Journal of Civil Engineering and Materials Application
Journal home page: http://journals.lexispublisher.com/jcema

Received: 25 June 2017 • Accepted: 14 September 2017

Research

doi: 10.15412/J.JCEMA.12010205

The Effect of Magnesium Oxide Nano Particles on the Mechanical and Practical Properties of Self-Compacting Concrete

Hossein Ebrahimi Fard, Mohammad Mahdi Jabbari*

Department of Civil Engineering, Shiraz Branch, Islamic Azad University, Shiraz, Iran

*Correspondence should be addressed to Mohammad Mahdi Jabbari, Department of Civil Engineering, Shiraz Branch, Islamic Azad University, Shiraz, Iran; Tell: +987136410068; Fax: +987136410054; Email: jabbari@iaushiraz.ac.ir .

ABSTRACT

One of the most important advances in the civil engineering industry is the application of nanotechnology and concrete performance in combination with some materials in order to improve their properties, behavior and structure, as well as the use of nanomaterials to produce high performance and multi-purpose concrete. Concrete's properties, behavior and performance depends on the nanostructure of concrete and cement material which creates adhesion, cohesion and integrity. Therefore, concrete studies at the nanoscale are very important to develop new concrete materials and their applications. In this research, the effect of magnesium oxide (MgO) nanoparticles on the mechanical and practical properties of self-compacting concrete was investigated. Here, self-compacting concrete with different percentages of 1, 2, 3, and 4 of cement weight was made from MgO nanoparticles, and experiments of slump flow, slump flow T = 50 cm, L-box, U-box and V-funnel tests were conducted. The results showed that adding MgO nanoparticles of 2% by weight of cement to self-compacting concrete, increases compressive, tensile and flexural strength respectively by 33%, 20% and 59% at the age of 28-days.

Key words: Magnesium Oxide Nanoparticles, Mechanical Properties (Compressive, Tensile and Flexural Strength).

Journal of Civil Engineering and Materials Application is published by *Lexis Publisher*; Journal p-ISSN xxxx-xxxx; Journal e-ISSN 2588-2880.

1. INTRODUCTION

In concrete structures, concrete is vibrated in different ways to achieve the required resistance, and reduce the porosity and air inside the concrete and obtain stability. With the increasing development of concrete works and the relative shortage of skilled workers or their negligence in workshops, or because of physical and mental disturbances or the cost of vibrating concrete when pouring it in the mold, especially in areas where rebar density exists, vibration is not done completely and properly. Finally, the mechanical properties of the concrete are not appropriately obtained; therefore, construction of concrete without any need to vibration has been always a solution for this problem. As a result, construction of such concrete has been a dream for concrete technologists who could achieve this goal by applying various chemical additives and changes in the amount of material used in mixing design, and could release the concrete from vibrating and its practical imperfection. In this research, the effect of magnesium oxide nanoparticles on the mechanical and practical properties of self-compacting concrete is investigated. Despite the large number of studies conducted by Iranian and foreign researchers on most of nanomaterials and the effect of these nanomaterials on the properties of ordinary and self-compacting concrete, so far no research has been done on the effect of magnesium oxide (MgO) nanoparticles on self-compacting concrete. However, a number of researches that investigated the effect of MgO nanoparticles on cement or ordinary concrete are presented. Gao, Wu et al. (2007) examined The autoclave expansion of concrete depends on the addition of MgO, fly ash, autoclave temperature and time, but the expansion values increase with the increase in the amount of MgO and go up rapidly. Even if the 5% content limit of MgO in cement is exceeded, for example, 7.6% (in total), the concretes are sound (1). Westin and Fay (2011) concluded that, concrete made with extra-MgO generally have higher compressive and tensile strengths than concrete made without extra-MgO7. Multiple factors could contribute to this increase in strength. Firstly, the higher temperature during curing will increase the hydration rate of both the MgO and the cement, leading to a sufficient hydration and thus a denser microstructure. Secondly, there is a decrease on the number and size of cracks due to the expansion. Lastly, substitution of some cement with MgO powder decreases the water demand in the mix, leading to a lower water-cement ratio. In addition to strength gain, decreased permeability and increased abrasion/erosion resistance can be realized (2). Moradpour, Taheri et al. (2013) concluded the mechanical properties and permeability of cement-based composites containing nano-MgO were studied, and the experimental results indicated that the mechanical strength of the composites mixed with the nano-MgO, measured at different ages, were higher than those of a plain composite. The results from the treated composites compared to those of the plain composite indicated that the compressive strength of sample containing 1% nano-MgO of binder by weight (MGC1) increased by at 7 days and 28 days, respectively, and that the flexural strength of MGC1 equaled 4.66 and 5.1 MPa, which were 95% and 70% higher than those of the plain composite (PC) respectively. SEM revealed that the microstructure of the composites with nano-MgO were more compact and homogeneous than that of plain composite because of expansive effect of nano-MgO (3). Mo, Deng et al. (2014) proved Compensating shrinkage with expansion produced by MgO has been proved to effectively prevent the thermal cracking of mass concrete, and reduce the cost of temperature control measures and speed up the construction process. Moreover, the expansion properties of MgO could be designed flexibly, through adjusting its microstructure by changing the calcination conditions (calcining temperature and residence time) (4). Yuan, Shi et al. (2014) proved, the addition of NM particles to aluminate cement paste significantly affected both thermal and mechanical properties, including thermal conductivity, volume heat capacity and compressive strength. Then the properties of the hydration pastes are shown to be highly sensitive to heat-treatment at different temperatures. The pore distribution of the composite paste was greatly optimized at 1wt% NM particles loading and the typical 'doublepeak' phenomenon appeared (5). Polat, Demirboga et al. (2015) proved that MgO25, MgO50, and MgO75 decreased the AS by 40%, 43% and 47%, and MgO nanoparticles reduced AS by 53%, 56% and 80%, respectively in 28 days. MgO nanoparticles were appeared to be more effective than micro size MgO. The maximum and the same percentage of reduction were observed for both CaO75 and nano-MgO75, and was around 80% (6). Qing, Kaikai et al. (2015) concluded that Based on the application of MgO in clinker and light burnt MgO to the thermal and autogenous shrinkage compensation of dam concrete, the variation of expansion properties of cement paste with MgO nanoparticles was studied. Results indicated that the maximum content of MgO nanoparticles added in ordinary Portland cement reached up to 8% for soundness. The hydration rate of MgO nanoparticles cured in water at 20 ^{O}C was low, and a little of MgO nanoparticles existed till the age of 365 days. The paste expansions increased gradually with the increase of the MgO nanoparticles content cured at 20 ^{o}C in water within 365 days and through autoclaving after the ages of 365 days. The results suggest that added with MgO nanoparticles and mixed with light burnt MgO, the shrinkages of dam concrete may be completely compensated in safety (7).

2. METHOD OF RESEARCH

Since MgO nanoparticles is very expensive, and the amount of MgO nanoparticles used in self-compacting concrete depends on the weight of cement, it was tried to use the least amount of cement in the construction of self-compacting concrete; this requires a new mixing design depending on shape, size and dimension of large aggregates (gravel) and fine aggregates (sand). Three mixing designs were prepared, and fresh self-compacting concrete experiments including (slump flow, slump flow T=50 cm, V-Funnel, L-Box, U-Box) were conducted on samples. When all requirements of self-compacting concrete were accepted, the same mixing design was combined with MgO nanoparticles the final mixing design (Table 1). All materials used in this research have been gathered from mines around Shiraz. Calcium carbonate powder (limestone powder) was also used to construct self-compacting concrete. Cement type 1-525 with 3000 cm^2/g fineness, prepared from Fars Nov Cement Co. was used. Properties of MgO nanoparticles used in this research, which is the product of US Research Nanomaterials, Inc (Table 2). In Figure 1 and Figure 2, MgO nanoparticles scanning electron micrograph (SEM) and X-ray diffraction (X-RD) graph are shown.

Table 1. Final Mix design

No.	Type of material	Required quantity
1	Cement type (1-525)	350 Kg/m^3
2	Washed sand	669 Kg/m^3
3	Calcium carbonate powder (limestone)	150 Kg/m^3
4	Blown sand (0.15-1.18 mm)	546 Kg/m^3
5	Almond gravel (12-25 mm)	351 Kg/m^3
6	Pea gravel (5-12 mm)	234 Kg/m^3
7	Super plasticizer (SP) based on polycarboxylate (P100)	%1.18 * Cement
8	Water	156 Kg/m^3
9	Maximum aggregate size (M.A.S)	19 mm
10	Fineness modulus (F.M)	4.17

Table 2. Properties of Nano-MgO (8)

Purity: +99%	Average Particle Size: 20 nm
Specific Surface Area :> 60 m² / g	Color: white
Morphology: polyhedral	Bulk Density: 0.145 g / cm³
True Density: 3.58 g / m³	

3. A SUMMARY OF NANO-MGO MATERIAL SAFETY DATA SHEET (MSDS)

The Registry of Toxic Effects of Chemical Substances (RTECS) reports the following effects in laboratory animals: Brain and Coverings - recordings from specific areas of CNS. Blood - changes in serum composition. Biochemical - Enzyme inhibition, induction, or change in blood or tissue levels - true cholinesterase. Tumorigenic - equivocal tumorigenic agent by RTECS criteria. Sense Organs and Special Senses (Olfaction) – tumors, Lung, Thorax, or Respiration - tumors (9).

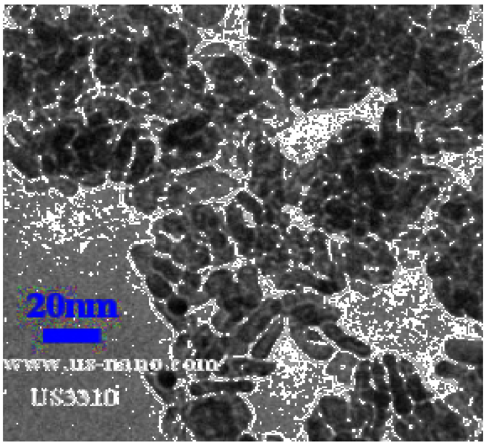

Figure 1. Nano-MgO Scanning Electron Micrograph

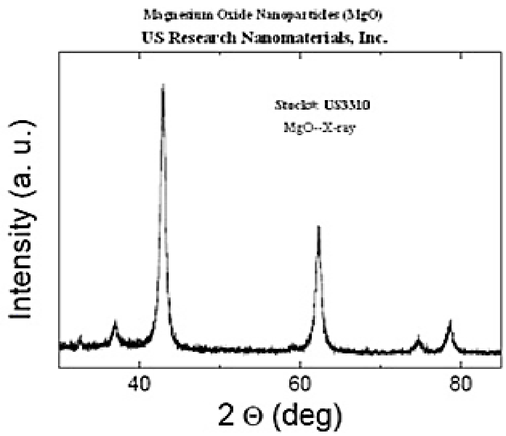

Figure 2. Nano-MgO X-RD

When self-compacting concrete was made according to the above-mentioned mix design, fresh self-compacting concrete tests were performed on it and the results (Table 1) were obtained, and showed that the values are within the range of proposed numbers EFNARC2002 and EFNARC2005 (10, 11). Then the concrete is poured into 15x15x15 cm cubic, 15x30 cm cylindrical and 15x15x50 cm beam molds, and no vibrations should be made. After 24-hours, the molds are opened and are kept in water pond. At the age of 7 and 28 days, samples are taken out of the water and compressive, tensile (ASTM C496) and flexural strength (ASTM C78) are calculated (Figure 3, Figure 4, Figure 5, Figure 6, Figure 7 and Figure 8).

Table 3. Results obtained from fresh self-compacting concrete testing according to final mix design (third)

No.	Test type	Test result
1	Slump flow	710 mm
2	Slump flow T = 50 cm	3 s
3	L-Box	0.98
4	U-Box	10 mm

5	V-Funnel at 5 minutes	10^{s}

Figure 3. All equipment of testing fresh self-compacting concrete

Figure 4. L-Box test

Figure 5. U-Box test

Figure 6. V-Funnel test

Figure 7. Slump test and slump flow T=50 cm

Figure 8. Tests for determining compressive, tensile and flexural strength

4. IMPLEMENTATION OF SELF-COMPACTING CONCRETE WITH MAGNESIUM OXIDE NANOPARTICLES

One of the challenges ahead for combining MgO nanoparticles with self-compacting concrete was that whether MgO nanoparticles is used as a wet mixed in concrete or a dry compound. By 2014, the wet mixing has been more conventional, but since 2015, dry mixing method has been used. Moradpour, Taheri et al. (2013) To prepare a well-dispersed suspension and mix the specimens, 0.5% of the cement weight of poly ethylene glycol was added to water, and the nanomaterial was gradually added while stirring for 1 min. Then, the nano-particles were further dispersed by sonification for 5 min using a Hielscher UP 400 with an unchanged constant frequency of approximately 70 Hz. The cement was added to the sand and mixed by a rotary mixer for 2 min. Then, the suspension containing the nanomaterial was gradually added to the cement–sand, mixed for another 2 min and left at rest for approximately 1 min (3). Yuan, Shi et al. (2014) For better dispersion of the pastes,NM particles and polycarboxylate were first dispersed in water with mechanical stirring at a speed of 120 rpm for 5 min,and then the mixture was added to the cement powders for hydration reaction (5). Polat, Demirboga et al. (2015) Powder mixtures were vigorously dry mixed with cement and silica fume for 7 min to disperse the micro-nano particles. Then, the dry mixed powder was added to the sand and mixed for 5 min in a drum mixer, and finally the mixture of water and the superplasticizer was added (6). Qing, Kaikai et al. (2015) To make cement mortar, first MgO nanoparticles and cement were combined as dry mix, and then water and sand were added to this mixture (7). According to the studies conducted in 2015, dry mix method could be selected and experiments could be continued; however, to compare dry and wet mixing, some 5 × 5 × 5 cm samples of cement mortar with MgO nanoparticles were constructed both by dry and wet method, and then samples were cured and broken, and the results were compared.

5. WET MIXING METHOD

First, water and super plasticizer are combined; then, MgO nanoparticles is gradually added to this solution and they are mixed by a stirrer at a speed of 120 rpm for 5 min. Next, sand and cement are completely mixed for two minutes, and finally the solution of water, super plasticizer and MgO nanoparticles are combined with the mixture of sand and cement in a mixer for 5 minutes. When the mortar is made, it is poured into cubic molds with 5 × 5 × 5 cm dimensions in layers, and each layer is rammed for 25 times; head of each mold is cleaned and then they are kept in the lab under appropriate conditions. After 24 hours, the molds are opened and put in water ponds for curing. After 28 days of curing, samples were placed under the jack and they were broken, and the results were obtained. It should be noted that in wet mixing method, mortar was made in three cases; first case: sand and cement mortar (control sample); second case: mortar with 2% weight of cement of MgO nanoparticles; third case: mortar with 4% weight of cement of MgO nanoparticles. Also, in the second and third cases, the same amount of MgO nanoparticles added to the concrete is reduced from the weight of cement; namely, MgO nanoparticles is replaced by a part of cement (in both dry and wet mixing method). The mix design used for wet mixing (Table 4).

Table 4. Mix design for wet mixture

Control sample			2% nano					4% nano				
Water (gr)	**Cement (gr)**	**sand (gr)**	**Water (gr)**	**Cement (gr)**	**sand (gr)**	**Super plasticizer**	**Nano Mgo (gr)**	**Water (gr)**	**Cement (gr)**	**sand (gr)**	**Super plasticizer**	**Nano Mgo (gr)**
110	220	660	110	215.60	660	0.88	4.40	110	211.20	660	3.80	8.80

6. DRY MIXED METHOD

First, cement and the considered percentage of MgO nanoparticles (2% and 4% by the weight of cement) were combined as dry mixed for 7 minutes; then, the mixture was completely combined with sand, and finally water and super plasticizer were gradually added. When the mortar was made, curing of concrete and breaking samples were conducted exactly like what were done in wet mixed method. The mix plan used for dry mixed (Table 5) and comparison of compressive strength between dry and wet mixture (Table 6), and Figure 9 also shows the break of a sample with dimensions of 5x5x5 cm.

Table 5. Mix design for dry mixture

Control sample			2% nano					4% nano				
Water (gr)	Cement (gr)	sand (gr)	Water (gr)	Cement (gr)	sand (gr)	Super plasticizer	Nano Mgo (gr)	Water (gr)	Cement (gr)	sand (gr)	Super plasticizer	Nano Mgo (gr)
110	220	660	110	215.60	660	1.98	4.40	110	211.20	660	4.20	8.80

Table 6. Comparing compressive strength increase between wet and dry methods

No.	*Nano-MgO 2%*	*Nano-MgO 4%*
Wet method	1.50%	6%
Dry method	14%	30%
Proportion of strength increase of dry method to wet method	Nearly 10 times (1000 %)	5 times (500 %)

Figure 9. 5 x 5 x 5 cm sample

Therefore, it was found that composition of MgO nanoparticles as dry mix gives better results than wet method, and self-compacting concrete is made by MgO nanoparticles with percentages of 1, 2, 3 and 4 weight of cement mixing design of self compacting concrete (SCC) with every percentage of Nano Mgo (Table 7).

Table 7. Mix design For SCC with Nano Mgo (79.44 lit)

No	Cement (kg)	Nano MgO (gr)	Washed sand (Kg)	Lime stone (Kg)	Blown Sand (Kg)	Almond gravel (Kg)	Pea gravel (kg)	Super plasticizer (gr)	Water (kg)
1%Nano Mgo	27.52	278.7	53.14	11.91	43.37	27.88	18.58	417	12.39
2%Nano Mgo	27.24	558.4	53.14	11.91	43.37	27.88	18.58	556	12.39
3%Nano Mgo	26.96	834.1	53.14	11.91	43.37	27.88	18.58	598	12.39
4%Nano Mgo	26.68	1112	53.14	11.91	43.37	27.88	18.58	653.3	12.39

7. METHOD OF CONSTRUCTING SELF-COMPACTING CONCRETE WITH NANO-MGO

First, almond gravel (12-25mm), cement and MgO nanoparticles as dry mixed have been combined in a mixer for 10 minutes; since MgO nanoparticles are dangerous substance, mixer lid is covered with plastic, so that no dust can come out from the mixer. Then, pea gravel (5-12mm) is added and mixed for 2 minutes. At the next step, washed sand, blown sand and calcium carbonate powder are added and mixed for 2 minutes, and finally water and super plasticizer are gradually poured into mixer and mixed with other materials to obtain self-compacting concrete. Consequently, self-compacting concrete was constructed based on the third mix design with different percentages of 1, 2, 3 and 4 percent of MgO nanoparticles, and the same amount of MgO nanoparticles weight added to the concrete is reduced from the weight of cement. Fresh self – compacting concrete tests including slump flow, slump flow T = 50 cm, L-box, U-box and V-funnel are performed and the results (Table 8) and the related graph is also shown in Figure 10.

Table 8. Results obtained from experiments on fresh self-compacting concrete with and without MgO nanoparticles

sample	Slump flow (mm)	Slump T=50cm (s)	U Box (mm)	L Box	V Funnel (s)
SCC	710	3	10	0.98	10
SCC 1% nano mgo	700	3	15	0.97	10
SCC 2% nano mgo	680	4	20	0.97	12
SCC 3% nano mgo	675	4	20	0.96	13
SCC 4% nano mgo	650	5	30	0.96	14

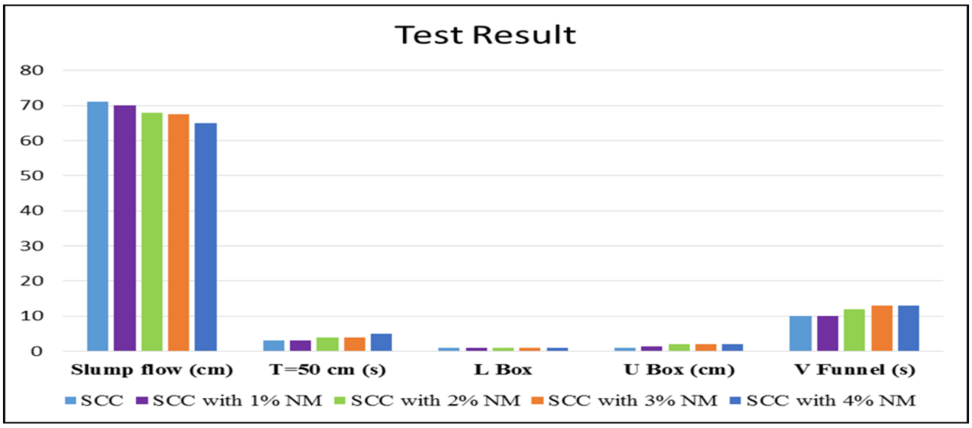

Figure 10. Comparing the results obtained from experiments on self-compacting concrete without NM and with different percentages of NM

8. SCANNING ELECTRON MICROGRAPH (SEM)

To acquire SEM images, samples were cut from the composite specimens. The diameter of specimens was approximately 5−10 millimeter. The specimens were regular, and the surface was completely polished. 1000, 2000 and 5000 x magnification of SCC with and without MgO nanoparticles polished section at a curing age of 28 days. SEM micrograph analysis was performed to examine the mechanism of mechanical properties of concrete and also to investigate the effect of MgO nanoparticles on cement matrix. The results indicated that MgO nanoparticles affect the nanostructured behavior of hardened cement paste. In the case of MgO concretes, when MgO is hydrated, the final product, which is magnesium hydroxide, has a larger volume than its constituents, which causes MgO-composites to be expansive and have a better filling effect in comparison with other nanoparticles. Because the charge density of Mg^{2+} is higher than that of Ca^{2+}, a cationic exchange between interlayer Ca^{2+} and Ca^{2+} in the calcium–silicate–hydrate, and therefore hydrated magnesium silicate formation, may occur, and this may be another reason for the variation in the mechanical process (3). By examining the results of SEM images, it is shown that by adding MgO nanoparticles to concrete up to 4% by weight of cement, microstructure of the concrete becomes denser and the number of small cracks decreases, and their length and width are reduced. This is due to the production of C-S-H modified magnesium that fills the cracks and forms the crystals mentioned. The SEM images of SCC without and with different percentages of MgO nanoparticles are shown in Figure 11).

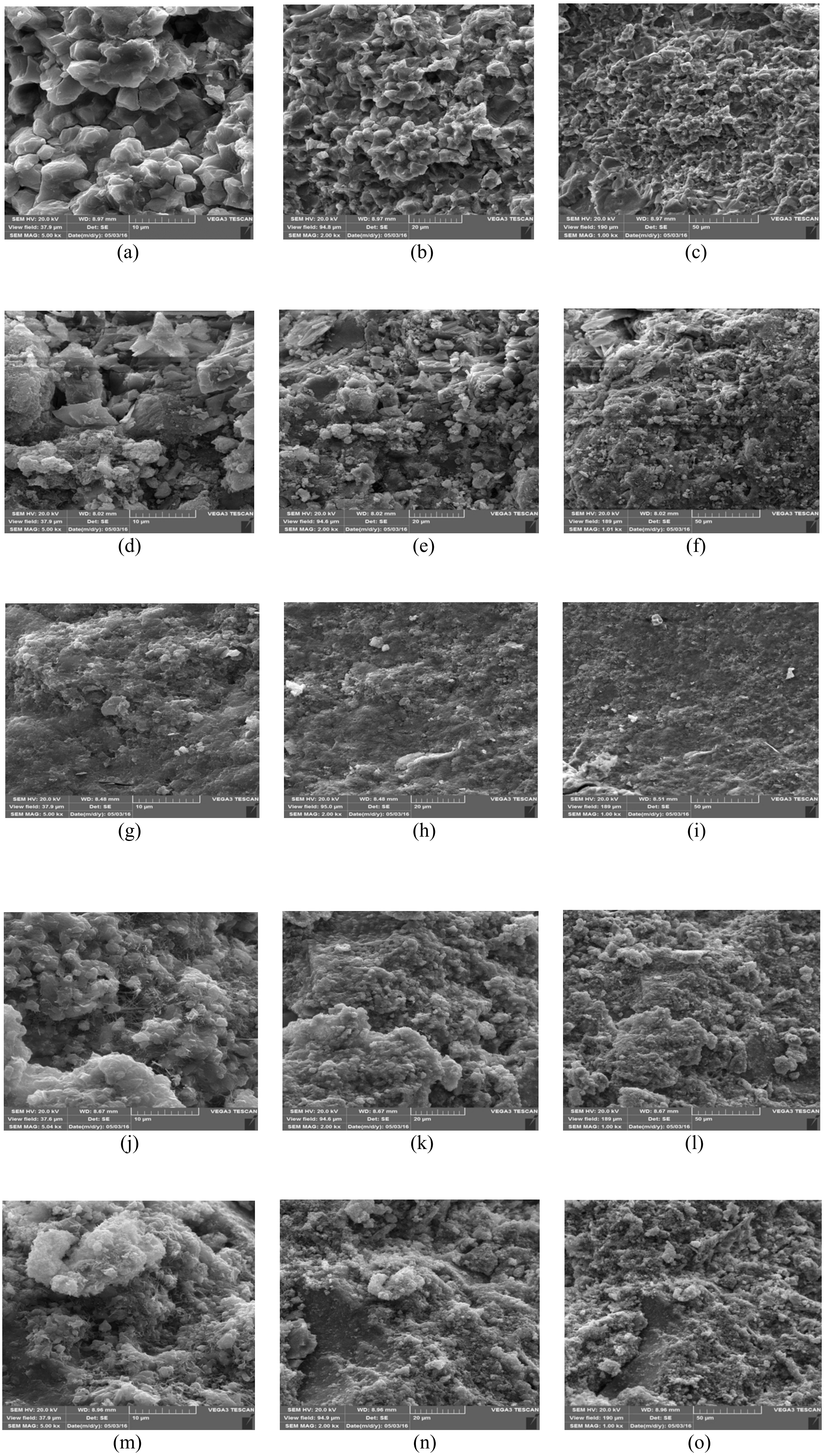

Figure 11. Self-compacting concrete samples (a), (b), (c) without MgO nanoparticles; (d), (e), (f) containing 1% MgO nanoparticles; (g), (h), (i) containing 2% MgO nanoparticles; (j), (k), (l) containing 3% MgO nanoparticles; (m), (n), (o) containing 4% MgO nanoparticles

9. MODELING AND ANALYZING THE RESULTS

When the self-compacting concrete was made as a dry mix by MgO nanoparticles, and fresh self- compacting concrete tests were conducted, then Scc is poured into 15x15x15 cm cubic, 15x30 cm cylindrical and 15x15x50 cm beam molds, and after 24-hours, the molds are opened and are kept in the water pond. At the age of 7 and 28 days, samples are taken out of the water and are broken. Compressive, tensile and flexural strength indicated in Table 9, Table 10 and Table 11, and the related graphs are also shown in Figure 12, Figure 13 and Figure 14.

Table 9. Comparing compressive strength increase in cubic samples

sample	7days (kg/cm²)	Increase the strength 7days (%)	28days (kg/cm²)	Increase the strength 28 days (%)
SCC	146.71	--------	190.47	------
SCC1% nano mgo	173.28	18 %	201.80	6 %
SCC2% nano mgo	216.60	47.60 %	253.90	33 %
SCC3% nano mgo	217.19	48 %	255.22	34 %
SCC4% nano mgo	217.19	48 %	257.87	35 %

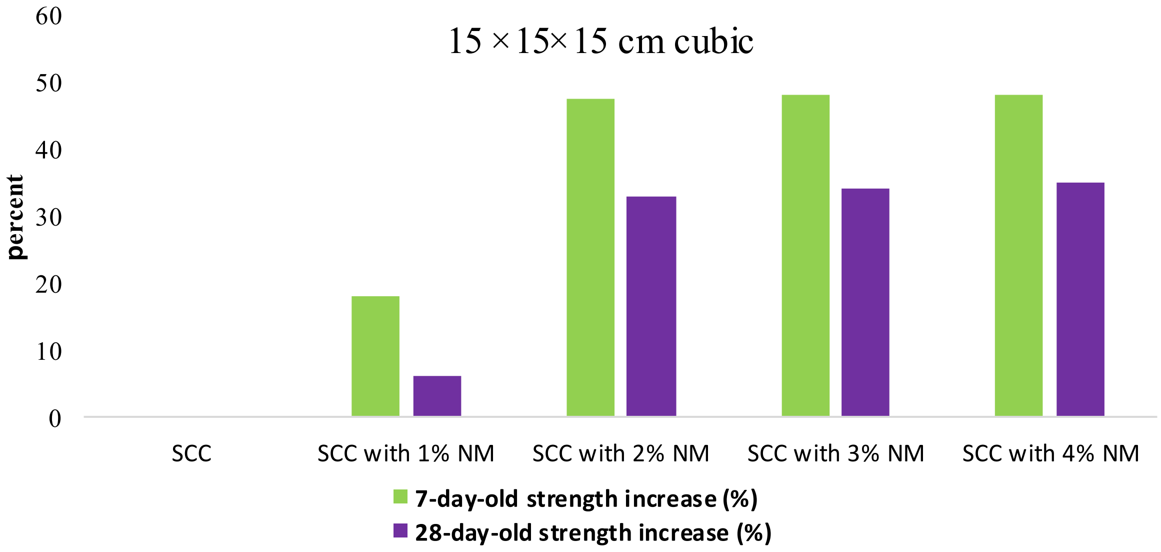

Figure 12. Comparing compressive strength increase in (7 and 28-day) cubic sample

Table 10. Comparing tensile strength increase in cylindrical samples

sample	7days (kg/cm²)	Increase the strength 7days (%)	28days (kg/cm²)	Increase the strength 28 days (%)
SCC	18.96	--------	23.10	------
SCC1% nano mgo	21	10 %	26.59	15 %
SCC2% nano mgo	24.57	29.50 %	27.76	20 %
SCC3% nano mgo	24.70	30 %	29.33	27 %
SCC4% nano mgo	24.70	30 %	29.92	29.50 %

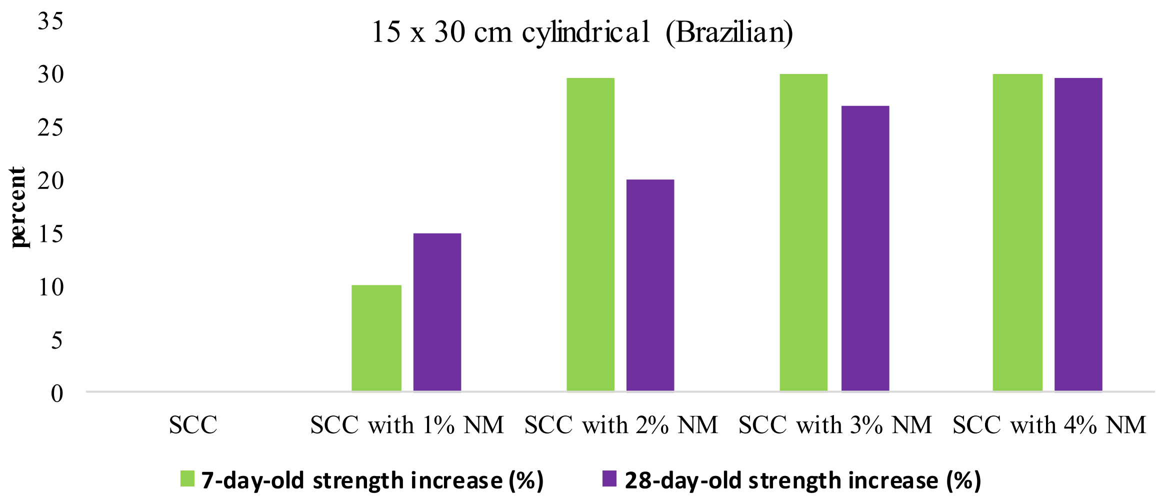

Figure 13. Comparing tensile strength increase in (7 and 28-day) cylindrical sample

Table 11. Comparing flexural strength increase

sample	*7days (kg/cm²)*	*Increase the strength 7days (%)*	*28days (kg/cm²)*	*Increase the strength 28 days (%)*
SCC	24.27	--------	30.47	------
SCC1% nano mgo	31.85	31 %	37.91	24 %
SCC2% nano mgo	38.86	60 %	48.59	59 %
SCC3% nano mgo	41.26	70 %	50.58	66 %
SCC4% nano mgo	42.96	77 %	51.56	69 %

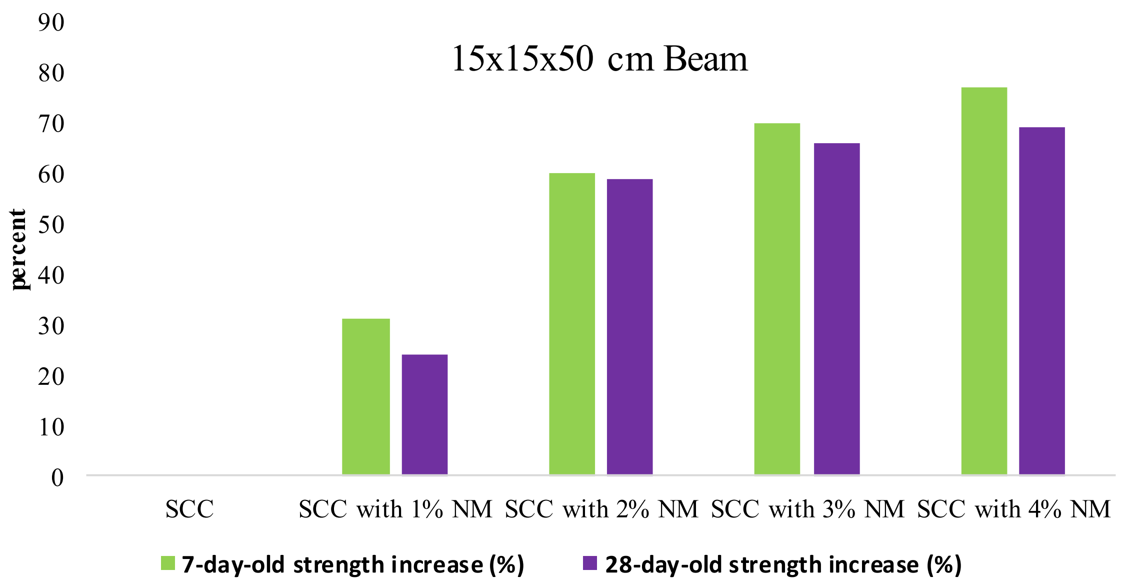

Figure 14. Comparing flexural strength increase (7 and 28-day)

10. CONCLUSION

MgO nanoparticles are very small and expandable particles that due to the high specific surface area, they can be swollen during the mixing process and consequently increase the viscosity of concrete. The viscosity of a concrete specimen with MgO nanoparticles is enhanced by an increase in the amount of MgO nanoparticles, which increases the use of super plasticizer. Adding MgO nanoparticles 1% by weight of cement to self-compacting concrete leads to increasing compressive, tensile and flexural strength respectively by 6, 15 and 24 percent at the age of 28 days. Adding these nanoparticles 2% by weight of cement to self-compacting concrete leads to increasing compressive, tensile and flexural strength respectively by

33, 20 and 59 percent at the age of 28 days. Adding MgO nanoparticles 3% by weight of cement to self-compacting concrete leads to increasing compressive, tensile and flexural strength respectively by 34, 27 and 66 percent at the age of 28 days. Adding mentioned nanoparticles 4% by weight of cement to self-compacting concrete leads to increasing compressive, tensile and flexural strength respectively by 35, 29.5 and 69 percent at the age of 28 days. Due to minor changes in compressive strength in 2 and 4 percentages, it seems that the used nanoparticles 2% can be considered as the optimal amount of use.

FUNDING/SUPPORT

Not mentioned any Funding/Support by authors.

ACKNOWLEDGMENT

The researcher expresses his gratitude and appreciation to the Managing Director of Shiraz Concrete Savannah and the Management of the Concrete and Bastarazma Laboratory.

AUTHORS CONTRIBUTION

This work was carried out in collaboration among all authors.

CONFLICT OF INTEREST

The author (s) declared no potential conflicts of interests with respect to the authorship and/or publication of this paper.

REFERENCES

1. Gao P-w, Wu S-x, Lu X-l, Deng M, Lin P-h, Wu Z-r, et al. Soundness evaluation of concrete with MgO. Construction and Building Materials. 2007;21(1):132-8.
2. Snyder KA, Lew HS. Alkali-Silica Reaction Degradation of Nuclear Power Plant Concrete Structures: A Scoping Study. NIST Interagency/Internal Report (NISTIR)-7937. 2013.
3. Moradpour R, Taheri-Nassaj E, Parhizkar T, Ghodsian M. The effects of nanoscale expansive agents on the mechanical properties of non-shrink cement-based composites: The influence of nano-MgO addition. Composites Part B: Engineering. 2013;55:193-202.
4. Mo L, Deng M, Tang M, Al-Tabbaa A. MgO expansive cement and concrete in China: Past, present and future. Cement and Concrete Research. 2014;57:1-12.
5. Yuan H, Shi Y, Xu Z, Lu C, Ni Y, Lan X. Effect of nano-MgO on thermal and mechanical properties of aluminate cement composite thermal energy storage materials. Ceramics International. 2014;40(3):4811-7.
6. Polat R, Demirboğa R, Khushefati WH. Effects of nano and micro size of CaO and MgO, nano-clay and expanded perlite aggregate on the autogenous shrinkage of mortar. Construction and Building Materials. 2015;81:268-75.
7. Ye Q, Yu K, Zhang Z. Expansion of ordinary Portland cement paste varied with nano-MgO. Construction and Building Materials. 2015;78:189-93.
8. Ding Y, Zhang G, Wu H, Hai B, Wang L, Qian Y. Nanoscale magnesium hydroxide and magnesium oxide powders: control over size, shape, and structure via hydrothermal synthesis. Chemistry of materials. 2001;13(2):435-40.
9. Chloride C, CHLORIDE A. Material safety data sheet. 2005.
10. EFNARC F. Specification and guidelines for self-compacting concrete. European 29 Federation of National Associations Representing producers and applicators of specialist 30 building products for Concrete (EFNARC). 2002;32:31.
11. Brouwers H, Radix H. Self-compacting concrete: theoretical and experimental study. Cement and Concrete Research. 2005;35(11):2116-36.