

## Corrosion Resistance, Porosity and Strength of Blended Portland Cement Mortar Containing Rice Husk Ash And Nano-SiO<sub>2</sub>

*M.J. Pellegrini-Cervantes<sup>1,2\*</sup>, F. Almeraya-Calderon<sup>3</sup>, A. Borunda-Terrazas<sup>1</sup>, R.G. Bautista-Margulis<sup>4</sup>, J.G. Chacón-Nava<sup>1</sup>, G. Fajardo-San-Miguel<sup>5</sup>, J.L. Almaral-Sanchez<sup>2</sup>, C.P. Barrios-Durstewitz<sup>2</sup>, A. Martínez-Villafañe<sup>1</sup>*

<sup>1</sup>Departamento de Integridad y Diseño de Materiales Compuestos. Centro de Investigación en Materiales Avanzados. S.C. CIMAV. Miguel de Cervantes No. 120, Complejo Industrial Chihuahua, C.P 31109, Chihuahua, Chihuahua, México.

<sup>2</sup>Facultad de Ingeniería Mochis, Universidad Autónoma de Sinaloa. Fuente de Poseidón y Prol. Ángel Flores S/N, Los Mochis, Sinaloa C.P. 81223, México.

<sup>3</sup>Universidad Autónoma de Nuevo León. FIME – Centro de Innovación e Investigación en Ingeniería Aeronáutica. Av. Universidad s/n. Ciudad Universitaria. San Nicolás de los Garza, Nuevo León, México

<sup>4</sup>Universidad Juárez Autónoma de Tabasco, División Académica de Ciencias Biológicas, C.P. 86040, Villahermosa, Tabasco, México.

<sup>5</sup>Facultad de Ingeniería Civil, Universidad Autónoma de Nuevo León  
Av. Universidad S/N, C.U. San Nicolás de los Garza, N.L. C.P. 66450, México.

\*E-mail: [manuel.pellegrini@cimav.edu.mx](mailto:manuel.pellegrini@cimav.edu.mx)

*Received: 23 May 2013 / Accepted: 16 June 2013 / Published: 1 August 2013*

---

Nanoparticles (NP) have exceptional physic and chemical properties used in the improvement of the performance or mortar concrete at nanometer scale. Researchers have incorporated nano-SiO<sub>2</sub> (nSO), nanoalumina, iron oxide and titanium nanometer, among other NP, in mortars. The use of ashes to improve the properties of mortar has also been studied. However, the study of synergy in the simultaneous use of NP and ashes is scarce, research has focused on improving the physical and mechanic properties of mortar, existing few reports referring to the corrosion resistance. The performance of the simultaneous use of rice husk ash (RHA) and nSO as a replacement for ordinary Portland cement (OPC) in mortar with plastic consistency was evaluated. Studies of compressive strength, total porosity in open pore and accelerated corrosion test with impressed voltage 12.0 V in mortars were made, using replacements of OPC by 10-30% of RHA and 1.00-2.00% of nSO in single and simultaneous use. For the purpose of determining the performance of the OPC replacements on the properties of the mortar, resulting in the most effective use with simultaneous decrease in porosity up to 5.7% and increased compressive strength and corrosion of 7.8% and 51.1%, respectively. The use of superplasticizer facilitated the making of mixtures with RHA and nSO, but affected the physical and chemical properties of hardened mortar. Replacement of OPC by RHA and nSO in simultaneous

use in mortars with plastic consistency present the advantage of improving physical and mechanical properties in replacements up to 20% RHA, due to the synergistic effect of RHA-nSO and porosity – compressive strength.

---

**Keywords:** plastic–mortar, mortar-nanometer, accelerated corrosion, nanoparticles.

## 1. INTRODUCTION

In mortar and reinforced concrete, the arrival of aggressive ions to the surface of the reinforcement is the main cause of corrosion initiation. These ions move through the water contained in the pore network, their mobility is defined by the porosity and permeability of the cement matrix. As the durability of mortar and concrete is demerited with corrosion of reinforcement, it is also a direct consequence of the pore structure, porosity and pore size distribution of the mass of mortar [1-3]. With the purpose of providing durability to mortars and concrete, researchers have replaced cement with different types of ash, RHA [4,5], fly ash (FA), blast furnace slag, cane bagasse ash, among others [6-15], improving mechanical properties, structural, physical, chemical and electrochemical, reducing the effect of corrosion of reinforcement in adverse environments [11,16-18]. These ashes are products of various industrial and agricultural processes. For example, rice husk is an agricultural waste used for energy production in power plants, being the resulting RHA discarded in waste spillways, causing an environmental problem [19]. By virtue of the pozzolanic properties of RHA, it has been used as a replacement of cement, avoiding the problem of waste and reducing the amount of cement used in the mixture. The reduction in the use of cement contributes to the environmental aspect, because in its production it generates high levels of pollution [20,21]. The replacement or addition of cement is not limited only to ashes, different researchers have used NP taking the advantage of exploiting the properties conferred by their nanometric size [22].

In recent years, with the aid of nanotechnology great progress has been made in improving material properties, inclusive mortars by adding NP in the mixture. In several studies cement with NP has been replaced individually, nSO [23-25], Iron oxide, Titanium oxide and Zirconium, among others [26-30]. NP in addition or replacement of cement provide to mortars and concrete of increased durability and benefit in physical and mechanical properties [22]. In addition, it has been investigated the synergistic effect obtained from the simultaneous use of nSO with FA and sludge ash, where the pozzolanic activity is accelerated at early ages due to high silica content and high surface area of nSO. It has been concluded that the generated C-H-S gel works as filling in the voids of the cementitious matrix, achieving a more uniform and compact matrix, and consequently an increase in the durability of the mortar [31-36]. However, there are few investigations of the simultaneous use of NP and ash in the replacement of cement.

In the study of the performance of nSO and ash incorporated into a cementitious matrix, reports relating to FA predominate [31-33], focusing on mechanical, physical and chemical properties of the matrix. According to related investigations, the incorporation of RHA improves the microstructure of the paste and reduces the effects of corrosion [4,5]. However, there are no scientific reports that

address the durability and corrosion of reinforced mortars with replacement of OPC by nSO and RHA in simultaneous use. The replacement of OPC by RHA and nSO in simultaneous use should favor the matrix microstructure, obtaining mortars with smaller porosities and higher performance in mechanical strength and corrosion resistance.

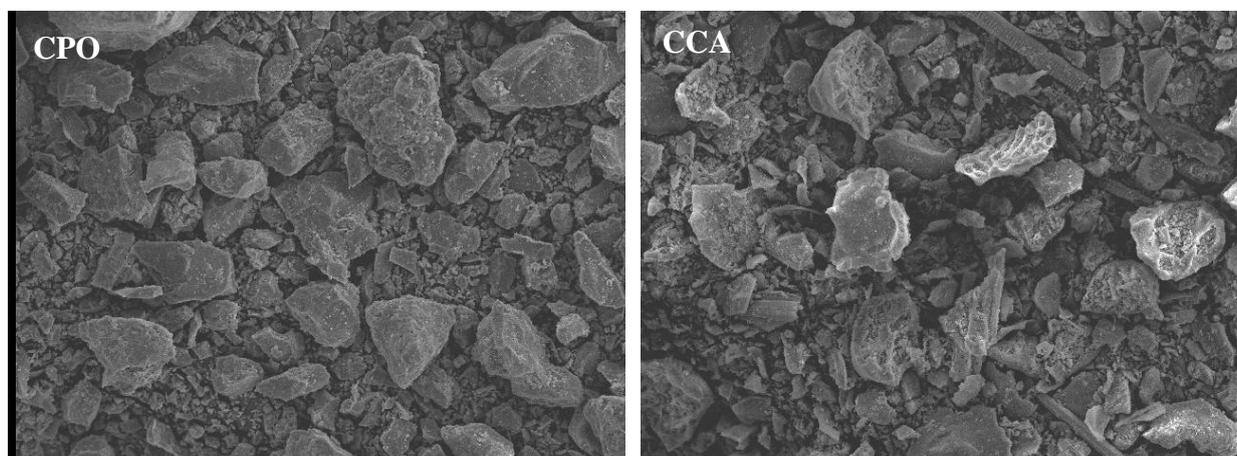
The purpose of this research work was to study the performance of the porosity, mechanical strength and resistance to corrosion in a reinforced mortar, replacing OPC by RHA and nSO individual and simultaneously, with RHA replacements up to 30% and nSO up to 2% of the weight of the total cementitious. To achieve it, studies of porosity in open pore, simple compressive strength and accelerated corrosion test with impressed voltage (ACTIV) were realized.

## 2. EXPERIMENTAL PROCEDURE

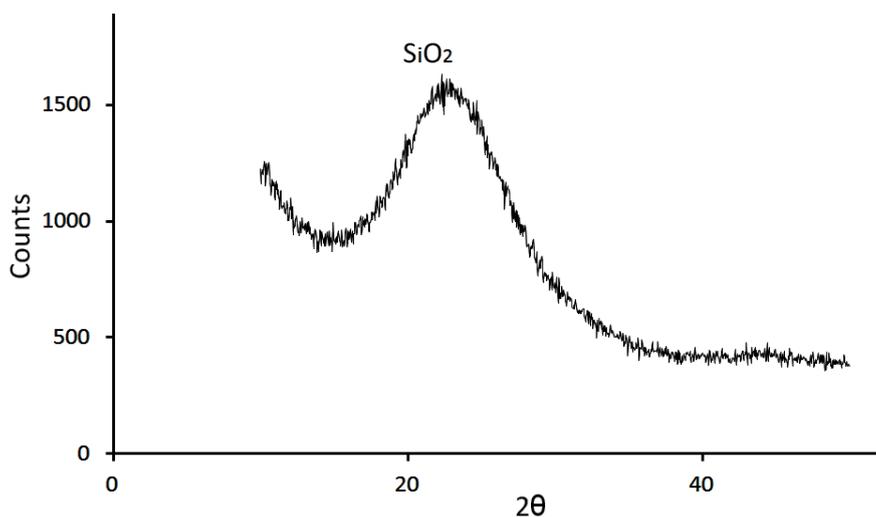
### 2.1 Materials

For the manufacture of the specimens fine aggregate, OPC, RHA, nSO, distilled water and superplasticizer (SP) were used. The fine aggregate was silica sand river, graded according to ASTM C 33-03 [37], fineness modulus of 2.61, mass density  $2660 \text{ kg/m}^3$  and 3.7% absorption. The physical properties of cementitious materials are shown in

Table 1. The SP was a high rank water-reducing additive of short delay without chlorides type F and type I, according to ASTM C 494/C 494M – 99a [38] and C1017 / C1017M - 07 [39]. The OPC was supplied by local cement company, while the RHA was obtained from industrial wastes of Odisha, India, ground in Los Angeles apparatus for 2 hr. and sieved in mesh No. 325 (opening  $45 \mu\text{m}$ ). The nSO was commercially obtained without any additional treatment for its use. The chemical properties of OPC, RHA and nSO, according to chemical analysis of Gravimetry (G) and Stoichiometry (S) are shown in Table 2 and Scanning Electron Microscopy (SEM) of cementitious in Figure 1. Furthermore, the Rx dispersion analysis of nSO is shown in Figure 2.



**Figure 1.** Ordinary Portland Cement and rice Husk Ash SEM (x500).



**Figure 2.** nSO Rx Dispersion.

**Table 1.** Physical properties of cementitious materials.

Property	OPC	RHA	nSO
Mass density (kg/m <sup>3</sup> )	3071	2251	-
Superficial area (m <sup>2</sup> /g)	20.23	23.82	777.7
Average particle size (Φm)	27.61	29.88	0.015

**Table 2.** Chemical components of materials.

Oxide	OPC	RHA	nSO	Analysis method
SiO <sub>2</sub>	20.046	84.375	71.451	G
SO <sub>3</sub>	2.589	0.080	-	S
CaO	2.605	0.702	-	S
Fe <sub>2</sub> O <sub>3</sub>	1.976	0.309	-	S
MgO	0.762	0.276	-	S
K <sub>2</sub> O	0.317	1.242	-	S
Al <sub>2</sub> O <sub>3</sub>	0.294	0.235	N.D.*	S
TiO <sub>2</sub>	0.228	0.018	-	S
P <sub>2</sub> O <sub>5</sub>	0.123	0.566	-	S
MnO	0.048	0.103	-	S
Na <sub>2</sub> O	0.007	0.057	0.003	S

\*N.D. Not Detected

## 2.2 Preparation of mixture and specimens.

In mortar mixtures a water/cementitious ratio (W/C) of 0.60 and sand/cementitious ratio of 2.75 were used, incorporating an SP in order to obtain mortar mixtures with similar flow of  $110 \pm 5\%$ . The dosage of the cementitious mortar mixtures is shown in **Error! Reference source not found.**

**Table 3.** Dosing in cementitious mortar mixtures (%).

Mixture	OPC	RHA	nSO
M100-0-0	100.0	0.0	0.0
M90-10-0	90.0	10.0	0.0
M80-20-0	80.0	20.0	0.0
M70-30-0	70.0	30.0	0.0
M99-0-1	99.0	0.0	1.0
M89-10-1	89.0	10.0	1.0
M79-20-1	79.0	20.0	1.0
M69-30-1	69.0	30.0	1.0
M98-0-2	98.0	0.0	2.0
M88-10-2	88.0	10.0	2.0
M78-20-2	78.0	20.0	2.0
M68-30-2	69.0	30.0	2.0

The mixing procedure was similar to ASTM C 305-12 [40] with some variants:

- 1) If the mixture contained RHA, it was dry blended with OPC until achieving a uniform consistency.
- 2) If the mixture contained nSO, 95% of the total water of the mixture was added; it was then subjected to ultrasonic dispersion for 10 min.
- 3) Cementitious material was added to 95% of water; it was then mixed for 30 sec. at slow speed.
- 4) The mixer was stopped and changed to medium speed; it was then mixed for 30 sec. while the sand was slowly added during that period.
- 5) After mixing for 30 sec. at medium speed, the SP + 5% of water were slowly added in the first 10 sec.
- 6) After stopping the mixer, it remained in rest for 90 sec. In the first 15 sec. the walls of the container were quickly scraped and the mixture was covered for the remaining time.
- 7) Finally, it was mixed for 90 sec. at medium speed.

The mixture flow was verified according to ASTM C 1437-99 [41], then the mixture was poured into P.V.C. molds and covered with plastic for 24 hr. until hardened.

## 2.2 Total porosity and compressive strength.

The compressive strength was performed according to ASTM C 109/C 109M-05 [42] in cubic specimens of 2.5 cm side. After test, the residues of the specimens were immersed in methanol for SEM analysis.

The porosity of the hardened mortar was determined according to equation **Error! Reference source not found.**. The method used was in vacuum saturated condition, successfully accepted method by several authors for the calculation of porosity in cementitious materials [43,44].

$$P (\%) = 100 * \frac{W_a - W_d}{W_a - W_w} \tag{1}$$

Where:

P= Total Porosity (g).

W<sub>a</sub>= Specimen weight in saturated conditions (g). The saturated condition is achieved by 1 hr. vacuum in air, 3 hr. of submerged vacuum in deaerated water and 20 hr. of submerged at ambient pressure.

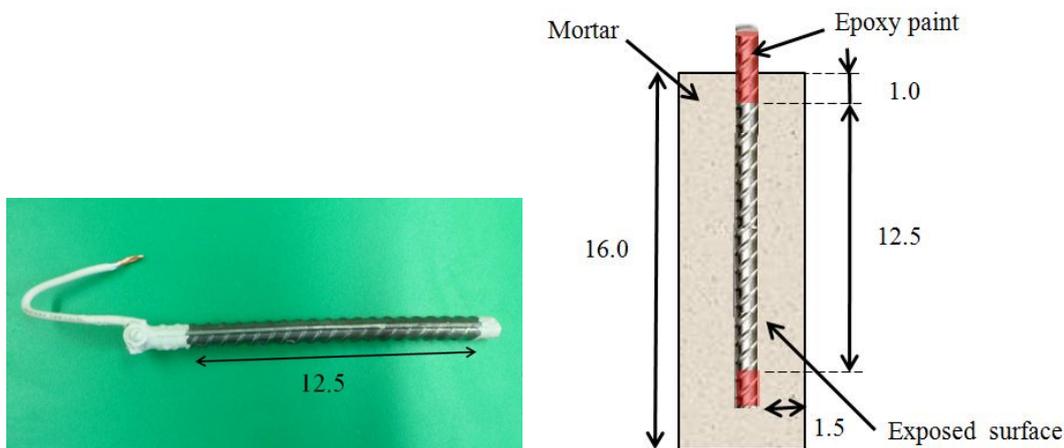
W<sub>d</sub>= Dry specimen weight after 24 hr. of drying in an oven at 100 ± 5 ° C (g).

W<sub>w</sub>= Specimen weight in saturated conditions submerged in water (g).

Both tests were performed at 30 and 90 days of curing in distilled water, 100% relative humidity and temperature of 23 ± 2 °C. The results reported are the average of three tests.

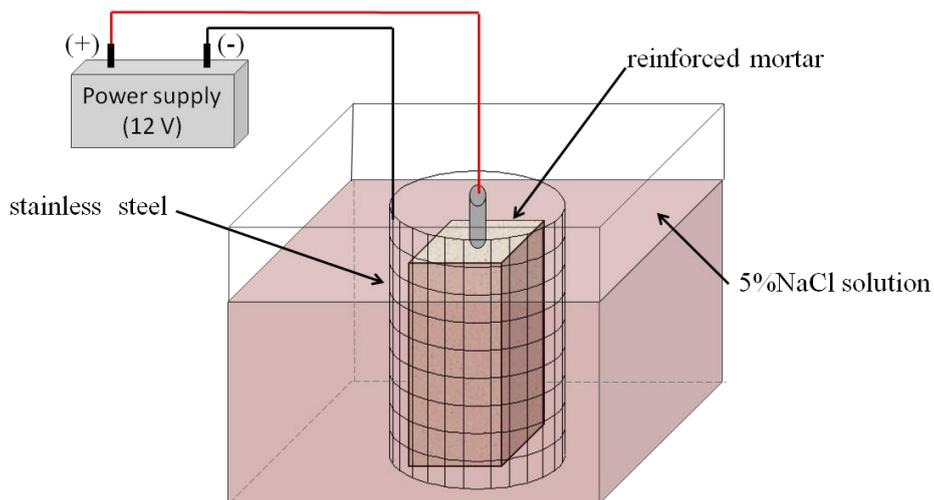
### 2.3 Accelerated corrosion test with impressed voltage.

ACTIV provides an indirect comparison parameter for estimating the corrosion resistance of cementitious materials [44]. The specimens were 4.0x4.0x16.0 cm, reinforced with steel rods 0.95 cm in diameter and 16.0 cm long as shown in Figure 3. Steel was protected at the air-mortar interface, coating of 1.5 cm and steel surface exposed to the environment of 37.3 cm<sup>2</sup>.



**Figure 3.** Steel reinforcement and reinforced mortar specimen.

After 90 days of curing, the specimens were subjected to ACTIV under arrangement as show in Figure 4 , they were immersed in aqueous solution at 5% NaCl by applying constant voltage 12 ± 0.1 V at a temperature of 25 ± 2 °C. The condition of the prism was monitored continuously until cracking of the specimen, recording the time of initiation of the first crack (TIFC). The results reported are the average of three tests.



**Figure 4.** Experimental arrangement ACTIV.

### 3. RESULTS AND DISCUSSION

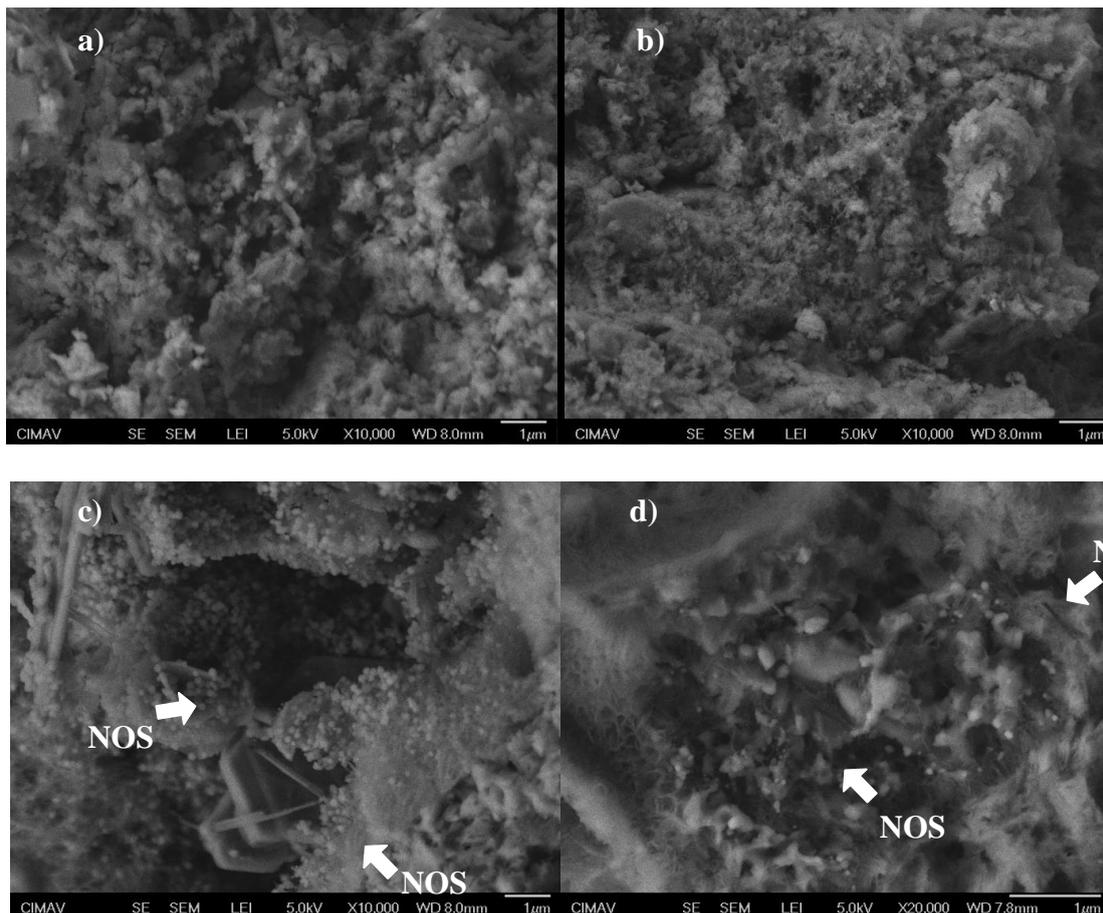
#### 3.1 Materials

The use of RHA and nSO as replacement OPC provides higher performance to the properties of mortar and concrete, creating products that serve to fill in the gaps in the matrix [5,23]. According to SEM shown in Figure 1, the particles that make up the RHA are irregular and with sharp edges, size from 1.7 to 45.4  $\mu\text{m}$ , they are also irregular in OPC but having softer edges with sizes from 1.3 to 63.0  $\mu\text{m}$ . The OPC has finer particles than the RHA. The RHA is a natural ash calcined Type N according to ASTM C618-99 [45], with  $\text{SiO}_2 + \text{Al}_2\text{O}_3 + \text{F}_2\text{O}_3 > 70\%$  y  $\text{SO}_3 < 4.0\%$ . The nSO has a content of  $\text{SiO}_2$  of 71.45%, higher OPC and less than RHA. The particle size distribution of the cementitious, their physical and chemical properties define the microstructure of the hardened mortar.

#### 3.2 Mortar Mixtures and morphology of hardened mortar

The hygroscopic nature of RHA and its surface area greater than OPC brings mixtures requiring more quantity of water [46], or increasing the amount of SP used in A/C constant [47]. In the case of ashes and NP in simultaneous use, researchers have used A/C up to 0.70 [34], being well accepted the use of SP to achieve the desired flow of the mixture [44]. In the current mixtures, replacement of OPC by nSO and RHA in combined use increased the amount of SP and surface area of the cementitious as shown in

Table 4. The surface area of the mixture due to replacements of nSO and RHA set to the hygroscopic nature of RHA contributed to the increase of SP, reaching rates of up to 5.2% in M68-30-2 and surface area of 36.5  $\text{m}^2/\text{g}$ . The properties of the mixture in the fresh state and the cure conditions contributed to define the microstructure of the hardened mortar.



**Figure 5.** SEM photos of Hardened mortars, age 90 days a) M100-0-0 b) M70-30-0 c) M98-0-2 b) M68-30-2.

**Table 4.** SP and surface area in mortar mixtures.

Mixture	SP (%)	Cementitious Surface Area (m <sup>2</sup> /g)
M100-0-0	1.0	20.2
M90-10-0	1.5	20.6
M80-20-0	2.6	20.9
M70-30-0	4.1	21.3
M99-0-1	1.7	27.8
M89-10-1	2.6	28.2
M79-20-1	3.3	28.5
M69-30-1	4.9	28.9
M98-0-2	2.3	35.4
M88-10-2	3.7	35.7
M78-20-2	4.0	36.1
M68-30-2	5.2	36.5

The nSO uniform dispersion plays an important role in improving the microstructure of the cementitious matrix, contributing to an early hydration [48]. The microstructure of hardened mortar

with and without replacements is shown in Figure 5. The morphology of the cementitious matrix with RHA replacement is more compact than that for OPC or OPC + nSO. Likewise clusters of nSO were not located, denoting good dispersion of the nSO. The porosity and the mechanical properties of hardened mortar are defined mostly by the microstructure of the matrix.

### 3.2 Total porosity and compressive strength.

Total mortars porosity decreased in higher replacement of OPC by RHA, however, porosity again increased in certain percentage [44]. Total porosities resulting from hardened mortar are shown in **Error! Reference source not found.** For the individual replacement of RHA age 30 days, porosity increased to greater RHA with respect to M100-0-0, while in 90 days appeared the lower porosity in 10% RHA. In general, nSO individual replacement favored porosity, showing at 30 days the lower porosity in M98-0-2. The simultaneous replacement of RHA and nSO was more favorable at 90 days of age, presenting minimum porosity for M89-10-1, less than M98-0-2. The simultaneous use of RHA and nSO favored the reduction of porosity for replacements to 10% RHA, and 1% nSO, outperforming the individual use of RHA or nSO. Several investigations [4,5,22,23] have shown the favorable effect for the replacement of OPC by RHA or nSO with respect to physical properties, reporting also profits in mechanical properties.

**Table 5.** Total porosity de hardened mortar [% (% reference)].

Mixture	Age (days)	
	30	90
M100-0-0	27.2 (100.0)	26.1 (100.0)
M90-10-0	28.0 (102.9)	25.4 (97.3)
M80-20-0	28.8 (105.9)	27.6 (105.7)
M70-30-0	27.5 (101.1)	26.8 (102.7)
M99-0-1	26.8 (98.5)	26.6 (101.9)
M89-10-1	27.8 (102.2)	24.6 (94.3) *
M79-20-1	28.5 (104.8)	25.3 (96.9)
M69-30-1	28.5 (104.8)	26.4 (101.1)
M98-0-2	26.2 (96.3) *	24.7 (94.6)
M88-10-2	27.2 (100.0)	25.3 (96.9)
M78-20-2	27.5 (101.1)	26.1 (100.0)
M68-30-2	28.8 (105.9)	27.4 (105.0)

The compressive strength of hardened mortar increased its performance at higher replacement of OPC by RHA, nevertheless, the compressive strength decreased again in certain percentage [44]. The results of compressive strength of hardened mortars are shown in

Table 6. In general, in individual replacement of OPC by RHA age 30 and 90 days, at greater replacement of RHA presented an increase of resistance with respect to M100-0-0, being highest in

replacements of RHA of 20%, since M70-30-0 decreased to values close to M100-0-0 or even less. Individual replacement of OPC by nSO ages of 30 and 90 days, favored the performance of compressive strength showing increases of up to 7.4%. On the other hand, the simultaneous replacement of RHA and nSO was more effective at 90 days of age, presenting maximum resistance in M68-30-2, and obtaining the highest performance in M78-20-2 at 30 days of age. Based on the results, the replacement of OPC by RHA and nSO in simultaneous use promoted the performance of compressive strength of hardened mortar. Hence the performance of mechanical properties and its corrosion resistance play a major role in the performance of cementitious materials.

**Table 6.** Compressive strength of hardened mortar [MPa (% reference)].

Mixture	Age (days)	
	30	90
M100-0-0	43.2 (100.0)	45.0 (100.0)
M90-10-0	44.7 (103.4)	47.4 (105.4)
M80-20-0	45.2 (104.6)	48.1 (106.8)
M70-30-0	42.0 (97.3)	46.1 (102.4)
M99-0-1	44.6 (103.2)	47.4 (105.3)
M89-10-1	45.4 (105.1)	48.2 (107.1)
M79-20-1	46.1 (106.7)	48.4 (107.6)
M69-30-1	44.4 (102.7)	46.9 (104.1)
M98-0-2	45.9 (106.2)	48.1 (106.9)
M88-10-2	46.4 (107.4)	48.3 (107.3)
M78-20-2	46.4 (107.5) *	48.5 (107.8)
M68-30-2	44.8 (103.8)	48.7 (108.2) *

### 3.3 Accelerated corrosion test with impressed voltage.

The use of rapid tests or accelerated with the application of electric fields to increase the mobility of chlorides in the cementitious matrix is accepted in reinforced mortars study [47]. ACTIV provides TIFC produced by corrosion of reinforcement steel in mortars, TIFC increments have been reported up to 89% with the individual use of RHA [44]. TIFC results by ACTIV are shown in Figure 6 and specimens after ACTIV in Figure 7. In all replacement cases of OPC by RHA or nSO individual or simultaneous, an increase in TIFC with regards to M100-0-0 was obtained. TIFC was of 45.0 hr. in M100, 0-0; in individual replacement of OPC by RHA it was obtained up to a maximum of 62.0 hr. in M90, 10-0; in individual replacement of OPC by RHA and nSO a maximum of 66.0 hr. in M98-0-2 and for simultaneous replacement of OPC by RHA and nSO a maximum of 68.0 hr. in M89-10-1. Based on the results, the ACTIV presented higher performance with simultaneous replacement of OPC by RHA and nSO, as in the case of porosities of hardened mortar. Mortar porosity and compressive strength are determinants in the mobility of the chlorides in the cementitious matrix.

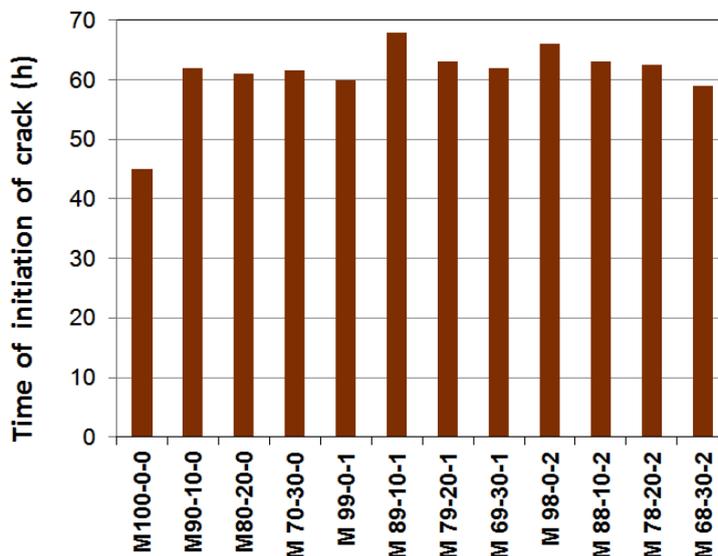


Figure 6. TIFC in Accelerated corrosion test with impressed voltage.

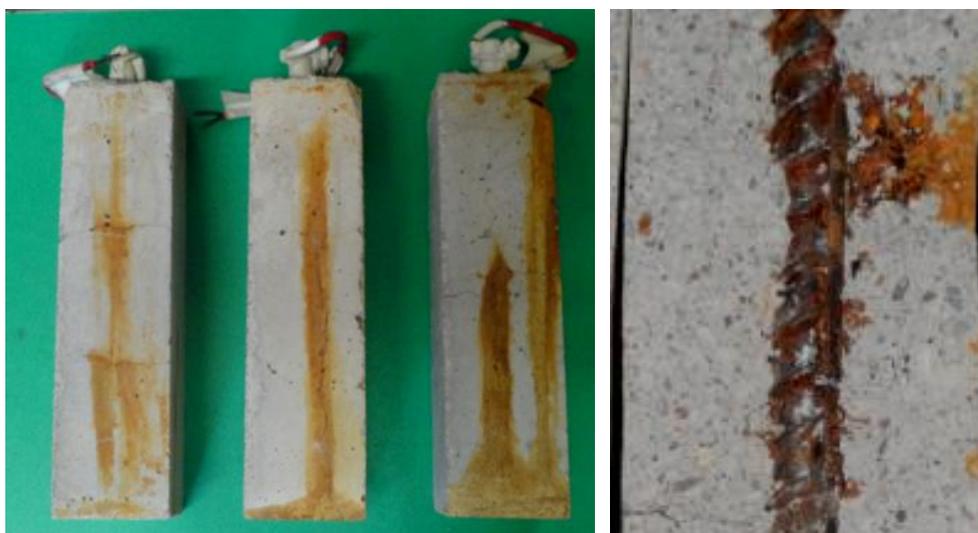


Figure 7. Specimens after ACTIV.

The correlation between porosity and TIFC is shown in Figure 8, mortars M89-10-1 and M98-0-2 had the lowest porosities and the highest TIFC. TIFC tendency is increasing with the decreasing of porosity, being inversely proportional to it. Similarly, the correlation (compressive strength)<sub>reference</sub>/porosity<sub>reference</sub> ( $RC_r/P_r$ ) and TIFC is shown in Figure 9, this relationship of variables shows the interaction that porosity and compression strength have to define the resistance to corrosion or to TIFC, where the parameter  $RC_r/P_r$  is directly proportional to TIFC. Based on the results, the ACTIV provides an indirect parameter of comparison which combines the effect of porosity and compression strength of the cementitious matrix defining the corrosion resistance of a reinforced mortar.

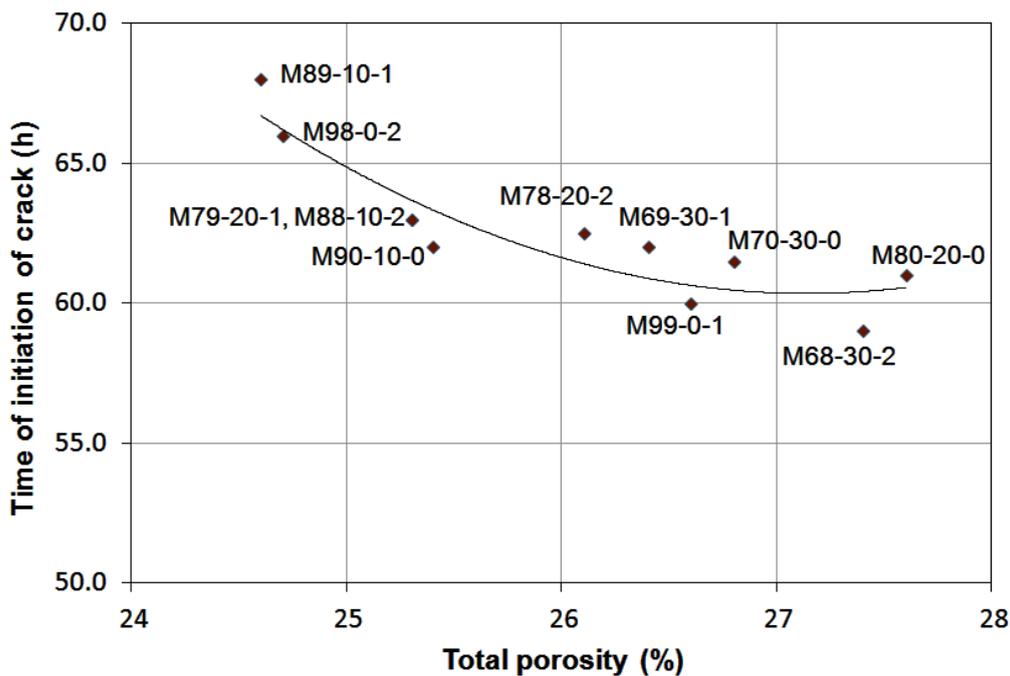


Figure 8. Total porosity vs TIFC.

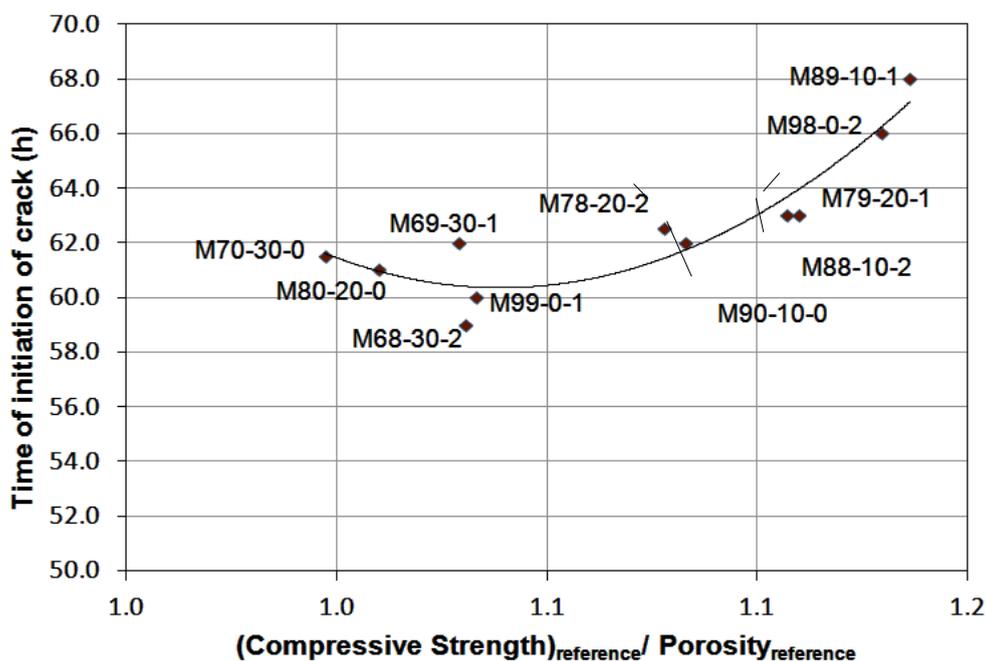


Figure 9.  $RC_v/P_r$  vs TIFC.

#### 4. CONCLUSIONS

The results of this study show that:

Producing mortar with plastic consistency with the replacement of OPC by RHA and nSO is possible with the use of SP and ultrasonic dispersion of nSO. The use of SP affects the performance of

the synergy by simultaneous use of RHA and nSO in mortars, owing to its high percentage of use for the production of mixtures.

The porosity in mortars of plastic consistency have higher performance with the individual use of nSO at 30 days of age, decreasing to 3.7% of reference. However, it has a maximum yield of 10% RHA in simultaneous use and 1% nSO at 90 days, decreasing to 5.7% of reference. The compressive strength has a maximum performance in simultaneous use of 20% RHA + 2% nSO at 30 days and 30% RHA + 2% nSO at 90 days, increasing 7.5 and 7.8% of reference, respectively. The resistance to corrosion has a better performance in simultaneous use of 10% RHA + 1% nSO at 90 days, increasing the time of initiation of the first crack to 51.1% of reference.

Based on the results, the replacement of OPC by RHA and nSO in simultaneous use in mortars of plastic consistency is advantageous in the performance of physical, mechanical and corrosion resistance properties, due to the synergy of RHA and nSO for replacements of up to 20% RHA.

#### ACKNOWLEDGEMENTS

The authors express their gratitude to the Universidad Autónoma de Sinaloa (UAS) for the financial support and to Grupo Cementos Chihuahua (GCC) and SIKA Corp for the support material supply. The first author would like to thank Centro de Investigación en Materiales Avanzados (CIMAV) and Universidad Autónoma de Nuevo Leon (UANL) for its support in the accomplishment of the present work.

#### References

1. L. Hanzic and L. Ilic, *Cement Concrete Res*, 33 (2003) 1385–1388.
2. R. Kumar and B. Bhattacharjee, *Cement Concrete Res*, 33 (2003) 417-424.
3. R. Kumar and B. Bhattacharjee, *Cement Concrete Res*, 34 (2004) 321-328.
4. B. Chatveeraa and P. Lertwattanakul, *J Environ Manag*, 92 (2011) 59-66.
5. A. A. Ramezani-pour, M. Mahdi khani and G. Ahmadibeni, *Int. J. Civ. Eng.* 7 (2009) 83-91.
6. M. Sahmaran and V.C. Li, *Cement Concrete Res*, 39 (2009) 1033–1043.
7. P. Chindaprasirt, C. Chotithanorn, H.T. Cao and V. Sirivivatnanon, *Constr. Build. Mater.* 21 (2007) 356–361.
8. R. Manoharan, P. Jayabalan and K. Palanisamy, *ARPJ. Eng. Appl. Sci.* 4 (2009) 13–26.
9. M. Bohác and M. Gregerova, *Mater. Charact.* 60 (2009) 729–734.
10. H. W. Song and V. Saraswathy, *J. Hazard. Mater.* 138 (2006) 226–233.
11. K. Ganesan and K. Rajagopal, *Anti-Corros. Methods Mater.* 54 (2007) 230-236.
12. S. Rukzon and P. Chindaprasirt, *Indoor Built Environ*, 18 (2009) 313-318.
13. C. H. K. Lam, A. W. M. Ip, J. P. Barford and G. McKay, *Sustainability*, 2 (2010) 1943-1968.
14. W.T. Tsai and Y.H. Chou, *Renew. Sust. Energ. Rev.* 10 (2006) 491–502.
15. U. I Hernández Toledo, R. Alavéz Ramírez and P. Montes García, *Naturaleza y Desarrollo*, 7 (2009) 34–45.
16. V. Saraswathy and H.W. Song, *Constr. Build. Mater.* 21 (2007) 1779–1784.
17. B. H. Abu Bakar, R. Putrajaya and H. Abdulaziz, *Concr. Res. Lett.* 1 (2010) 6–13.
18. Tae-Hyun Ha, S. Muralidharan, J.H. Bae, Y.C. Ha, H.G. Lee, K.W. Park and D.K. Kim, *Build. Environ.* 42 (2007) 78–85.
19. P. Chindaprasirt, S. Homwuttiwongb and C. Jaturapitakkulb, *Constr. Build. Mater.* 21 (2007) 1492–1499.

20. P.K. Mehta. In: *Advances in concrete technology*, 2nd ed.(1994) 419–44..
21. V.T.A. Van, C. Rößler, D.D. Bui and H.M. Ludwig, *Constr. Build. Mater.*, 43 (2013) 208–216.
22. F. Pacheco Torgal and S. Jalali, *Constr. Build. Mater.*, 25 (2011) 582-590.
23. A. Nazari and S. Riahi, *Compos. Pt. B-Eng.* 42 (2011) 570-578.
24. A. Najji Givi, S. A. Rashid, F. N. A. Aziz and M. A. Mohd Salleh, *Compos. Pt. B-Eng.*, 42 (2011) 562-569.
25. A. Najji Givi, S. A. Rashid, F. N. A. Aziz and M. A. Mohd Salleh, *Compos. Pt. B-Eng.*, 41 (2010) 673-677.
26. A. Nazari, S. Riahi, S. Riahi, S. Fatemeh Shamekhi and A. Khademno, *J. Amer. Sci.*, 6 (2010) 90-93.
27. A. Nazari and S. Riahi, *Mater. Sci. Eng. A*, 528 (2010) 756-763.
28. A. Nazari and S. Riahi, *Mater. Res.*, 57 (2008) 243-250.
29. T. Nochaiya and A. Chaipanich, *Appl. Surf. Sci.*, 257 (2011) 1941-1945.
30. S. Musso , J. M. Tulliani, G. Ferro and A. Tagliaferro, *Compos. Sci. Technol.* 69 (2009) 1985–1990.
31. G. Li, *Cement Concrete Res*, 34 (2004) 1043–1049.
32. T. Ji, *Cement Concrete Res*, 35 (2005) 1943–1947.
33. Y. Qing, Z. Zenan, K. Deyu and C. Rongshen, *Constr. Build. Mater.*, 21 (2007) 539–545.
34. D.F. Lin, K.L. Lin, W.C. Chang, H.L. Luo and M.Q. Cai, *Waste Manage.*, 28 (2008) 1081–1087.
35. K.L. Lin, W.C. Chang, D.F. Lin, H.L. Luo and M.C. Tsai, *J. Environ. Manage.* 88 (2008) 708–714.
36. H.L. Luo, W.T. Kuo and D.F. Lin, *Water Sci. Technol.*, 42 (2011) 570-578.
37. ASTM C33-03, *Standard Specification for Concrete Aggregates*, *Book of standards*, vol. 04.02 (2003).
38. ASTM C 494/C 494M – 05a, *Standard Specification for Chemical Admixtures for Concrete*, *Book of standards*, vol. 04.02 (2005).
39. ASTM C1017 / C1017M - 07, *Standard Specification for Chemical Admixtures for Use in Producing Flowing Concrete*, vol. 04.02 (2007).
40. ASTM C 305-12, *Standard Practice for Mechanical Mixing of Hydraulic Cement Pastes and Mortars of Plastic Consistency*, vol. 04.01 (2012).
41. ASTM C 1437-99, *Standard Test Method for Flow of Hydraulic Cement Mortar*, vol. 04.01 (1999).
42. ASTM C 109/C 109M – 05, *Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50-mm] Cube Specimens)*, vol. 04.01 (2005).
43. S. Rukzon, P. Chindaprasirt and R. Mahachai, *Int. J. Miner. Metall. Mater.*, 16 (2009) 242-247.
44. P. Chindaprasirt and S. Rukzon, *Constr. Build. Mater.*, 22 (2008) 1601-1606.
45. ASTM C 618 – 99, *Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Concrete*, vol. 04.02 (1999).
46. P.K. Metha. The chemistry and technology of cement made from rice husk ash. In: *Proceedings UNIDO/ESCAP/RCTT Workshop on Rice Husk Ash Cements*, Peshawar, Pakistan, January 1979. Regional Centre for Technology Transfer, Bangalor (India), 1979.p. 113–22.
47. P. Chindaprasirt, S. Rukzon and V. Sirivivatnanon, *Constr. Build. Mater.*, 22 (2008) 932–938.
48. H. Li, H. G. Xiao, J. Yuan and J. Ou, *Compos. Pt. B-Eng.*, 35 (2004) 185-189.