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Mixture rule for studding the environmental pollution reduction in concrete structures containing nanoparticles

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Abstract. Nanotechnology is an upcoming technology that can provide solution for combating pollution by controlling shape and size of materials at the nanoscale. This review provides comprehensive information regarding the role of nanotechnology in pollution control at concrete structures. Titanium dioxide (TiO2) nanoparticles are a good item for concrete structures for diminishing the air polluting affect by gasses of exhaust. In this article, the mixture rule is presented for the effect of nanoparticles in environmental pollution reduction in concrete structures. The compressive strength, elastic modulus and reduction of steel bars in the concrete structures are studied. The Results show that TiO2 nanoparticles have significant effect on the reduction of environmental pollution and increase of stiffness in the concrete structures. In addition, the nanoparticles can reduce the use of steel bars in the concrete structure.

Keywords: environmental pollution reduction; nanoparticles; concrete structures; mixture rule; steel bar

1. Introduction

The mix of concrete and nanoparticles produces a nanocomposite. In nanocomposite, common base nanoparticles include metals, oxides, carbides, or carbon nanotubes. The main advantage of nanocomposite is high strength (Lata and Kaur 2019, Senthil *et al*. 2019).

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, Zemri 2015, Larbi Chaht 2015, Belkorissat 2015, Ahouel 2016, Bounouara 2016, Bouafia 2017, Besseghier 2017, Bellifa 2017, Mouffoki 2017, Khetir 2017).

Ryu *et al*. (2004) studied vibration and dynamic stability of cantilevered pipes conveying fluid on elastic foundations. Amabili (2008) studied vibration and stability of cylindrical shell conveying fluid using different theories. The instability of simply supported pipes conveying fluid under thermal loads was studied by Qian *et al*. (2009). A relatively new semi-analytical method, called differential transformation method (DTM), was generalized by Ni *et al*. (2011) to analyze the free

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vibration problem of pipes conveying fluid with several typical boundary conditions. Instability of supported pipes conveying fluid subjected to distributed follower forces was investigated by Wang (2012) based on the Pflüger column model. Marzani *et al*. (2012) investigated the effect of a non-uniform Winkler-type elastic foundation on the stability of pipes conveying fluid fixed at the upstream end only. The dynamics of fluid-conveying cantilevered pipe consisting of two segments made of different materials was studied by Dai and Ni (2013), focusing on the effects induced by different length ratios between the two segments. An analytical study of the velocity profile effects for a straight pipe was presented by Kutin and Bajsić (2014). A numerical simultaneous solution involving a linear elastic model was applied by Sun and Gu (2014) to study the fluid-structure interaction (FSI) of membrane structures under wind actions. Based on Euler- Bernoulli beam theory, Dai *et al.* (2014) studied instability of tubes conveying fluid. The unsteady fluid-structure interaction (FSI) problems with large structural displacement were solved by He (2015) using partitioned solution approaches in the arbitrary Lagrangian-Eulerian finite element framework. Rivero-Rodriguez and Pérez-Saborid (2015) carried out a numerical investigation of the three dimensional nonlinear dynamics of a cantilevered pipe conveying fluid in the presence of gravity. Texier and Dorbolo (2015) described the deformation of an elastic pipe submitted to gravity and to an internal fluid flow. Maalawi *et al*. (2016) enhanced the pipe overall stability level and avoid the occurrence of flow. Ghaitani and Majidian (2017) addressed vibration and instability of embedded functionally graded (FG)-carbon nanotubes (CNTs)-reinforced pipes conveying viscous fluid. Structural model for a slender and uniform pipe conveying fluid, with axially moving supports on both ends, immersed in an incompressible fluid, was formulated by Ni *et al*. (2017). A hybrid method which combines reverberation-ray matrix method and wave propagation method was developed by Deng *et al*. (2017) to investigate the stability of multi-span viscoelastic functionally graded material (FGM) pipes conveying fluid.

To the best of author knowledge, no work has been presented on reduction of environmental pollution in concrete structures using nanoparticles based on mixture rule. However, we presented the effect of nanoparticles on the mechanical properties and reduction of environmental pollution in concrete structures utilizing mixture rule.

2. Mixture rule

According to this theory, the effective Young and shear moduli of structure may be expressed as

$$E_{11} = \eta_1 V_{TiO2} E_{r11} + (1 - V_{TiO2}) E_m , \tag{1}$$

$$\frac{\eta_2}{E_{22}} = \frac{V_{TiO2}}{E_{r22}} + \frac{(1 - V_{TiO2})}{E_m} , \tag{2}$$

$$\frac{\eta_3}{G_{12}} = \frac{V_{TiO2}}{G_{r12}} + \frac{(1 - V_{TiO2})}{G_m} , \tag{3}$$

where E_{r11}, E_{r22} and E_m are Young's moduli of TiO_2 and matrix, respectively; G_{r11} and G_m are shear modulus of TiO_2 and matrix, respectively; V_{TiO_2} and V_m show the volume fractions of the TiO_2 and matrix, respectively; η_j (j=1, 2, 3) is TiO_2 efficiency parameter for considering the size-dependent material properties. Noted that this parameter may be calculated using molecular dynamic (MD). Furthermore, the density (ρ) of the nano-composite structure can be written as

$$\rho = V_{TiO2}\rho_r + V_{m,}\rho_{m,}, \tag{4}$$

where

$$V^*_{TiO2} = \frac{w_{TiO2}}{w_{TiO2} + (\rho_{TiO2} / \rho_m) - (\rho_{TiO2} / \rho_m) w_{TiO2}}, \tag{5}$$

where $w_{\mathrm{TiO_2}}$ is the mass fraction of the TiO_2; ρ_m and $\rho_{\mathrm{TiO_2}}$ present the densities of the matrix and TiO_2, respectively.

3. Numerical results

Based on Mixture model, the elastic modulus of the concrete with respect to the volume percent of TiO_2 nanoparticles is shown in Fig. 1. As can be seen, with enhancing the volume percent of TiO_2 nanoparticles, the elastic modulus is increased significantly. In other words, reinforcing the concrete with 10% TiO_2 nanoparticles leads to 45% increase in the elastic modulus. This is due to this fact that with enhancing the volume percent of TiO_2 nanoparticles, the stiffness of the structure improves.

The effect of TiO_2 nanoparticle volume percent on the compressive strength of the concrete is presented in Fig. 2. It is obvious that with increasing the volume percent of TiO_2 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 72.39 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 times.

Fig. 3 presented the effect of TiO_2 nanoparticle volume percent on the armature percentage in the concrete. It can be found that with increasing the TiO_2 nanoparticle volume percent, the armature

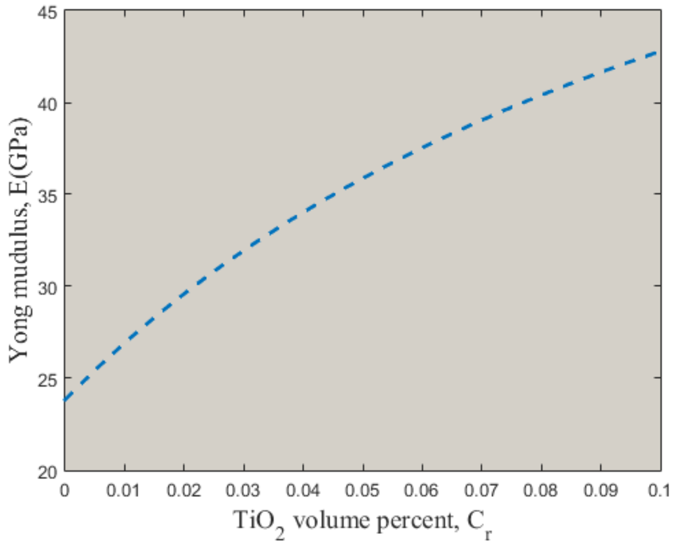

Fig. 1 The effect of TiO_2 nanoparticles on the elastic modulus of the concrete

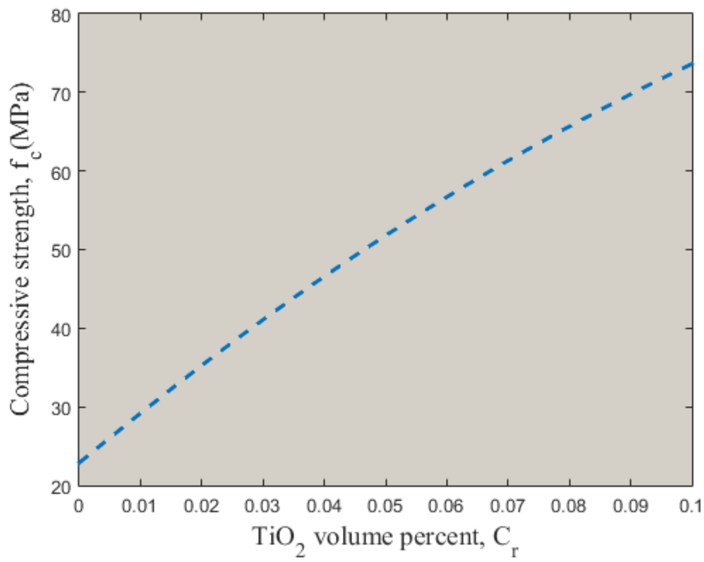

Fig. 2 The effect of TiO_2 nanoparticles on the compressive strength of the concrete

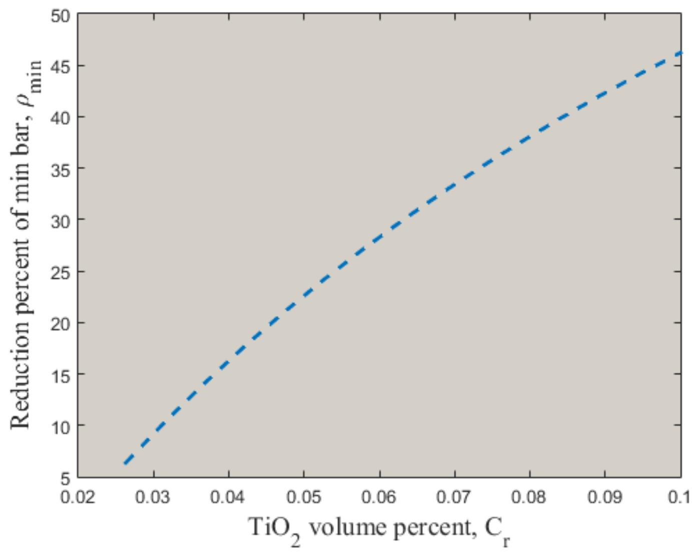

Fig. 3 The effect of TiO_2 nanoparticles on the compressive strength of the concrete

percentage will be decreased. For example, with reinforcing the concrete with 10% silica nanoparticles, the armature percentage is decreases about 52%.

6. Conclusions

The reduction of environmental pollution by applying TiO_2 nanoparticles for construction of concrete structure was studied in this paper based on mixture rule. The analytical method was presented by mixture rule where the effect of nanoparticles was studied on the elastic modulus, compressive strength and reduction of steel bar. The results show that reinforcing the concrete with 10% TiO_2 nanoparticles leads to 45% increase in the elastic modulus. Reinforcing the concrete with 10% silica nanoparticles leads to increase in the compressive strength of the concrete about 3 times. In addition, with reinforcing the concrete with 10% silica nanoparticles, the armature percentage was decreases about 52%.

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