

## Compressive Strength of Cement Mortar Modified with Nano-Alumina in Correlation with Different Water-to-Cement Ratios and Curing Periods - A Statistical Analysis

Muhammed Halkawt Abdullah<sup>1</sup>

Serwan Khorsheed Rafiq<sup>1</sup>

<sup>1</sup>University of Sulaimani - College of Engineering - Department of Civil Engineering

### Article Inform

#### Article History:

Received 11 February 2020

Accepted 19 June 2020

Available online 30 December 2020

**Keywords:** Correlation, Mortar, Nanomaterials, Nano-engineering, Nano-cement, Sustainability, Nano Al<sub>2</sub>O<sub>3</sub>, Nano alumina.

#### About the Authors:

##### Corresponding author:

Muhammed Halkawt Abdullah

E-mail: muhammed.abdullah@univsul.edu.iq

##### Researcher Involved:

Serwan Khorsheed Rafiq

**DOI Link:** <https://doi.org/10.17656/sjes.10135>



© The Authors, published by University of Sulaimani, college of engineering.  
This is an open access article distributed under the terms of a Creative Commons Attribution 4.0 International License.

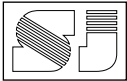
### Abstract

One promising insight to extended service life of cement mortar and improve it is durability by assimilating nano mechanism into the cement-based materials. Regardless of many research studies on the effect of nano alumina on the mechanical performance of cement mortar, there has not been a widespread study examining the effect of nano Al<sub>2</sub>O<sub>3</sub>, curing period (t), and water-to-cement ratio (w/c) on the compressive strength ( $\sigma_c$ ) of cement mortar. Consequently, this study explores the subject matter which could be helpful for the building and construction field. In this study, the data collected on the compressive strength of the cement mortar modified with different percentages of nano alumina ranging from 0.5% to 13.5% (by dry weight of the cement) were gathered from the literature. A nonlinear modeling NLM and statistical data analysis were performed on above 500 assembled data. The w/c ratio of the cement mortar varied from 0.3% to 0.79%, and the compressive strength of cement mortar modified with nano alumina and cured for 1,7 and 28 up to 90 days leads to high strength ranged from (10 MPa to 68 MPa). The result of NLM showed that curing period has the highest effect on the compressive strength in combination with water to cement ratio and percentage of nano alumina replacement with a coefficient of determination (R<sup>2</sup>) of 0.85.

### 1. Introduction

Current nano-scale studies in cement intensified on the enquiry of the structure of cement-based materials, as studying the nanostructure of cement-based materials improves the ability to control the procedures associated with hydration, strength development and fracture (Bartos, 2009; K.

Sobolev et al., 2009). The word nano means anything of size  $10^{-9}$ , nano particles is a solid particle of having size in the range of 1 to 100 nm. As the science world started to make new materials and to investigate their properties with nanotechnology, thus the usage of nanotechnology has become widespread in all branches of science. Therefore, studies of



nanoscale would be increased for cement mortar (Zaki & Ragab, 2009). For years, the majority of advances in the performance of cement mortar were attained by applying super-fine particles: silica fume, fly ash, metakaolin, and now nano materials (Plassard, Lesniewska, Pochard, & Nonat, 2004). Nano- $\text{Al}_2\text{O}_3$  as an example can be used as a stabilizer to boost the strength and workability (Colleparidi, Colleparidi, Skarp, & Troli, 2004). The nano-sized cementitious constituent is found by the crushing of a traditional or low temperature Portland cement clinker or is mass-produced by the self-assembly course by means of sol-gel method or mechano-chemically induced topo-chemical reactions (Konstantin Sobolev & Gutiérrez, 2005). The nanoparticles can also be well-thought-out as nanocrystals as the atoms inside the particle are flawlessly well-ordered, or crystal-like. After the dimensions of a material are minimized from macro- to nano-size, though significant changes in optical absorption, electronic conductivity, mechanical properties and even chemical reactivity emerge. With reducing in size, more atoms are located on the surface of a particle and, along with a notable surface area of nano powders; this informs a significant alteration in surface morphologies and surface energies. Consequently, all these features modify the basic characteristics and the chemical reactivity of nanomaterials. The change in properties assists to develop a better catalytic ability, adjustable wavelength sensing ability, as well as enables to design better self-cleaning and self-healing features (Klabunde & Richards, 2009; Roco & Williams, 1999; Konstantin Sobolev & Shah, 2008). This study demonstrates the work of previous researchers regarding the usage of nano materials and shows the advantages concerning mechanical properties of cement mortar and the criteria which has not been covered as determined and summarized in Table (1).

In the current study, data were gathered from the literature as shown in tables (1) and (2), and statistical analysis and modeling were performed on these data. Relying on the literature data, no correlation was noted between compressive

strength, NL content, and w/c ratio up to 90 days of curing period. The effect of w/c, curing period, and nano alumina content on the compressive strength of cement mortar was quantified using a nonlinear model. The goals of the study were as follows:

- a. To study statistical alteration of the mechanical properties, water-to-cement ratio, nano alumina content, and curing period of cement mortar
- b. To examine and quantify the interactions of the compressive strength of cement mortar with w/c and nano  $\text{Al}_2\text{O}_3$  (%) cured up to 90 days
- c. To investigate the nonlinear correlation to assess the influence of w/c ratio curing period, and nano alumina content on the compressive strength of cement mortar

## 2. Objectives

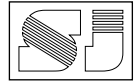
Discovering novel methods and new cement-based materials characterized with improved mechanical capability is essential for sustainable infrastructure with longer service life. Nano-engineering, or nanomodification of cement is a quickly emerging field. Synthesis and assembly of materials in the nanometer scale range offer the possibility for the development of new cement additives such as nano based cement.

The inclusive objective of this study was to model and assess scientific equations that indulge the relationship and correlation between compressive strength ( $\sigma_c$ ) stating to the percentage on nano-based material, also to fine the effect of inclusion on nano-materials on the mechanical and physical properties of cement mortar effecting the cement to produce sustainable properties.

## 3. Materials and Methods

### 3.1. Data Collection

This study was engrossed on the correlation between compressive strength ( $\sigma_c$ ), in regard to the percentage on nano based material and water to cement ratio. The focus of this study was on the statistical variation and correlations between



compressive strength with w/c ratio and curing period for the cement mortar modified with nano alumina. Above 500 data allocated from numerous research studies to attain a sensible conclusion. The concrete properties were based on many variables as summarized in Table (2).

### 3.2. Modeling

The modeling of mechanical properties on concrete parameters and the properties of cement mortar presumed by comparing the collected data. Through the inspection, the graphs from the collected data attained.

In order to compare the model predictions statistical quantification such as coefficient of determination ( $R^2$ ) and the root-mean-square error (RMSE) was used and quantified Eq. (1) and (2) as follows:

$$R^2 = \left( \frac{\sum_i (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_i (x_i - \bar{x})^2} * \sqrt{\sum_i (y_i - \bar{y})^2}} \right)^2 \quad (1)$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^n (y_i - x_i)^2}{N}} \quad (2)$$

while

$y_i$  = experimental value,

$x_i$  = predicted value from the model,

$\bar{y}$  = mean of the collected data,

$\bar{x}$  = mean of calculated values and N is the number of data.

#### 3.2.1. Regression Analysis

Regression analysis was performed to develop the relationships between the compressive strength of the cement mortar as a function of w/c, nano alumina %, and curing period up to 90 days.

#### 3.2.2. Correlation of Compressive Strength with w/c Ratio and Curing Period

The compressive strength of cement mortar modified with nano alumina (NL) were affected by

the curing period (t) and water-to cement ratio (w/c (%))(Vipulanandan & Mohammed, 2015). The effects of nano alumina (%), t (days), and w/c (%) of the cement mortar were divided as follows:

Compressive strength ( $\sigma_c$ ) of cement mortar only (NL= 0%):

$$\sigma_c = a \left( \frac{w}{c} \right)^b (t)^c \quad (3a)$$

Compressive strength ( $\sigma_c$ ) of cement mortar modified with any percentage of nano alumina:

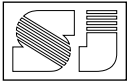
$$\begin{aligned} \sigma_c &= a \left( \frac{w}{c} \right)^b (t)^c \\ &+ d \left( \frac{w}{c} \right)^e (t)^f (NL)^g \end{aligned} \quad (3b)$$

Based on data collected from various research studies in the literature, the correlation parameters ( $a$ ,  $b$ ,  $c$ ,  $d$ ,  $e$ ,  $f$ , and  $g$ ) were calculated using least-squares multiple regression analysis, as summarized in Table (3).

## 4. Statistical Analysis for the Affecting Factors

### 4.1. Water-to-Cement Ratio (w/c)

Based on the total of 54 w/c ratio data for the cement mortar collected from various research studies Table (1), the w/c for the cement mortar ranged from 0.26 to 0.55% with a mean of 0.3% and a standard deviation of 0.08%, as summarized in Table (2). The number of data points in each set of w/c values was measured. More than 50% of the total w/c of the cement mortar ranged between 0.3% and 0.5%, as shown in Fig. (1). Based on the total of 82 water-to-binder ratio (w/b) data for the cement mortar modified with nano alumina Table (1), the w/c ratio ranged from 0.3% to 0.79% with a mean of 0.44% and a standard deviation of 0.1% Table (2). Almost 100% of the total w/b data ranged between 0.3% and 0.79%, as shown in Fig. (2). There were no direct correlations observed between the compressive



strength and water-to-cement ratio (w/c) up to 90 days of curing.

#### 4.2. Nano Alumina Content (NL) (%)

According to the literature the total 82 nano alumina (NL) percent data used to modify the cement mortar, the data ranged from 0.5% to 13.5% with a standard deviation of 3.6% and COV of 76.8%. About 70% of the total nano alumina varied between 0.5% and 9%, as shown in Fig. (3).

#### 4.3. Compressive Strength of Cement Mortar

A total of 54 compressive strength ( $\sigma_c$ ) data for the cement mortar were collected from various research studies Table (1). The compressive strength ( $\sigma_c$ ) of the cement mortar up to 90 days of curing varied from 7 MPa to 49 MPa with a mean of 29.7 MPa, a standard deviation of 9.5 MPa, and a COV of 32.1% Table (2). Different distribution tests for the compressive strength of cement mortar were performed. The lognormal frequency distribution for the compressive strength of cement mortar was observed based on the Anderson-Darling (AD) statistic and P values Fig. (4).

#### 4.4. Compressive Strength of Cement Mortar Modified with Nano Alumina

A total of 82 compressive strength ( $\sigma_c$ ) data for cement mortar modified with different percentage of nano alumina were collected from the literature Table (1). The  $\sigma_c$  ranged from 10 MPa to 68 MPa with a mean of 42.3 MPa, a standard deviation of 12.5 MPa, and a COV of 29.6% Table (2). Based on the AD and P values, the probability distribution was a normal distribution, as shown in Fig. (5).

### 5. Suggested Correlations

#### 5.1. Relationship between Compressive Strength and w/c of Cement Mortar Modified with Nano Alumina

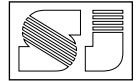
More than 362 data for compressive strength and w/c ratio of cement mortar modified with nano alumina at the age of 1,7 and 28 up to 90 days were collected from various research studies. There were no correlations between the  $\sigma_c$  and w/c ratio up to 90 days of curing Fig. (6-9).

#### 5.2. Relationship between Measured and Predicted Compressive Strengths of Cement Mortar

Depending on the 152 results from literature, the relationship between the compressive strength ( $\sigma_c$ ) in (MPa) units, water to cement ration (w/c), and curing period (t) in (days) was not directly observed, the compressive strength ( $\sigma_c$ ) was correlated with the independent variables (i.e., w/c ratio and curing period) using a nonlinear relationship Eq. (4), as shown in Fig. (10). The model parameters were obtained from least-squares multiple regression analyses Table (3). Based on the nonlinear model parameter a Eq. (3a), the compressive strength of cement mortar was affected by w/c ratio and curing period. The model parameters,  $R^2$ , and RMSE are summarized in Table (3):

$$\sigma_c = \frac{8.36 t^{0.22}}{w/c^{0.92}} \cdot R^2 = 0.86 \quad (4)$$

Based on the data from the literature, an adequate coefficient of determination ( $R^2$ ) of 0.86 attained from the NML equation Eq. (4), the limitation factor of Eq. (4) for w/c is between (0.26-0.55) and for curing days is between (1-90).



### 5.3. Relationship between Compressive Strength and Nano Alumina (%)

More than 296 data for compressive strength and w/c of cement mortar at different curing periods 1,7 and 28 up to 90 days were collected from various research studies. The coefficient of determination ( $R^2$ ) were (0.68, 0.04, 0.0006, 0.047) for 1,7, 28 and 90 days consecutively as a result, there were no correlations between the  $\sigma_c$ , w/c, and nano alumina (%) up to 90 days of curing Fig. (11-14).

### 5.4. Relationship between Measured and Predicted Compressive Strengths ( $\sigma_c$ ) of Cement Mortar Modified with Nano Alumina

The  $\sigma_c$  was correlated with the independent variables (i.e., w/c, NL, and curing period) using a nonlinear relationship Eq. (5). The model parameters were achieved from least-squares multiple regression analyses Table (3). The model parameters,  $R^2$ , and RMSE are summarized in Table (3). A unique relationship was observed between measured and predicted compressive strengths ( $\sigma_c$ ) Fig. (15). Based on the nonlinear model parameter a Eq. (3b), the curing period had the highest effect on the increase of the compressive strength compared with the nano alumina content as demonstrated in Table (3):

$$\sigma_c = \frac{7.61t^{0.276}}{w/c^{0.75}} + \frac{0.27 NL^{0.007} t^{0.05}}{w/c^{3.43}}. R^2 = 0.85 \quad (5)$$

Based on the data from the literature (328 results), an adequate coefficient of determination ( $R^2$ ) of 0.85 attained from the NML equation Eq. (5), the limitation factor of Eq. (5) for w/c is between (0.3-0.79), for NL (%) is between (0.5-13.5) and for curing days is between (1-90).

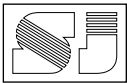
## 6. Conclusions

Based on over 500 data collected from various research studies and mathematical models, correlation between water to cement ratio (w/c), compressive strength ( $\sigma_c$ ), curing period (days), percentage of nanomaterial (%) analyzed. Correlation among the properties were inspected and modeled based on the composed data from literature. the following points were advanced:

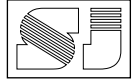
- 1- There were no direct correlations observed between the compressive strength and water-to-cement ratio (w/c) for 1,7 and 28 up to 90 days of curing.
- 2- Based on the NLM parameters, the nano alumina had significant effect on the increase of the compressive strengths of the cement mortar up to 68 MPa.
- 3- The result of the proposed NLM showed that curing period had the highest effect on the compressive strength in combination with water to cement ratio and percentage of nano alumina replacement.
- 4- With respect to the data from the literature, an adequate coefficient of determination ( $R^2$ ) of 0.85 attained from the NLM equation.
- 5- The limitation factor of the proposed NLM for w/c is between (0.3-0.79), for NL (%) is between (0.5-13.5) and for curing days is between (1-90).
- 6- Based on the collected data and the modeled correlations, curing period and w/c ratio doesn't affect the compressive strength individually, unless both factors considered with respect of the nano alumina percentage.

## References

1. Barbhuiya, S., Mukherjee, S., & Nikraz, H. (2014). Effects of nano- $Al_2O_3$  on early-age microstructural properties of cement paste. *Construction and Building Materials*, 52, pp.189-193.
2. Bartos, P. J. M. (2009). *Nanotechnology in Construction 3 Proceedings of the NICOM3*. In Springer. Springer Science & Business Media.
3. Collepardi, M., Collepardi, S., Skarp, U., & Troli,



- R. (2004). Optimization of silica fume, fly ash and amorphous nano-silica in superplasticized high-performance concretes. Proceedings of 8th CANMET/ACI International Conference on Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete, SP-221, Las Vegas, USA, pp.495-506.
4. Gowda, R., Narendra, H., Rangappa, D., & Prabhakar, R. (2017). 6- Effect of nano-alumina on workability, compressive strength and residual strength at elevated temperature of Cement Mortar. *Materials Today: Proceedings*, 4(11), pp.12152-12156.
  5. Klabunde, K. J., & Richards, R. M. (2009). *Nanoscale Materials in Chemistry: Second Edition*. In *Nanoscale Materials in Chemistry: Second Edition*. John Wiley & Sons.
  6. Li, W., Li, X., Chen, S. J., Long, G., Liu, Y. M., & Duan, W. H. (2017). 3- Effects of nanoalumina and graphene oxide on early-age hydration and mechanical properties of cement paste. *Journal of Materials in Civil Engineering*, 29(9), pp.1-9.
  7. Liu, J., Li, Q., & Xu, S. (2015). 12 Influence of nanoparticles on fluidity and mechanical properties of cement mortar. *Construction and Building Materials*, 101, pp.892-901.
  8. Miyandehi, B. M., Behforouz, B., Khotbehsara, E. M., Balgouri, H. A., Fathi, S., & Khotbehsara, M. M. (2014). 2- An experimental investigation on nano- $\text{Al}_2\text{O}_3$  based self-compacting mortar. *Journal of American Science*, 10(11), pp.229-233.
  9. Mohseni, E., Khotbehsara, M. M., Naseri, F., Monazami, M., & Sarker, P. (2016). 7- Polypropylene fiber reinforced cement mortars containing rice husk ash and nano-alumina. *Construction and Building Materials*, 111, pp.429-439.
  10. Mohseni, E., Miyandehi, B. M., Yang, J., & Yazdi, M. A. (2015). 15 Single and combined effects of nano- $\text{SiO}_2$ , nano- $\text{Al}_2\text{O}_3$  and nano- $\text{TiO}_2$  on the mechanical, rheological and durability properties of self-compacting mortar containing fly ash. *Construction and Building Materials*, 84, pp.331-340.
  11. Mohseni, E., & Tsavdaridis, K. D. (2016). 5- Effect of nano-alumina on pore structure and durability of class F fly ash self-compacting mortar. *American Journal of Engineering and Applied Sciences*, 9(2), pp.323-333.
  12. Oltulu, M., & Şahin, R. (2011). 17 Single and combined effects of nano- $\text{SiO}_2$ , nano- $\text{Al}_2\text{O}_3$  and nano- $\text{Fe}_2\text{O}_3$  powders on compressive strength and capillary permeability of cement mortar containing silica fume. *Materials Science and Engineering A*, 528(22-23), pp.7012-7019.
  13. Oltulu, M., & Şahin, R. (2013). 18 Effect of nano- $\text{SiO}_2$ , nano- $\text{Al}_2\text{O}_3$  and nano- $\text{Fe}_2\text{O}_3$  powders on compressive strengths and capillary water absorption of cement mortar containing fly ash: A comparative study. *Energy and Buildings*, 58, pp.292-301.
  14. Plassard, C., Lesniewska, E., Pochard, I., & Nonat, A. (2004). Investigation of the surface structure and elastic properties of calcium silicate hydrates at the nanoscale. *Ultramicroscopy*, 100(3-4), pp.331-338.
  15. Roco, M. C., & Williams, R. S. (1999). *Nanotechnology Research Directions: IWGN Workshop Report Vision for Nanotechnology R & D in the Next Decade*. In *Science And Technology (Vol. 15)*. NATIONAL SCIENCE AND TECHNOLOGY COUNCILARLINGTON VA.
  16. Roychand, R., De Silva, S., Setunge, S., & Law, D. (2017). 1- A quantitative study on the effect of nano  $\text{SiO}_2$ , nano  $\text{Al}_2\text{O}_3$  and nano  $\text{CaCO}_3$  on the physicochemical properties of very high volume fly ash cement composite. *European Journal of Environmental and Civil Engineering*, 8189(December), pp.1-16.
  17. Sobolev, K., Flores, I., Torres-Martinez, L. M., Valdez, P. L., Zarazua, E., & Cuellar, E. L. (2009). *Engineering of  $\text{SiO}_2$  Nanoparticles for Optimal Performance in Nano Cement-Based Materials*. In *Nanotechnology in Construction 3* (pp.139-148). Springer.
  18. Sobolev, Konstantin, & Gutiérrez, M. F. (2005). How nanotechnology can change the concrete world. *American Ceramic Society Bulletin*, 84(10), pp.14.
  19. Sobolev, Konstantin, & Shah, S. P. (2008). *Nanotechnology of Concrete: Recent Developments and Future Perspectives*. In *American Concrete Institute, ACI Special Publication*. ACI.
  20. Vipulanandan, C., & Mohammed, A. (2015). Smart cement modified with iron oxide nanoparticles to enhance the piezoresistive behavior and compressive strength for oil well applications. *Smart Materials and Structures*, 24(12), pp.12-20.
  21. Zaki, S. I., & Ragab, K. S. (2009). How nanotechnology can change concrete industry. 1st International Conference " Sustainable Built Environment Infrastructures in Developing Countries", pp.95.



## النمذجة غير الخطية للقوة الانضغاطية لمونة الاسمنت المعدلة مع النانو ألومينا لعدة نسب من الماء إلى الإسمنت وأوقات المعالجة

محمد هلكوت عبدالله<sup>1</sup>

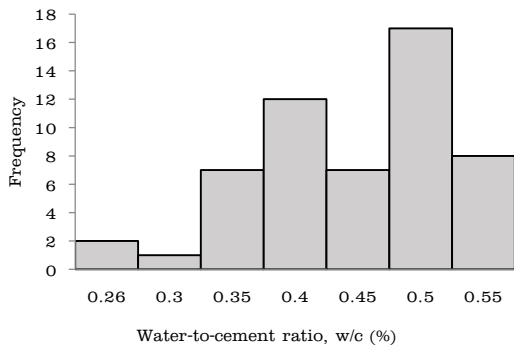
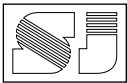
أ.م.د. سيران خورشيد رفيق<sup>1</sup>

<sup>1</sup>جامعة السليمانية، كلية الهندسة، قسم الهندسة المدنية

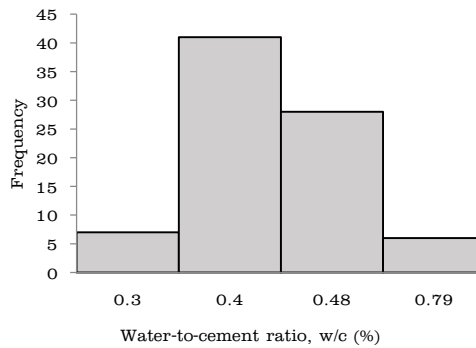
### المستخلص

من بين الأفكار الواعدة لإطالة عمر خدمة المونة الأسمنتية وتحسين المتانة هي من خلال استيعاب آلية النانو في المواد القائمة على الأسمنت. بغض النظر عن العديد من الدراسات البحثية حول تأثير النانو ألومينا على الأداء الميكانيكي للمونة الأسمنتية، لم تكن هناك دراسة واسعة النطاق تبحث تأثير النانو ( $Al_2O_3$ ) ووقت المعالجة ( $t$ )، ونسبة الماء إلى الإسمنت ( $w/c$ ) على قوة الضغط ( $\sigma_c$ ) لمونة الأسمنتية. بناء على ذلك، تستكشف هذه الدراسة الموضوع الذي يمكن أن يكون مفيداً لمجال البناء والتشييد. في هذه الدراسة، البيانات التي تم جمعها من المؤلفات عن القوة الانضغاطية لمونة الاسمنت المعدلة بنسب مختلفة من النانو ألومينا تتراوح بين 0.5% إلى 13.5% (بالوزن الجاف للأسمنت). تم إجراء النمذجة غير الخطية (NLM) وتحليل البيانات الإحصائية على البيانات المجمعة فوق 500 البيانات. تراوحت نسبة الماء إلى الإسمنت ( $w/c$ ) من المونة الأسمنتية من 0.3% إلى 0.79%، وقوة الضغط للمونة الأسمنتية مع إضافة النانو ألومينا وتحت تأثير مدة المعالجة من 1 و7 و28 يوماً إلى 90 يوماً، تراوحت بين 10 ميغا باسكال إلى 68 ميغا باسكال. أظهرت نتيجة النمذجة غير الخطية (NLM) المقترحة أن وقت المعالجة له أعلى تأثير على قوة الضغط في تركيبة مع نسبة الماء إلى الإسمنت والنسبة المئوية لاستبدال النانو ألومينا بمعامل تحديد ( $R^2$ ) عند 0.85.

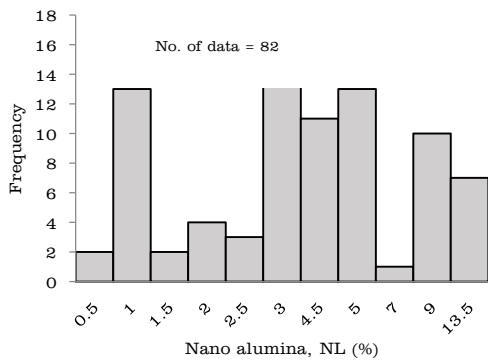
**الكلمات المفتاحية:** نموذج غير خطي، المونة، مواد نانوية، هندسة النانو، نانو الأسمنت، الاستدامة، نانو  $Al_2O_3$ ، نانو ألومينا.



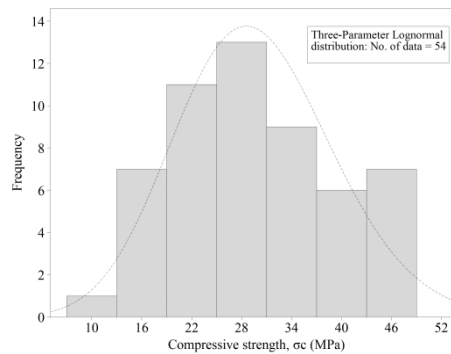
**Fig. 1: Histogram of the water-to-cement ratio (w/c) for cement mortar.**



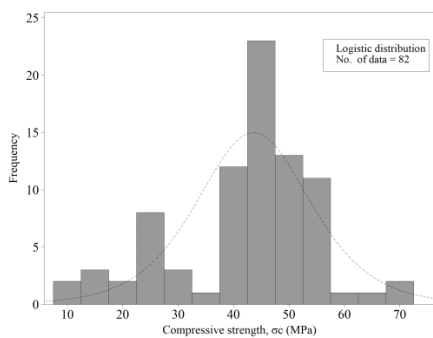
**Fig. 2: Histogram of the water-to-cement ratio (w/c) for cement mortar modified with nano alumina (NL).**



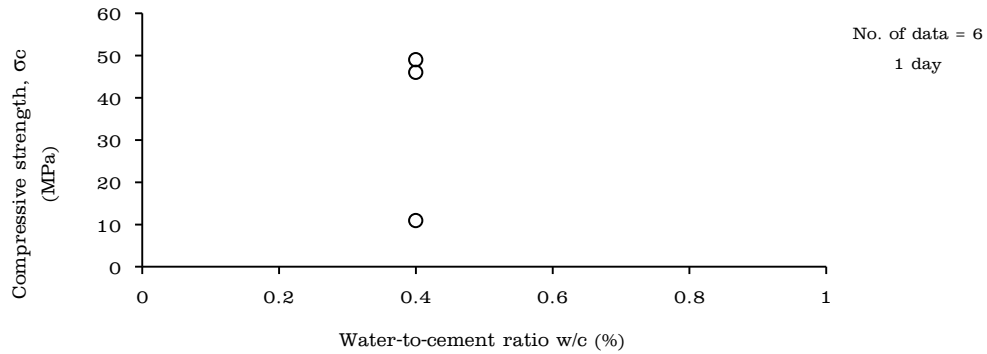
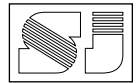
**Fig. 3: Histogram of percent of nano alumina (NL) added to the cement mortar.**



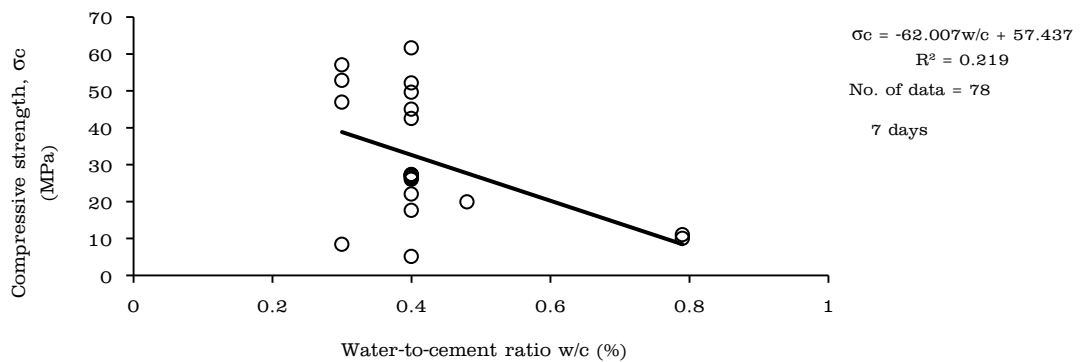
**Fig. 4: Statistical distribution of the compressive strength for cement mortar up to 90 days of curing.**



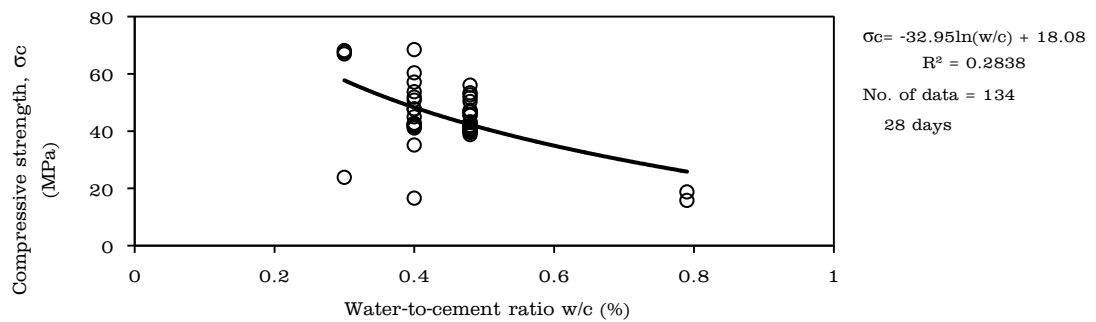
**Fig. 5: Statistical distribution of the compressive strength for cement mortar modified with nano alumina (NL) up to 90 days of curing.**



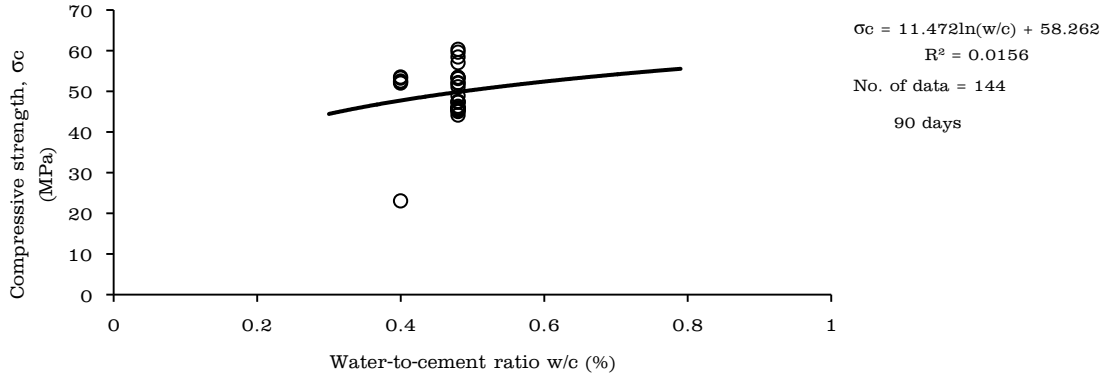
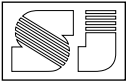
**Fig. 6: Variation between w/c and compressive strength of cement Mortar modified with nano alumina at 1 day curing period.**



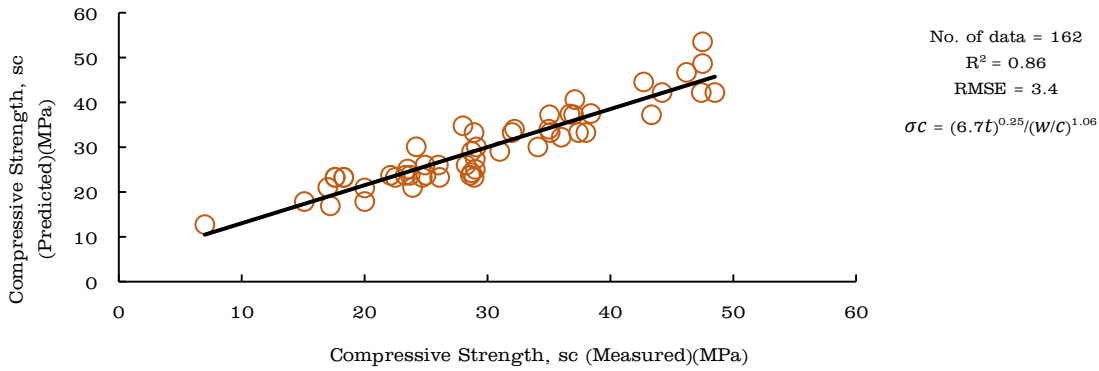
**Fig. 7: Variation between w/c and compressive strength of cement Mortar modified with nano alumina at 7 days curing period.**



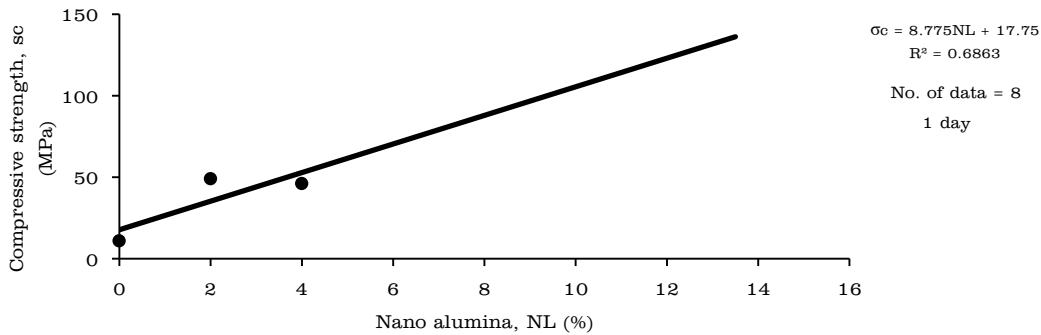
**Fig. 8: Variation between w/c and compressive strength of cement mortarmodified with nano alumina at 28 days curing period.**



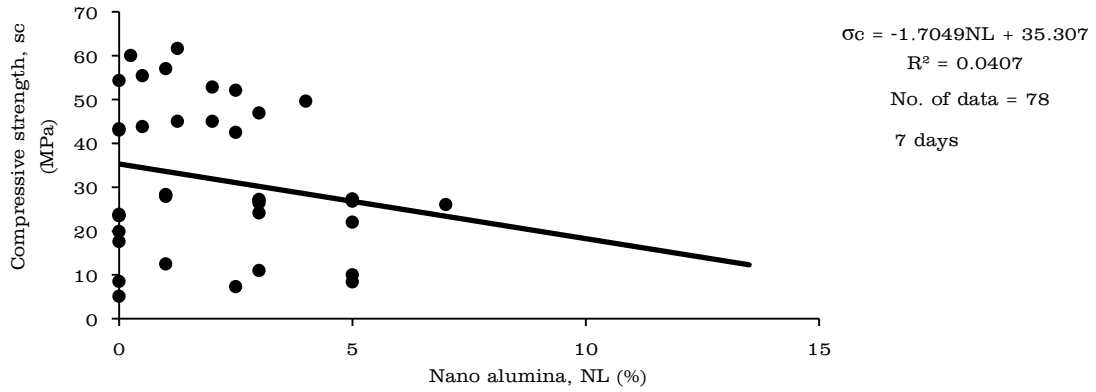
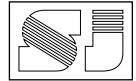
**Fig. 9: Variation between w/c and compressive strength of cement Mortar modified with nano alumina at 90 days curing period.**



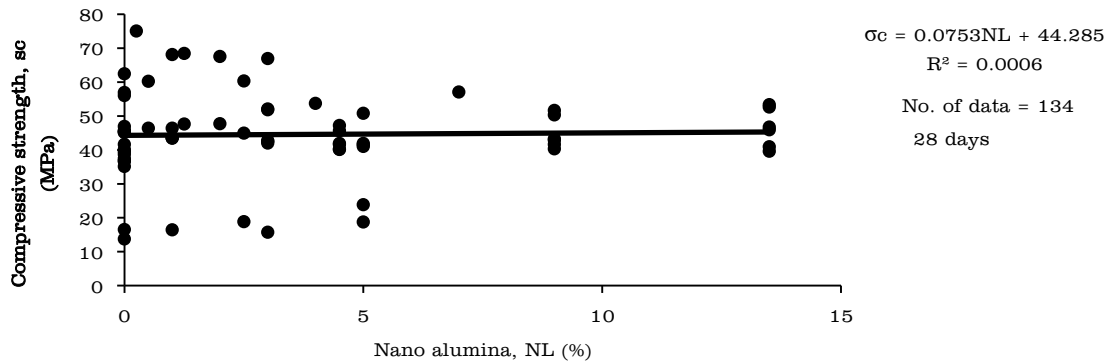
**Fig. 10: Relationship between measured and predicted compressive strengths for cement mortar.**



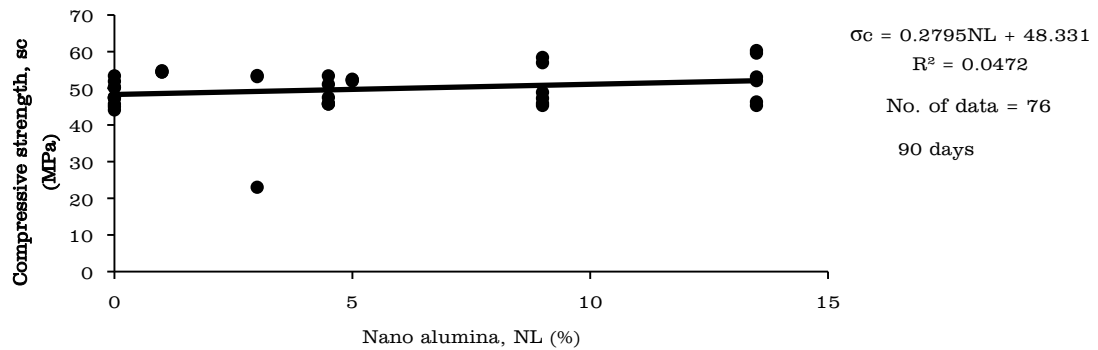
**Fig. 11: Variation between percentage of nano alumina (NL) and compressive strength of cement mortar modified with nano alumina at 1 day curing period.**



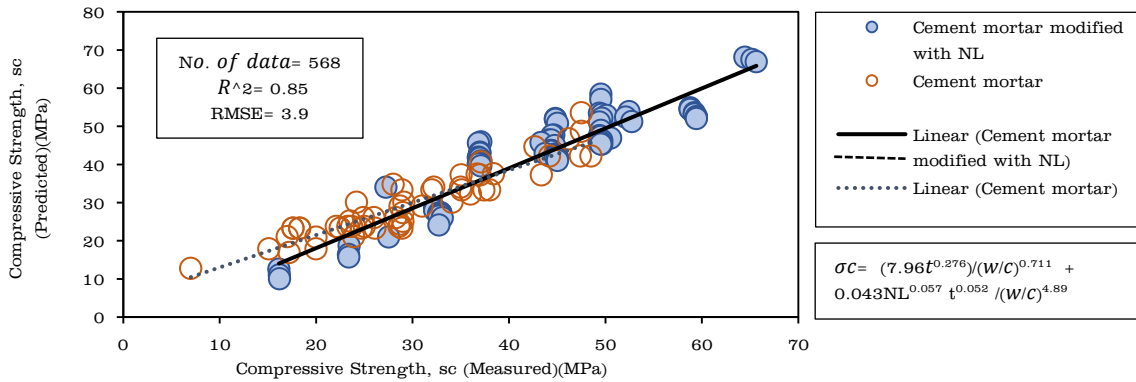
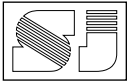
**Fig. 12: Variation between percentage of nano alumina (NL) and compressive Strength of cement mortar modified with nano alumina at 7 days curing period.**



**Fig. 13: Variation between percentage of nano alumina (NL) and compressive Strength of cement mortar modified with nano alumina at 28 days curing period.**



**Fig. 14: Variation between percentage of nano alumina (NL) and compressive Strength of cement mortar modified with nano alumina at 90 days curing period.**



**Fig. (15): Relationship between measured and predicted compressive strengths for cement mortar modified with nano alumina (NL).**

**Table (1): Summary properties of cement mortar modified with nano alumina obtained from the literature.**

Reference	Country	Nano alumina NL (%)	Water to cement ratio w/c	Curing period, t (days)	Compressive strength, s <sub>c</sub> (MPa)	Tests
(Liu, Li, & Xu, 2015)	China	0-3	0.3	3, 7, 28	40-68	Compressive strength
(Mohseni, Miyandehi, Yang, & Yazdi, 2015)	China	0-5	0.4	3, 7, 28	11.5-54.4	Compressive strength
(Oltulu & Şahin, 2011)	Turkey	0-2.5	0.4	3, 7, 28, 56	42.2-68	Compressive strength
(Oltulu & Şahin, 2013)	Australia	0-2.5	0.4	3, 7, 28, 56	34-53.8	Compressive strength
(Roychand, De Silva, Setunge, & Law, 2017)	Iran	0-5	0.3	7, 28	10-23.8	Compressive strength
(Miyandehi et al., 2014)	China	0-5	0.4	3, 7, 28, 90	12.1-54.8	Compressive strength
(Li et al., 2017)	Australia	0-4	0.4	28	35.1-53.7	Compressive strength
(Barbhuiya, Mukherjee, & Nikraz, 2014)	UK	0-4	0.4	1, 3, 7	7-50.2	Compressive strength
(Mohseni & Tsavdaridis, 2016)	Inia	0-5	0.4	3, 7, 28, 90	12-54.5	Compressive strength
(Gowda, Narendra, Rangappa, & Prabhakar, 2017)	Australia	0-5	0.79	7, 28	10.5-18.7	Compressive strength
(Mohseni, Khotbehsara, Naseri, Monazami, & Sarker, 2016)	China	0-13.5	0.48	28, 90	38.7-59.6	Compressive strength

Remarks      6 countries      Varied from 0 to 13.5 %      Varied from 0.3 to 0.79      Varied from 1 day up to 90 days      Varied from 7 MPa to 68 MPa      Compressive strength tests