

A Review on the Effects of Nanoparticles on Properties of Self-Compacting Concrete

Yan Chen

School of Civil Engineering, Shenzhen University, Shenzhen 518060, China

*Corresponding author e-mail: chenyan2016@email.szu.edu.com

Abstract. Nanotechnology is one of the most active research areas with both novel science and useful applications that has gradually established itself during last two decades. Nanoparticles belong to be prospective materials in the field of civil engineering. Some researchers have employed nanoparticles into concretes such as self-compacting concrete (SCC) aiming to modify fresh properties and mechanical strength of this system. This paper presents an overview of the effects on SCC by using nano SiO₂, TiO₂ and Al₂O₃ into concretes. This overview can be used as a short guide for civil engineering.

1. Introduction

Nowadays, self-compacting concrete (SCC) is widely developed and is a new type of concrete under self-weight to reach every corner of the formwork. Also, it is a highly flowing concrete that consolidated without any vibration effort [1]. Vibration of concrete sometimes is not only inherently difficult, but also can pose some health and safety problems, such as white finger syndrome which is a serious challenge for construction workers, as well as the noise pollution and vibration problems [2]. One of the disadvantages of SCC is its cost, related to use of chemical admixtures and high volumes of Portland cement [1]. High cement content usually introduces high hydration heat, high autogenous shrinkage [3]. A remedial to decrease the cost of SCC is using of mineral additives such as nanomaterials.

Nano-engineering encompasses the techniques of manipulation of the structure at the nanometer scale to develop a new generation of tailored, multifunctional, cementitious composites with superior mechanical performance and durability potentially having a range of novel properties. Nanotechnology is recently receiving special attention because of its performance. In recent years, the number of studies is related with nanotechnology that often initiated to determine the strategies of military, technology and science of the countries have increased dramatically. Nanotechnology is comprehension and utilization of new properties of materials that attains novel physical effects [1]. When Nano-scale particles are incorporated in concrete, the products with different properties will be created. Nanoparticles can accelerate cement hydration due to their high activity and also they act as a nano-filler, compacting the microstructure, and consequently reduce the porosity [1]. While nano-engineering of cement-based materials is seen as having tremendous potential, nonetheless, several challenges will need to be solved to realize its full potential, including the proper dispersion of the nanoscale additives, scale-up of laboratory results and implementation on larger scale, and a lowering



of the cost benefit ratio. However, most of the research work were still conducted with nano SiO₂ (NS), nano Al₂O₃ (NA) and nano TiO₂ (NT).

There are several works on incorporating nanoparticles in concrete. Most of them have been conducted with NS, NA and NT. This paper conducted a literature review focused on the effects of different nanoparticles on some properties (as workabilities and mechanical properties) of SCC and drawbacks that nanoparticles create as well as advantages in SCC.

2. Properties of SCC with different nano particles addition

2.1. Fresh properties of SCC

2.1.1. Rheological properties. The rheological properties of the fresh concrete is the microscopic manifestation of workability and influenced by many factors, especially its rheological parameters must be obtained by certain test methods. It is difficult to test the rheology parameter of the complex system of concrete mixture directly, and it is not only a high requirement for the test equipment. Also, it is not suitable for practical applications, so the specific effects of nano-materials on the rheological properties of fresh SCC still need further study.

2.1.2. Workability. The workability of the fresh concrete is usually reflected by the fluidity of concrete and the resistance to segregation. Wang et al [3] through the T50 and V Funnel to test the workability of SCC and found that the addition of NS decreased the fluidity of concrete. But, Zhang [4] found the fluidity of a mixture containing 2% NS does not make a big difference compared with the mixture without NS. However, when adding 10% silica fume (SF) and 2% NS in SCC, it is different from with the mixture contain only fly ash [2]. Mohseni [5] find that with the increase of nanoparticles, V-funnel time decreases slowly, and the content of nanoparticles lower, the V-funnel time higher. Jalal [2] indicates that the concrete will be more viscous after the addition of NT. NT with different volume fraction has different influence on the fluidity. But not any nanoparticle has a significant effect on the fluidity of SCC. When the nanoparticles mixed with a certain proportion of SF, the effect of fluidity on SCC is more obvious.

2.2. Mechanical properties of SCC

2.2.1. Compressive strength. Some studies showed that Ca(OH)₂ reacted with nanoparticles and then transformed into C-S-H gel with large specific surface area and strong binder force, which improved the strength [6-8]. In addition, the Ca(OH)₂ on the surface of aggregate decreased and improved the structure of cement paste between interface transition zone of aggregate, enhancing the early strength of concrete. Due to the presence of nano additives, the density of the mixture increased and the compressive strength increased.

According to some studies, with the addition of 3% NS, 1% NA and 5% NT in SCC, the compressive strength of SCC reached the highest, respectively. In addition, NS has higher volcanic ash activity and water demand and with the increase of NS, the strength of concrete increases at all ages. NS has an appropriate dosage, and after exceeding this range, NS will lead to the reduction of strength for concrete [1, 8].

Relevant studies showed that when NT and NA were mixed together, the compressive strength of SCC did not change significantly [8]. Agarkar [9] proposed that when only 1% NA was added, the compression strength of SCC was increased. When the NA content continued to increase, the compressive strength of SCC began to decrease. Jalal et al [10] showed that when NT was added only in SCC, the compressive strength increased with the increase of NT, especially in the later hydration process. Therefore, different nanomaterials have different effects on the compressive strength of the SCC. For different nanomaterials, the optimum compressive strength of the SCC should be achieved, and the optimal proportions of nanoparticles are also different.

2.2.2. *Split tensile strength.* Neville [11] found that the tensile strength was related to the compressive strength. However, early tensile strength of concrete with nanomaterials changes faster than compressive strength. The growth rate of tensile strength of SCC mixed with nanoparticles is much higher than that of conventional SCC. With the increasing of nanoparticles, the tensile strength of SCC can be increased by up to 4%. Jalal [12] showed that the tensile strength increased with the addition of 4% nanoparticles, and the tensile strength decreased after the addition to a certain proportion.

Therefore, as the dosage of nanoparticles increases, the tensile strength of SCC will also increase. However, when the dosage reaches a certain proportion, the tensile strength decreases.

2.2.3. *Flexural strength.* Jalal [2] indicated that NS, NT mix NA, and NT had the greatest influence on the flexural strength of SCC. During curing of 7, 28 and 90 days, the flexural strength of concrete mixed with 10% NS increased by 20%, 52% and 52% respectively. However, according to Yu [13], after adding NS into concrete, its mechanical properties (especially flexural strength) were significantly improved. Beigi [14] also found that when 4% NS was added into concrete, the flexural and split tensile strength were significantly increased, and the flexural strength was further improved when fly ash was added. In the SCC, when the content of nanoparticles reaches 4%, the flexural strength is obviously increased, and then the flexural strength will decrease again. Nazari [15] also showed that the flexural strength decreases when the content of NT exceeds 4%. Mostafa [16] showed that the growth rate of flexural strength in the SCC with nanoparticles was much higher than that of SCC containing fly ash.

Therefore, NT is most effective in improving the flexural strength of concrete, but the proportion of nanoparticles should be controlled within a certain range, generally about 4%. Moreover, when nanomaterials and fly ash are mixed in a certain proportion and then added into SCC, the flexural strength of concrete will be further improved.

3. Conclusion

In this paper, the effects of workability and mechanical strength of SCC with different nanoparticles are studied. The effect of nanoparticles at different proportions and combinations on the properties of SCC was investigated.

Although, there are many related studies on mechanical properties and a lot of meaningful results have been achieved. However, there are relatively few studies on workability and durability of SCC, which are still in the preliminary stage and need to be further studied. Due to the high cost of nanomaterials on the market, how to extend the long-term service life of SCC mixed with nanomaterials are still a big difficulty in the future. The use of nanomaterials to achieve higher performance of SCC is still the goal of this field.

References

- [1] A. Nazari, S. Riahi, Al₂O₃ nanoparticles in concrete and different curing media, *Energ. Buildings.* 43 (2011) 1480-1488.
- [2] M. Jalal, A. Pouladkhan, O.F. Harandi, D. Jafari, Comparative study on effects of Class F fly ash, Nano silica and silica fume on properties of high performance self-compacting concrete. *Constr. Build. Mater.* 94 (2015) 90-104.
- [3] L.G. Wang, D.P. Zheng, S.P. Zhang, H.Z. Cui, D.X. Li, Effect of nano-sio₂ on the hydration and microstructure of portland cement. *Nanomaterials.* 6/12 (2016) 1-15.
- [4] M.H. Zhang, J. Islam, Use of Nano-silica to reduce setting time and increase early strength of concretes with high volumes of fly ash or slag, *Constr. Build. Mater.* 29 (2012) 573-580.
- [5] E. Mohseni, B.M. Miyandehi, J. Yang, M.A. Yazdi, Single and combined effects of nano-SiO₂, nano-Al₂O₃ and nano-TiO₂ on the mechanical, rheological and durability properties of self-compacting mortar containing fly ash. *Constr. Build. Mater.* 84 (2015) 331-340.
- [6] A. Nazari, S. Riahi, Effects of CuO nanoparticles on compressive strength of self-compacting concrete, *Sadhana.* 36/3 (2011) 371-391.

- [7] A. Nazari, S. Riahi, The effects of ZnO₂ nanoparticles on properties of concrete using ground granulated blast furnace slag as binder. *Mater. Res.* 14/3 (2011) 299-306.
- [8] H. Li, X.H. Xiao, J. Yuan, J. Ou, Microstructure of cement mortar with nanoparticles, *Compos. Part B.* 35 (2004) 185-189.
- [9] S.V. Agarkar, M.M. Joshi, Study of effect of Al₂O₃ nanoparticles on the compressive strength and workability of blended concrete. *Int. J. Curr. Res.* 4 (2012) 382-384.
- [10] M. Jalal, M. Fathi, M. Farzad, Effects of fly ash and TiO₂ nanoparticles on rheological, mechanical, microstructural and thermal properties of high strength self-compacting concrete. *Mech. Mater.* 61 (2013) 11-27.
- [11] A.M. Neville, *Tecnologia del concreto*. Mexico: Limusa; 1988.
- [12] M. Jalal, A.A. Ramezani pour, M.K. Pool, Split tensile strength of binary blended self-compacting concrete containing low volume fly ash and TiO₂ nanoparticles. *Compos. Part B.* 55 (2013) 324-337.
- [13] R. Yu, P. Tang, P. Spiesz, H.J.H. Brouwers, A study of multiple effects of Nano-silica and hybrid fibers on the properties of Ultra-High Performance Fiber Reinforced Concrete (UHPFRC) incorporating waste bottom ash (WBA). *Constr. Build. Mater.* 60 (2014) 98-110.
- [14] M.H. Beigi, J. Berenjian, O. Lotfi Omran, A. Sadeghi Nik, I.M. Nikbin, An experimental survey on combined effects of fibers and Nano silica on the mechanical, rheological, and durability properties of self-compacting concrete. *Mater. Des.* 50 (2013) 1019-1029.
- [15] A. Nazari, S. Riahi, The effect of TiO₂ nanoparticles on water permeability and thermal and mechanical properties of high strength self-compacting concrete. *Mater. Sci. Eng. A.* 528 (2010) 756-763.
- [16] J. Mostafa, F. Mojtaba, F. Mohammad, Effects of fly ash and TiO₂ nanoparticles on rheological, mechanical, microstructural and thermal properties of high strength self compacting concrete. *Mechan. Mater.* 61 (2013) 11-27.