Computers and Concrete, *Vol. 22, No. 1 (2018) 117-122*
DOI: https://doi.org/10.12989/cac.2018.22.1.117

Technical and economical assessment of applying silica nanoparticles for construction of concrete structures

Sajad Shariati Rad*

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

(Received March 13, 2018, Revised May 8, 2018, Accepted May 19, 2018)

Abstract. The use of nanotechnology materials and applications in the construction industry should be considered for enhancing material properties. However, in this paper, the technical and economical assessment of applying silica nanoparticles for construction of concrete structure is studied. In order to obtain the equivalent material properties of the structure, the Mori-Tanaka model is used considering agglomeration of nanoparticles. The effect of using these nanoparticles on mechanical properties of concrete, such as the modulus of elasticity, compressive strength, as well as its indirect effect on armature percentage is investigated. Finally, the price of silica nanoparticles and its effect on the price increase of concrete structure is investigated. The results show that increasing the volume percent of silica nanoparticles up to 10% improves elastic modulus 111% and reduces amateur percentage up to 72%.

Keywords: silica nanoparticles; concrete structures; technical and economical assessment; Mori-Tanaka model

1. Introduction

Concrete can be nano-engineered by incorporating nano-sized building blocks or objects (e.g., nanoparticles and nanotubes) to control material behaviour and add novel properties, or by grafting molecules onto cement particles, cement phases, aggregates, and additives (including nano-sized additives) to provide surface functionality, which can be adjusted to promote specific interfacial interactions. The nanoparticle is the elementary building block in nanotechnology and is comprised of up to thousands of atoms combined into a cluster of 1-100 nm. A reduction in size provides an exceptional surface area-to-volume ratio and changes in the surface energy, surface chemistry, and surface morphology of the particle, altering its basic properties and reactivity (Scrivener 2009, Zhou *et al*. 2016). Computer programs in the field of civil engineering and other field is necessary for mathematical modeling of the structure (Yang and Yu 2017, Padhy and Panda 2017, Zhao *et al*. 2017, Rishikeshan and Ramesh 2017, Wen *et al*. 2017, Torres-Jimenez and Rodriguez-Cristerna 2017, Liu *et al*. 2018).

Mechanical analysis of nanostructures has been reported by many researchers (Zemri 2015, Larbi Chaht 2015, Belkorissat 2015, Ahouel 2016, Bounouara 2016, Bouafia 2017, Besseghier 2017, Bellifa 2017, Mouffoki 2017, Khetir 2017). Nanoparticles have been shown to significantly enhance the mechanical performance of a variety of materials, including metals, polymers, ceramic, and concrete composites (Jo *et al*. 2007). Nanosilica (silicon dioxide nanoparticles, nano-SiO_2), for example, has been shown to improve workability and strength in high-performance and self-compacting concrete (Sanchez and Sobolev 2010). Most research on nanotechnology in concrete has focused to date on the investigation of structure and mechanical properties of concrete at the nanoscale (Mart and Mijangos 2009). Recent advances in instrumentations have made it possible to characterize the structure of concrete at the nanoscale and to measure the local mechanical properties of its micro- and nanoscopic phases (Trtik and Bartos 2001). Significant progress in understanding nano-scale processes in cementitious materials has been achieved thanks to the use of nano-scale characterization techniques (Trtik and Bartos 2001). These advanced techniques include nuclear magnetic resonance, atomic force microscopy, micro-and nano-indentation, neutron scattering, ultrasonic force microscopy, and focus-ion beam (FIB) nanotomography. For example, the use of atomic force microscopy (AFM) has revealed that, contrary to general thought, nanoscale C-S-H has in fact a highly ordered structure. A better understanding of the structure of concrete at the nano-level will allow for a better control of concrete performance and even the tailoring of desired properties and is expected therefore to affect the method of production and use of concrete.

Another application of nanotechnology in concrete has come from the “bottom-up” possibilities of nano-chemistry with the development of new products such as novel superplasticizers and new coating materials (Babazadeh *et al*. 2016). The development of coating materials with new self-cleaning properties, discoloration resistance, anti-graffiti protection, and high scratch-and-wear resistance is promising direction. In addition to these, self-cleaning materials based on photo catalyst technology were developed (Babazadeh *et al*. 2016). Titanium dioxide (TiO_2) is used as a photo catalyst for the decomposition of organic

---

*Corresponding author, Ph.D.
E-mail: platengineer@gmail.com

http://www.techno-press.org/?journal=cac&subpage=8

ISSN: 1598-8198 (Print), 1598-818X (Online)

compounds. TiO_2 is active under exposure to UV light, exhibiting self cleaning and disinfecting properties. Another aspect of self-cleaning is provided by the hydrophilicity of the surface, which helps to prevent dust and dirt from attaching to it. In the past, major developments in concrete technology have been achieved through the use of super-fine particles such as fly ash and silica fume. Recent advances in nano-chemistry and the development of new methods for synthesis of nanoparticles are now expected to offer a new range of possibilities for improvement of concrete performance (Flores *et al.* 2010). Incorporation of nanoparticles into conventional construction materials can provide the materials with advanced or smart properties that are of specific interest for high-rise, long-span, or intelligent infrastructure systems (Flores *et al.* 2010). Nonlinear vibration of embedded nanocomposite concrete was investigated by Shokravi *et al.* (2017) based on Timoshenko beam model. A mathematical model was introduced by Bakhshandeh Amnieh and Zamzam (2017) for the concrete models reinforced by silicon dioxide (SiO_2) nanoparticles subjected to impact load for wave propagation analysis. Zamani Nouri (2016) studied stability analysis of concrete pipes mixed with nanoparticles conveying fluid.

To the best of author knowledge, no report has been found in the literature on technical and economical assessment of using silica nanoparticles for construction of concrete structure. Motivated by these considerations, in order to improve optimum design of concrete structures, we aim to present the effect of nanoparticles on the mechanical properties of concrete, such as the modulus of elasticity, compressive strength, as well as its indirect effect on amateur percentage. The agglomeration effects are considered based on Mori-Tanaka approach. In addition, the price of silica nanoparticles and its effect on the price increase of concrete is investigated.

2. Mori-Tanaka model and agglomeration effects

There are many new theories for modeling of different structures. Some of the new theories have been used by Tounsi and co-authors (Bessaim 2013, Bouderba 2013, Belabed 2014, Ait Amar Meziane 2014, Zidi 2014, Hamidi 2015, Bourada 2015, Bousahla *et al.* 2016a, b, Beldjelili 2016, Boukhari 2016, Draiche 2016, Bellifa 2015, Attia 2015, Mahi 2015, Ait Yahia 2015, Bennoun 2016, El-Haina 2017, Menasria 2017, Chikh 2017). In this section, the effective modulus of the concrete column reinforced by SiO_2 nanoparticles is developed. Different methods are available to obtain the average properties of a composite (Mori and Tanaka 1973). Due to its simplicity and accuracy even at high volume fractions of the inclusions, the Mori-Tanaka method (Mori and Tanaka 1973) is employed in this section. The matrix is assumed to be isotropic and elastic, with the Young's modulus E_m and the Poisson's ratio υ_m. The constitutive relations for a layer of the composite with the principal axes parallel to the r, θ and z directions are (Mori and Tanaka 1973)

$$\begin{Bmatrix}\sigma_{11}\\ \sigma_{22}\\ \sigma_{33}\\ \sigma_{23}\\ \sigma_{13}\\ \sigma_{12}\end{Bmatrix}=\begin{bmatrix}k+m & l & k-m & 0 & 0 & 0\\ l & n & l & 0 & 0 & 0\\ k-m & l & k+m & 0 & 0 & 0\\ 0 & 0 & 0 & p & 0 & 0\\ 0 & 0 & 0 & 0 & m & 0\\ 0 & 0 & 0 & 0 & 0 & p\end{bmatrix}\begin{Bmatrix}\varepsilon_{11}\\ \varepsilon_{22}\\ \varepsilon_{33}\\ \gamma_{23}\\ \gamma_{13}\\ \gamma_{12}\end{Bmatrix} \tag{1}$$

where σ_{ij}, ε_{ij}, γ_{ij}, k, m, n, l, p are the stress components, the strain components and the stiffness coefficients respectively. According to the Mori-Tanaka method the stiffness coefficients are given by (Mori and Tanaka 1973)

$$\begin{aligned}
k &= \frac{E_m\{E_m c_m + 2k_r(1+\nu_m)[1+c_r(1-2\nu_m)]\}}{2(1+\nu_m)[E_m(1+c_r-2\nu_m)+2c_m k_r(1-\nu_m-2\nu_m^2)]}\\
l &= \frac{E_m\{c_m\nu_m[E_m+2k_r(1+\nu_m)]+2c_r l_r(1-\nu_m^2)]\}}{(1+\nu_m)[E_m(1+c_r-2\nu_m)+2c_m k_r(1-\nu_m-2\nu_m^2)]}\\
n &= \frac{E_m^2 c_m(1+c_r-c_m\nu_m)+2c_m c_r(k_r n_r-l_r^2)(1+\nu_m)^2(1-2\nu_m)}{(1+\nu_m)[E_m(1+c_r-2\nu_m)+2c_m k_r(1-\nu_m-2\nu_m^2)]}\\
&\quad + \frac{E_m[2c_m^2 k_r(1-\nu_m)+c_r n_r(1+c_r-2\nu_m)-4c_m l_r\nu_m]}{E_m(1+c_r-2\nu_m)+2c_m k_r(1-\nu_m-2\nu_m^2)}\\
p &= \frac{E_m[E_m c_m+2p_r(1+\nu_m)(1+c_r)]}{2(1+\nu_m)[E_m(1+c_r)+2c_m p_r(1+\nu_m)]}\\
m &= \frac{E_m[E_m c_m+2m_r(1+\nu_m)(3+c_r-4\nu_m)]}{2(1+\nu_m)\{E_m[c_m+4c_r(1-\nu_m)]+2c_m m_r(3-\nu_m-4\nu_m^2)\}}
\end{aligned} \tag{2}$$

where the subscripts m and r stand for matrix and reinforcement respectively. C_m and C_r are the volume fractions of the matrix and the nanoparticles respectively and k_r, l_r, n_r, p_r, m_r are the Hills elastic modulus for the nanoparticles (Mori and Tanaka 1973). The experimental results show that the assumption of uniform dispersion for nanoparticles in the matrix is not correct and the most of nanoparticles are bent and centralized in one area of the matrix. These regions with concentrated nanoparticles are assumed to have spherical shapes, and are considered as "inclusions" with different elastic properties from the surrounding material. The total volume V_r of nanoparticles can be divided into the following two parts (Shi and Feng 2004)

$$V_r = V_r^{inclusion} + V_r^{m} \tag{3}$$

where $V_r^{inclusion}$ and V_r^{m} are the volumes of nanoparticles dispersed in the spherical inclusions and in the matrix, respectively. Introduce two parameters ξ and ζ describe the agglomeration of nanoparticles

$$\xi = \frac{V_{inclusion}}{V}, \tag{4}$$

$$\zeta = \frac{V_r^{inclusion}}{V_r}. \tag{5}$$

However, the average volume fraction c_r of nanoparticles in the composite is

$$C_r = \frac{V_r}{V}. \tag{6}$$

Assume that all the orientations of the nanoparticles are completely random. Hence, the effective bulk modulus (K) and effective shear modulus (G) may be written as

$$K = K_{out}\left[1+\frac{\xi\left(\frac{K_{in}}{K_{out}}-1\right)}{1+\alpha(1-\xi)\left(\frac{K_{in}}{K_{out}}-1\right)}\right] , \tag{7}$$

$$G = G_{out}\left[1+\frac{\xi\left(\frac{G_{in}}{G_{out}}-1\right)}{1+\beta(1-\xi)\left(\frac{G_{in}}{G_{out}}-1\right)}\right], \tag{8}$$

where

$$K_{in} = K_m + \frac{(\delta_r - 3K_m\chi_r)C_r\zeta}{3(\xi - C_r\zeta + C_r\zeta\chi_r)}, \tag{9}$$

$$K_{out} = K_m + \frac{C_r(\delta_r - 3K_m\chi_r)(1-\zeta)}{3\left[1-\xi - C_r(1-\zeta) + C_r\chi_r(1-\zeta)\right]}, \tag{10}$$

$$G_{in} = G_m + \frac{(\eta_r - 3G_m\beta_r)C_r\zeta}{2(\xi - C_r\zeta + C_r\zeta\beta_r)}, \tag{11}$$

$$G_{out} = G_m + \frac{C_r(\eta_r - 3G_m\beta_r)(1-\zeta)}{2\left[1-\xi - C_r(1-\zeta) + C_r\beta_r(1-\zeta)\right]}, \tag{12}$$

where χ_r, β_r, δ_r, η_r may be calculated as

$$\chi_r = \frac{3(K_m+G_m)+k_r-l_r}{3(k_r+G_m)}, \tag{13}$$

$$\beta_r = \frac{1}{5}\left\{\frac{4G_m+2k_r+l_r}{3(k_r+G_m)} + \frac{4G_m}{(p_r+G_m)} + \frac{2\left[G_m(3K_m+G_m)+G_m(3K_m+7G_m)\right]}{G_m(3K_m+G_m)+m_r(3K_m+7G_m)}\right\}, \tag{14}$$

$$\delta_r = \frac{1}{3}\left[n_r + 2l_r + \frac{(2k_r-l_r)(3K_m+2G_m-l_r)}{k_r+G_m}\right], \tag{15}$$

$$\eta_r = \frac{1}{5}\left[\frac{2}{3}(n_r-l_r) + \frac{4G_m p_r}{(p_r+G_m)} + \frac{8G_m m_r(3K_m+4G_m)}{3K_m(m_r+G_m)+G_m(7m_r+G_m)} + \frac{2(k_r-l_r)(2G_m+l_r)}{3(k_r+G_m)}\right]. \tag{16}$$

where, K_m and G_m are the bulk and shear moduli of the matrix which can be written as

$$K_m = \frac{E_m}{3(1-2\upsilon_m)} , \tag{17}$$

$$G_m = \frac{E_m}{2(1+\upsilon_m)}. \tag{18}$$

Furthermore, β, α can be obtained from

$$\alpha = \frac{(1+\upsilon_{out})}{3(1-\upsilon_{out})} , \tag{19}$$

$$\beta = \frac{2(4-5\upsilon_{out})}{15(1-\upsilon_{out})}, \tag{20}$$

$$\upsilon_{out} = \frac{3K_{out}-2G_{out}}{6K_{out}+2G_{out}}. \tag{21}$$

Finally, the elastic modulus (E) and poison's ratio (υ) can be calculated as

$$E = \frac{9KG}{3K+G} , \tag{22}$$

$$\upsilon = \frac{3K-2G}{6K+2G}. \tag{23}$$

3. Numerical results

Based on ACI, the elastic modulus of the concrete without nanoparticles can be calculated by

$$E_c = 4700\sqrt{f_c^{'}} = 4700\sqrt{21} = 21.5\,GPa \tag{24}$$

Based on Mori-Tanaka model, the elastic modulus of the concrete with respect to the volume percent of silica nanoparticles is shown in Fig. 1 for two cases of with and without agglomeration of nanoparticles. As can be seen, with increasing the volume percent of silica nanoparticles, the elastic modulus is increased significantly. In other words, reinforcing the concrete with 10% silica nanoparticles leads to 111% increase in the elastic modulus. This is due to this fact that with increasing the volume percent of silica nanoparticles, the stiffness of the structure improves. In addition, agglomeration of nanoparticles leads to reduction in the elastic modulus up to 20%. However, in

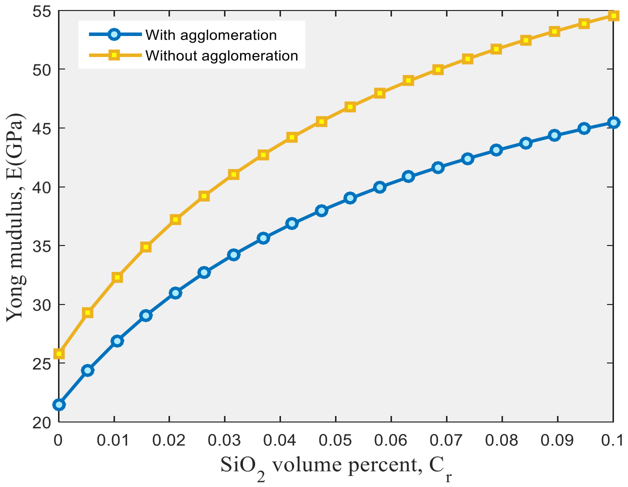

Fig. 1 The effect of silica nanoparticles on the elastic modulus of the concrete

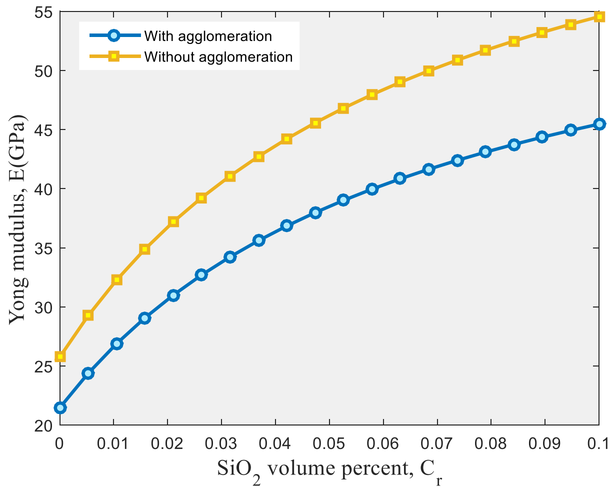

Fig. 2 The effect of silica nanoparticles on the compressive strength of the concrete

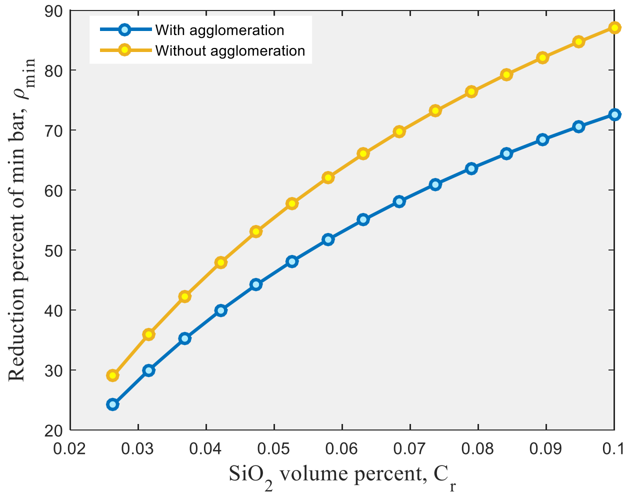

Fig. 3 The effect of silica nanoparticles on the compressive strength of the concrete

the process of construction, the disperse of nanoparticles in the water is very important to reduce the effect to agglomeration of nanoparticles.

The effect of silica nanoparticle volume percent and agglomeration on the compressive strength of the concrete is presented in Fig. 2. It is obvious that with increasing the volume percent of silica nanoparticle, the compressive strength of the concrete raises due to increases in the stiffness of the structure. For example, the compressive strength of the concrete without nanoparticle is 20.6 MPa while it is 92.39 MPa for the concrete reinforced by 10% silica nanoparticles. In other words, reinforcing the concrete with 10% silica nanoparticles leads to increase in the compressive strength of the concrete about 3.5 times. Furthermore, agglomeration of the nanoparticles decreases the compressive strength of the concrete.

Fig. 3 presented the effect of silica nanoparticle volume percent and agglomeration on the armature percentage in the concrete. It can be found that with increasing the silica nanoparticle volume percent, the armature percentage will be decreased. For example, with reinforcing the concrete with 10% silica nanoparticles, the armature percentage is decreases about 72%. In addition, the agglomeration of nanoparticle increases the armature percentage.

Table 1 Price analysis of using silica nanoparticle in the concrete

Concrete with 42 GPa	Cement price	Silica nanoparticle price	Total price
Sample 1	(503/1000)×25 =12.57$	0	12.57$
Sample 2	(265/1000)×25 =6.625$	(48/1000)×150 =7.2$	13.825$

In order to price analysis of using silica nanoparticle, we use from the source of “Alibaba” site. The price of 1 ton silica nanoparticle is 150$ and the price of cement for 1 ton is 25$. In order to obtain the compressive strength of 42 GPa as shown in Table 1, 503 Kg cement without nanoparticles or 265 Kg cement and 48 Kg silica nanoparticle can be used. Two samples of without nanoparticles (sample 1) and with nanoparticles (sample 2) are considered. As can be seen, in 1 ton concrete, the price will be increases about 1$ while reinforcing the concrete with silica nanoparticle increases the compressive strength about 3.5 times and reduce the armature percentage up to 72%.

4. Conclusions

The technical and economical assessment of applying silica nanoparticles for construction of concrete structure was studied in this paper based on Mori-Tanaka model. The effect of using these nanoparticles on the modulus of elasticity, compressive strength and armature percentage was investigated. In addition, the price analysis of the applying silica nanoparticles was done. The most findings of this paper were:

- ♦ Reinforcing the concrete with 10% silica nanoparticles leads to 111% increase in the elastic modulus.
- ♦ Agglomeration of nanoparticles leads to reduction in the elastic modulus up to 20%.
- ♦ With increasing the volume percent of silica nanoparticle, the compressive strength of the concrete raises due to increases in the stiffness of the structure.
- ♦ Reinforcing the concrete with 10% silica nanoparticles leads to increase in the compressive strength of the concrete about 3.5 times.
- ♦ With increasing the silica nanoparticle volume percent, the armature percentage will be decreased. For example, with reinforcing the concrete with 10% silica nanoparticles, the armature percentage is decreases about 72%.

References

Ahouel, M., Houari, M.S.A., Adda Bedia, E.A. and Tounsi, A. (2016), “Size-dependent mechanical behavior of functionally graded trigonometric shear deformable nanobeams including neutral surface position concept”, *Steel Compos. Struct.*, **20**(5), 963-981.

Attia, A., Tounsi, A., Adda Bedia, E.A. and Mahmoud, S.R. (2015), “Free vibration analysis of functionally graded plates with temperature-dependent properties using various four variable refined plate theories”, *Steel Compos. Struct*., **18**(1), 187-212.

Babazadeh, A., Burgueño, R. and Silva, P.F. (2016), “Evaluation of the critical plastic region length in slender reinforced concrete bridge columns“, *Eng. Struct.*, **125**, 280-293.

Bakhshandeh Amnieh, H. and Zamzam, M.S. (2017), “Theoretical and experimental analysis of wave propagation in concrete blocks subjected to impact load considering the effect of nanoparticles”, *Comput. Concrete*, **20**, 711-718.

Belabed, Z., Houari, M.S.A., Tounsi, A., Mahmoud, S.R. and Bég, O.A. (2014), “An efficient and simple higher order shear and normal deformation theory for functionally graded material (FGM) plates”, *Compos.: Part B*, **60**, 274-283.

Beldjelili, Y., Tounsi, A. and Mahmoud, S.R. (2016), “Hygro-thermo-mechanical bending of S-FGM plates resting on variable elastic foundations using a four-variable trigonometric plate theory”, *Smart Struct. Syst.*, **18**(4), 755-786.

Belkorissat, I., Houari, M.S.A., Tounsi, A. and Hassan, S. (2015), “On vibration properties of functionally graded nano-plate using a new nonlocal refined four variable model”, *Steel Compos. Struct*., **18**(4), 1063-1081.

Bellifa, H., Benrahou, K.H., Bousahla, A.A., Tounsi, A. and Mahmoud, S.R. (2017), “A nonlocal zeroth-order shear deformation theory for nonlinear postbuckling of nanobeams”, *Struct. Eng. Mech*., **62**(6), 695 - 702.

Bellifa, H., Benrahou, K.H., Hadji, L., Houari, M.S.A. and Tounsi, A. (2016), “Bending and free vibration analysis of functionally graded plates using a simple shear deformation theory and the concept the neutral surface position”, *J. Brazil. Soc. Mech. Sci. Eng*., **38**(1), 265-275.

Bennoun, M., Houari, M.S.A. and Tounsi, A. (2016), “A novel five variable refined plate theory for vibration analysis of functionally graded sandwich plates”, *Mech. Advan. Mater. Struct.*, **23**(4), 423 - 431.

Bessaim, A., Houari, M.S.A. and Tounsi, A. (2013), “A new higher-order shear and normal deformation theory for the static and free vibration analysis of sandwich plates with functionally graded isotropic face sheets”, *J. Sandw. Struct. Mater.*, **15**(6), 671-703.

Besseghier, A., Houari, M.S.A., Tounsi, A. and Hassan, S. (2017), “Free vibration analysis of embedded nanosize FG plates using a new nonlocal trigonometric shear deformation theory”, *Smart Struct. Syst.*, **19**(6), 601 - 614.

Bouafia, Kh., Kaci, A., Houari M.S.A. and Tounsi, A. (2017), “A nonlocal quasi-3D theory for bending and free flexural vibration behaviors of functionally graded nanobeams”, *Smart Struct. Syst.*, **19**, 115-126.

Bouderba, B., Houari, M.S.A. and Tounsi, A. (2013), “Thermomechanical bending response of FGM thick plates resting on Winkler-Pasternak elastic foundations”, *Steel Compos. Struct*., **14**(1), 85-104.

Bouderba, B., Houari, M.S.A., Tounsi, A. and Mahmoud, S.R. (2016b), “Thermal stability of functionally graded sandwich plates using a simple shear deformation theory”, *Struct. Eng. Mech*., **58**(3), 397-422.

Boukhari, A., Atmane, H.A., Tounsi, A., Adda Bedia, E.A. and Mahmoud, S.R. (2016), “An efficient shear deformation theory for wave propagation of functionally graded material plates”, *Struct. Eng. Mech.*, **57**(5), 837-859.

Bounouara, F., Benrahou, K.H., Belkorissat, I. and Tounsi A. (2016), “A nonlocal zeroth-order shear deformation theory for free vibration of functionally graded nanoscale plates resting on elastic foundation”, *Steel Compos. Struct*., **20**(2), 227-249.

Bourada, M., Kaci, A., Houari, M.S.A. and Tounsi, A. (2015), “A new simple shear and normal deformations theory for functionally graded beams”, *Steel Compos. Struct*., **18**(2), 409-423.

Bousahla, A.A., Benyoucef, S., Tounsi, A. and Mahmoud, S.R. (2016a), “On thermal stability of plates with functionally graded coefficient of thermal expansion”, *Struct. Eng. Mech*., **60**(2), 313-335.

Chikh, A., Tounsi, A., Hebali, H. and Mahmoud, S.R. (2017), “Thermal buckling analysis of cross-ply laminated plates using a simplified HSDT”, *Smart Struct. Syst*., **19**(3), 289-297.

Draiche, K., Tounsi, A. and Mahmoud, S.R. (2016), “A refined theory with stretching effect for the flexure analysis of laminated composite plates”, *Geomech. Eng.*, **11**, 671-690.

El-Haina, F., Bakora, A., Bousahla, A.A. and Hassan, S. (2017), “A simple analytical approach for thermal buckling of thick functionally graded sandwich plates”, *Struct. Eng. Mech.*, **63**(5), 585-595.

Flores, I., Sobolev, K., Torres, L.M., Valdez, P.L., Zarazua, E. and Cuellar, E.L. (2010), “Performance of cement systems with Nano-SiO_2 particles produced using Sol-gel method”, *TRB First International Conference in North America on Nanotechnology in Cement and Concrete*, Irvine, California, USA, May.

Jo, B.W., Kim, C.H. and Lim, J.H. (2007), “Investigations on the development of powder concrete with nano-SiO_2 particles”, *KSCE J. Civil Eng.*, **11**, 37-42.

Khetir, H., Bouiadjra, M.B., Houari, M.S.A., Tounsi, A. and Mahmoud, S.R. (2017), “A new nonlocal trigonometric shear deformation theory for thermal buckling analysis of embedded nanosize FG plates”, *Struct. Eng. Mech.*, **64**(4), 391-402.

Larbi Chaht, F., Kaci, A., Houari M.S.A. and Hassan, S. (2015), “Bending and buckling analyses of functionally graded material (FGM) size-dependent nanoscale beams including the thickness stretching effect”, *Steel Compos. Struct.*, **18**(2), 425 -442.

Liu, H., Ma, J. and Huang, W. (2018), “Sensor-based complete coverage path planning in dynamic environment for cleaning robot”, *CAAI Tran. Intell. Technol*., **3**, 65-72.

Mahi, A., Bedia, E.A.A. and Tounsi, A. (2015), “A new hyperbolic shear deformation theory for bending and free vibration analysis of isotropic, functionally graded, sandwich and laminated composite plates”, *Appl. Math. Model.*, **39**, 2489-2508.

Mart, J. and Mijangos, C. (2009), “Tailored polymer-based nanofibers and nanotubes by means of different infiltration methods into alumina nanopores”, *Langmuir*, **25**, 1181-1187.

Mehri, M., Asadi, H. and Wang, Q. (2016), “Buckling and vibration analysis of a pressurized CNT reinforced functionally graded truncated conical shell under an axial compression using HDQ method”, *Comput. Meth. Appl. Mech. Eng.*, **303**, 75-100.

Menasria, A., Bouhadra, A., Tounsi, A. and Hassan, S. (2017), “A new and simple HSDT for thermal stability analysis of FG sandwich plates”, *Steel Compos. Struct.*, **25**(2), 157-175.

Meziane, M.A.A., Abdelaziz, H.H. and Tounsi, A.T. (2014), “An efficient and simple refined theory for buckling and free vibration of exponentially graded sandwich plates under various boundary conditions”, *J. Sandw. Struct. Mater.*, **16**(3), 293-318.

Mori, T. and Tanaka, K. (1973), “Average stress in matrix and average elastic energy of materials with misfitting inclusions”, *Acta Metall. Mat.*, **21**, 571-574.

Mouffoki, A., Adda Bedia, E.A., Houari M.S.A. and Hassan, S. (2017), “Vibration analysis of nonlocal advanced nanobeams in hygro-thermal environment using a new two-unknown trigonometric shear deformation beam theory”, *Smart Struct. Syst*., **20**(3), 369 - 383.

Padhy, S. and Panda, S. (2017), “A hybrid stochastic fractal search and pattern search technique based cascade PI-PD controller for automatic generation control of multi-source power systems in presence of plug in electric vehicles”, *CAAI Trans. Intell.*

Technol., **2**, 12-25 .

Rishikeshan, C.A. and Ramesh, H. (2017), "A novel mathematical morphology based algorithm for shoreline extraction from satellite images", *Geo-spatial Inform. Sci*., **20**, 345-352.

Sanchez, F. and Sobolev, K. (2010), "Nanotechnology in concrete -A review", *Constr. Build. Mater*., **24**, 2060-2071.

Scrivener, K.L. (2009), "Nanotechnology and cementitious materials", *Proceed NICOM3, the 3rd International Symposium Nanotech. Const*., Prague, Czech Republic.

Shi, D.L. and Feng, X.Q. (2004), "The effect of nanotube waviness and agglomeration on the elastic property of carbon nanotube-reinforced composties", *J. Eng. Mater. Tech*., **126**, 250-270.

Shokravi, M. (2017), "Vibration analysis of silica nanoparticles-reinforced concrete beams considering agglomeration effects", *Comput. Concrete*, **19**, 333-338.

Torres-Jimenez, J. and Rodriguez-Cristerna, A. (2017), "Metaheuristic post-optimization of the NIST repository of covering arrays", *CAAI Trans. Intell. Technol*., **2**, 31-38 .

Trtik, P. and Bartos, P.J.M. (2001), "Nanotechnology and concrete: what can we utilise from the upcoming technologies?", *Proceedings of thed 2nd Annamaria Workshop: Cement Concrete : Trends & Challenges*.

Wen, Q., He, J., Guan, Sh., Chen, T., Hu, Y., Wu, W., Liu, F. and Qiao, Y. (2017), "The TripleSat constellation: a new geospatial data service model", *Geo-spatial Inform. Sci*., **20**, 163-173.

Yang, H. and Yu, L. (2017), "Feature extraction of wood-hole defects using wavelet-based ultrasonic testing", *J. Forest. Res*., **28**, 395-402.

Zamani Nouri, A. (2018), "The effect of Fe_2O_3 nanoparticles instead cement on the stability of fluid-conveying concrete pipes based on exact solution", *Comput. Concrete*, **21**, 31-37.

Zemri, A., Houari, M.S.A., Bousahla, A.A. and Tounsi A. (2015), "A mechanical response of functionally graded nanoscale beam: an assessment of a refined nonlocal shear deformation theory beam theory", *Struct. Eng. Mech*., **54**(4), 693-710.

Zhao, B., Gao, L., Liao, W. and Zhang, B. (2017), "A new kernel method for hyperspectral image feature extraction", *Geo-spatial Inform. Sci*., **20**, 309-318.

Zhou, X., Liu, J., Wang, X. and Frank Chen, Y. (2016), "Behavior and design of slender circular tubed-reinforced-concrete columns subjected to eccentric compression", *Eng. Struct.*, **124**, 1 17-28.

Zidi, M., Tounsi, A. and Bég, O.A. (2014), "Bending analysis of FGM plates under hygro-thermo-mechanical loading using a four variable refined plate theory", *Aerosp. Sci. Tech*., **34**, 24-34.

CC