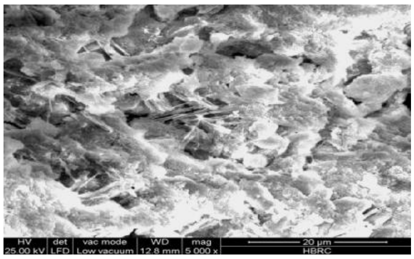


Fig. 7. SEM of M1

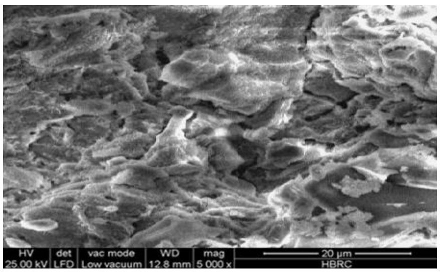


Fig. 8. SEM of M2

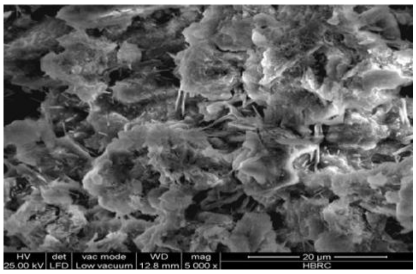


Fig. 9. SEM of M3

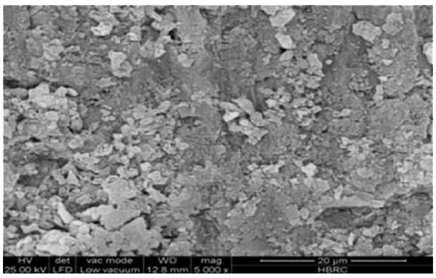


Fig. 10. SEM of M4 sample

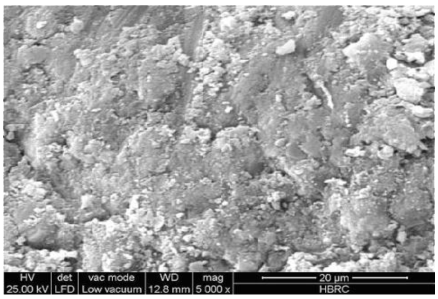


Fig. 11. SEM of M5

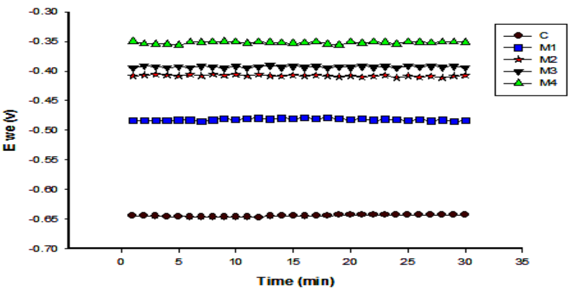


Fig. 12. OCP curves of reinforcement concrete samples

Fig.12 shows that, C specimen have the lowest E-ocp final reading value. This mean that steel rebar impeded in C concrete specimen have the highest tendency to corrosion, and the E-ocp values for M1, M2, M3 and M4 specimens shifted gradually toward the anode side of C to: (-484 mv), (-407 mv), (-393 mv) and (-351 mv) respectively. This regular shifting to positive region, means that the tendency to corrosion decreased by increasing the addition content of nanosilica up to 2%.This because of NS addition, which caused in enhanced concrete durability and consequently the improvement rebar protection from corrosion.

3.3.5.2. Linear polarization (polarization resistance)

The polarization curves for reinforcement concrete samples of C, M1, M2, M3 and M4 immersed in 0.5 M NaCl solution were illustrated in Fig. 13. Examination of this figure shows that current decreased gradually with NS addition.

Table (11): Corrosion parameters obtained from Tafel Plots for reinforcement concrete samples

Sample notation	O.C.P Results	Electrochemical measurements values obtained from OCV and potentiodynamic anodic polarization technique		RP (Ohm)
	E_{corr}(V)	Corrosion current density I_{corr}(μA/cm^2)	Corrosion rate (mm/year)	
C	-0.646	5.021	2.66911 e^{-3}	1215
M1	-0.4835	3.909	1.14374 e^{-3}	1404
M2	-0.4086	2.613	0.969358 e^{-3}	1628
M3	-0.3935	2.068	0.856192 e^{-3}	2542
M4	-0.2522	1.420	0.41548 e^{-3}	5378

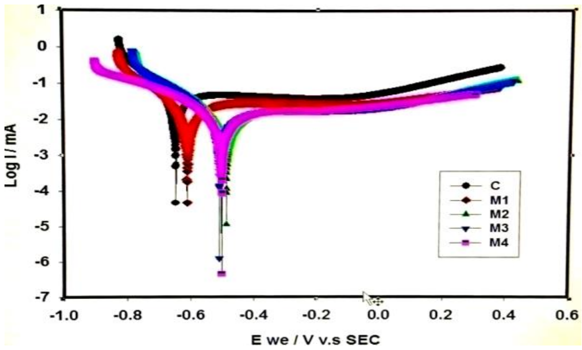


Fig. 13. Potentiodynamic polarization curve of reinforced concrete samples

Moreover, corrosion parameters calculated from Tafel Plots measured for tested samples were listed in Table 11. It is found that, C sample have the highest corrosion current (**I_{corr}**) and corrosion rate value and thus the lowest Rpvalue. This means that C sample have the lowest corrosion inhibition. While, corrosion rate values decreased gradually from 2.66911 e^{-3} mm/year For C, to1.14374 e^{-3},0.969358 e^{-3},0.856192 e^{-3} and0.41548 e^{-3} for M1, M2, M3 and M4 respectively. These results confirms with the corrosion current density values which decreased gradually from 5.021μA/cm^2 for C, to 3.909, 2.613, 2.068, 1420 for M1, M2, M3 and M4, respectively. This indicated that corrosion inhibition enhanced gradually by increasing the content of NS content. This obviously observed from Rp values, which increased from 1215 Ohm for C to 1404, 1628, 2542 and 5378 for M1, M2, M3 and M4 respectively. These results indicated that, corrosion inhibition increased by increasing Ns addition content. This is because of nanosilica addition improves durability and pore structure of concrete (as confirmed by SEM). Where, nano-silica decreased porosity and accordingly permeability decreased causing decrease in the current density and consequently corrosion rate decreased. Moreover, this result is in accord with the higher resistivity of the NS-containing concretes and may be associated to the fine porosity of the Ns-containing concretes [34]. Sharkawi et al. observed that, the optimum ratio for corrosion resistance of reinforced concrete was 2% NS and 8% MS as a replacement ratio [22]. While Elfeky et al. investigated that, 4.5 % Ns is the optimum replacement ratio for corrosion resistance of reinforced concrete [35]. Also, Radhakrishnan et al. reported that, the corrosion resistance in concrete improved gradually as the nanosilica content increased [36].

CONCLUSION

1- The physical and mechanical properties of concrete improved gradually with the addition of nano-silica to concrete mix design at specific limits of addition.

2- The highest compressive strength value at 28 days in a mixture with nano-silica 2% i.e 64.2 MPa.

3- The addition of nanosilica more than 2% can result in agglomeration duringthe mixing and consequently resulting in decreasing the compressive strength. The decrease in the compressive strength can be caused when the distribution mixing of nanosilica were added to the concrete uneven, in part, on the agglomeration and therefore cannot fill the pores in the mortar.

4- Nanosilica improves the microstructure of concrete.

5- The using of nanosilica improves the corrosion inhibition of steel rebar in reinforced concrete.

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الملخص العربى

يهدف هذا البحث الى رفع كفاءة الخرسانة المسلحة والعادية وذلك عن طريق اضافة مادة النانو سيليكا التى لها تأثير فعال فى تحسين خواص الخرسانة وتثبيط تأكل حديد التسليح. بعد توصيف المواد المستخدمة فى الدراسة تم استخدام النانو سيليكا فى الخلطات الخرسانية وذلك باضافاتها للخلطات بنسب مختلفة؛ النسب تتراوح من 0,5 - 2,5 من وزن الأسمنت. تم دراسة تأثير نسب الاضافة على خواص الخرسانة مثل قابلية التشغيل والكثافة. تم عمل مكعبات خرسانية من الخلطات المحضرة وتم تقييمها من حيث قوة الانضغاط وجد ان مادة النانو سيليكا تساهم بشكل كبير فى رفع قيمة قوة الانضغاط للخرسانة وذلك لانها تتفاعل مع هيدروكسيد الكالسيوم الناتج من عملية الهيدرة أثناء تحضير الخرسانة وتكون مادة الكالسيوم سيليكات هيدريت التى تتواجد فى المناطق البينة بين الركام والعجينة الأسمنتية مما يتسبب فى غلق مسامات الخرسانة المتصلدة ورفع كفائتها ؛ ووتم تأكيد ذلك من خلال الفحص المجهرى للمناطق البينية وذلك عن طريق الميكروسكوب الالكترونى . وجد أن اضافة النانو سيليكا تسهم بشكل كبير فى تحسين الخرسانة وذلك حتى نسبة اضافة 2% من وزن الاسمنت ولكن لوحظ أنه عندما تزداد الاضافة عن هذه النسبةفان كفائة الخرسانة تنخفض. وأخيرا تم دراسة تأثير اضافة النانو سيليكا على تثبيط تأكل حديد التسليح فى الخرسانة المسلحة وتوصلنا الى أن النانو سيليكا لها دور فعال فى تثبيط تأكل حديد التسليح الناتج عن تعرض المنشأت الخرسانية للبيئات الضارة المختلفة والتى تؤدى الى انهيار الأبنية الخرسانية.