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# Modification of microstructure and mechanical properties of cement by nanoparticles through a sustainable development approach

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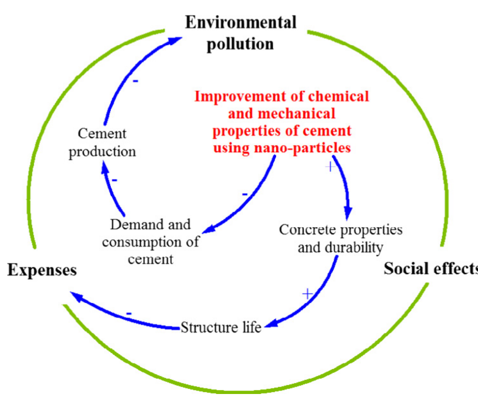
## HIGHLIGHTS

- Adding 1% of nano-MT particles can lead to improvement of cement microstructure.
- Nano-MT particles can strengthen the transition region.
- Adding nano-MT particles (NMTP) can lead to a denser matrix.
- Introduction of NMTP to 1.5% improved the chemical structure of cement matrix.
- NMTP could strengthen $K_{\alpha}$ transition of element in the NMTP + cement.

## GRAPHICAL ABSTRACT

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## ABSTRACT

Nowadays, sustainable development policies seek solutions to reduce environmental pollution. In this regard, the combined effects of different percentages of nano-Montmorillonite and nano-Titanium (nano-MT) particles on the improvement of mechanical and microstructural properties of hardened cement considering managerial and environmental aspects of reducing cement consumption are evaluated in this study. The replacement ratios of Portland cement with the same weight of nano-MT particles are 1, 2 and 3 weight percent (wt%). The mechanical properties of cement mortar and microstructural properties of hardened cement paste were investigated using Fourier Transform Infrared Spectroscopy (FTIR), X-ray Diffraction (XRD), Field Emission Scanning Electron Microscopy (FE-SEM) and Energy-dispersive X-ray spectroscopy (EDS) techniques. The results show that replacement of cement with nano-MT particles up to 1 wt% as an optimum percentage can improve microstructure and mechanical properties of cement significantly. Moreover, using nano-particles is one of the efficient approaches to reach sustainable development in construction industry that can contribute to decrease the pollution caused by cement production and consumption.



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## 1. Introduction

Production and consumption of cement especially in developing countries as well as construction projects have increased considerably in recent decades. Although cement is very important for economic development, the environmental problems caused by its production such as: emission of carbon dioxide ($CO_2$), nitrogen oxides ($NO_x$), sulfur dioxide ($SO_2$) and suspended particles in air have concerned many researchers so that pollution caused by cement production has become one of the most important environmental problems in recent decades.

Crystallites at nano-scale have unique and special properties so that they can perform differently in comparison with crystallites with larger sizes. For this reason, in recent decades, nanotechnology has caused fundamental changes in different sciences approximately [1–4]. In this regard, some researchers have attempted to improve the properties of construction materials using nanotechnology. The effects of different nano-particles on the improvement of cement [1,5,6] and concrete [3,7,8] properties have been studied. However, it seems more investigations should be performed. Although various investigations on concrete [9–14] and cement especially about the microstructure and nanostructure [15,16], hydration [17], hydrated products [18–21], mechanical and chemical properties were carried out in past decades, nanotechnology has emerged as a new research field in recent years.

The performed studies [22] on ordinary Portland cement shows that adding nano-montmorillonite particles about 0.6 wt% of cement can increase compressive strength of sample up to 13.24% at the age of 56 days in comparison with the reference sample. Moreover, microstructure of cement paste with nano-montmorillonite contain more dense solid material and more stable bonding framework.

In some researches, self-cleaning and photo-catalytic properties of titanium dioxide in construction materials [23], especially in cementitious ones [24–26] and concrete [27] have been studied. During some years ago, studies [28,29] have been conducted on the effects of nano-titanium particles as an additive on the mechanical and chemical properties of cement and concrete. The performed investigations [30] on Portland cement Type I containing 1, 3 and 5 wt% of 25 nm – size nano-titanium particles as an additive showed that compressive strength of cement mortar increased 20% and its workability decreased 20.8% at the age of 28 days in comparison with the reference sample. In addition, nano-titanium particles increased hydration speed. In another work [31], it was reported that adding nano-titanium particles about 0.1, 0.5, 1 and 1.5 wt% of cement to cement paste can increase flexural strength of sample. The maximum flexural strength increase rate occurred for sample with 1% of nano-titanium particles. Furthermore, nano- titanium particles decreased nano-roughness at sample surface and internal microcracks of cement paste. Limited studies [32] were carried out on cement mortars in which some amount of cement was replaced with nano-titanium particles. It was found [32] that replacement of 5 and 10 wt% of cement with anatase and rutile nano-titanium particles can lead to an increase in compressive and flexural strengths of cement mortar at early ages in comparison with the reference sample. However, workability of cement mortar decreased with increasing nano-titanium particles.

In this study, in order to improve mechanical, chemical and nano-structural properties of samples as well as considering environmental aspects and reducing cement consumption, it was attempted to replace 1, 2 and 3 wt% of cement with nano-Montmorillonite and nano-Titanium (nano-MT) particles in cement mortar. Then, mechanical properties of samples were evaluated using ASTM standards and with analyzing figures and spectra obtained from X- ray Diffraction (XRD), Field Emission Scanning Electron Microscopy (FE-SEM), Energy-dispersive X-ray spectroscopy (EDS) and Fourier Transform Infrared Spectroscopy (FTIR) techniques, the effects of nano-particles on cement and their role in sustainable development of concrete industry and construction were investigated.

## 2. Experimental program and sample preparation

In this section, materials, mix proportions and sample preparation, and test methods are explained respectively.

### *2.1. Materials*

In this work, nano-montmorillonite particles with the chemical compositions of Table 1 and physical and mechanical properties of Table 2 were used. In addition, anatase nano- titanium oxide particles with the physical and mechanical properties of Table 2 were applied. Besides, Portland cement Type II from Peyvand Golestan Cement Company, Iran complying with ASTM C150 standard [33] was used in this investigation. Chemical, and physical and mechanical properties of cement are presented in Tables 1 and 3 respectively. In addition, natural siliceous sand according to ASTM C778 standard [34] was used for making cement mortar.

### *2.2. Mix proportions and sample preparation*

In this research, a total of four series of mix designs including one control sample (CS) as a sample without nano-MT particles and other samples containing nano-MT particles about 1, 2 and 3 wt% of Portland cement were used. The mix designs of cement mortar samples were performed according to ASTM C109 standard [35] with the water to binder (cement + nano-MT (50% nano-montmorillonite + 50% nano-titanium)) ratio (W/B) and the sand/binder (S/B) ratio of 0.485 and 2.75, respectively. The proportions of the mixtures are presented in Table 4.

In order to better distribution of nano-MT particles in cement mortar, they were dispersed in water before mixing of cement mortar components. After complete mixing, cement mortar samples were molded in order to conduct mechanical tests. The samples were demolded 24 h after they were cast and then cured in water basin at a temperature of 23 ± 2 °C prior to test days.

### *2.3. Test methods*

Mechanical and microstructure tests performed in this research are presented in this section.

**Table 1**
Chemical compositions of Nano-Montmorillonite and Portland cement (wt%).

| Items | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | CaO | MgO | $Na_2O$ | $K_2O$ | $TiO_2$ | $SO_3$ | L.O.I | $C_3S$ | $C_2S$ | $C_3A$ | $C_4AF$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| NM | 50.95 | 19.60 | 5.62 | 1.97 | 3.29 | 0.98 | 0.86 | 0.62 | – | 15.45 | – | – | – | – |
| PC | 21.06 | 5.22 | 3.68 | 63.90 | 1.38 | – | – | – | 1.81 | 2.40 | 54.57 | 19.51 | 7.61 | 11.19 |

*NM: Nano-Montmorillonite.
*PC: Portland cement.
*L.O.I: Loss on ignition.