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Review

Influence of nano-SiO_2 on properties of fresh and hardened high performance concrete: A state-of-the-art review

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HIGHLIGHTS

- 83 papers are reviewed on high performance concrete (HPC) containing nano-SiO_2.
- Effect of nano-SiO_2 on the fresh properties of HPC is discussed.
- The mechanical properties and durability of HPC are also addressed.
- Influence of nano-SiO_2 on the microstructure of HPC is reviewed.

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ABSTRACT

Application of nano-SiO_2 (NS) particles to reinforce high performance concrete (HPC) has received widespread attention from both construction industry and researchers due to their interface improving effect, small size effect, filling effect and surface effect. This paper critically reviews previous research carried out on the effect of NS on properties of HPC. Detailed review on the fresh properties, mechanical properties and durability of high performance concrete containing NS particles are presented. Through 76 recent and past literatures, the influence of SiO_2 nano-particles on workability and setting time of fresh mixture, compressive strength, flexural properties, fracture properties, water anti-permeability, chloride permeability, abrasion resistance, frost resistance, water absorption capacity, resistance to high temperatures and microstructure of HPC is discussed in this paper. The properties of NS modified concrete are compared with control concrete. Furthermore, this paper presents on the benefits and advantages to improve the HPC by using NS. It is shown that, in general, the incorporation of SiO_2 nano-particles significantly improves the mechanical properties and durability of HPC though the flowability of the fresh concrete is decreased by the usage of NS. This literature review also aims to provide a comprehensive insight into possible application of NS modified concrete in the construction industry today.

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1. Introduction

As the most consumable building material, concrete has been generally used in the world, which has high strength, high elasticity modulus, well plasticity and workability. The orientation of the modern civil engineering structures is high-rise, high strength and long design lifetime, which has higher requirements on concrete. However, the control concrete is difficult to meet these requirements. Compared with the control concrete, ultra high performance concrete (UHPC) and high performance concrete (HPC) have more excellent mechanical properties and durability, and the use of them in civil engineering is becoming more and more widely [1–5]. HPC can be illustrated as a kind of concrete that can meet especial combinations of properties and requirements of uniformity, which cannot usually be obtained routinely using traditional raw materials and conventional mixing, placing, and curing methods [6]. With the development of HPC, there are several preparation methods to get HPC. Commonly, some admixtures can be added in the concrete to obtain high performance, and the common admixtures include mineral admixtures, chemical admixture and fiber materials [7,8]. Among the mineral admixtures added to concrete, nano mineral materials become more and more popular.

The definition of nanometer came into being in the early 1980s, and nano-materials can be defined as the particles with the particle size between 1 nm and 100 nm. The nano-particle exists in the transition areas from the atom cluster to the macroscopic matter with a high specific surface ratio, which includes metal nano-particle, nonmetal nano-particle, organic nano-particle, inorganic nano-particle and biology nano-particle [9]. Because of the ultra fine particle size of nano-particle, the surface electronic structure and crystal structure of the nano-particle change greatly so that some nanometer effects come into being, such as surface effect, small size effect, quantum effect and macroscopic quantum tunneling effect, which cannot be found for the macroscopic materials. Therefore, compared with the conventional granular materials, these superfine particles have a series of fantastic physical and chemical properties. As a kind of new materials, nano-material has already shown wide range of potential applications in the fields of national defense, electronic engineering, chemical industry, aerospace engineering, biology engineering and medical science based on its unique nanometer effects. The nano-particle has been regarded as a material which possesses great application prospect in the 21th century [10]. Because of the high specific surface ratio, the nano-particle with 4-nm diameter have more than 50% of its atoms at the surface and are thus very reactive [11]. The chemical reactions at the interface of the nano-particle and the agglomerates formed easily by the nano-particle have great influence on the behavior of the nano-materials. The free dispersed water in the mixture existing among the particles of cement, fly ash and nano-SiO_2 (NS) will be decreased by the high specific surface ratio of the nano-particle. As a result, the addition of nano-particle into the concrete not only can greatly changed the properties of the fresh concrete, but also can improved the mechanical and physical performance and microstructure of the hardened concrete [12]. There are many kinds of nano mineral materials can be used to enhance the concrete performance, such as nano-SiO_2 [13], nano-$CaCO_3$ [14], nano-Al_2O_3 [15], nano-Fe_3O_4 [16], nano-TiO_2 [17], nano-TiO_2 [18], nano-limestone [19], nano-flyash [20], and nano-metakaolin [21]. Among these nano-materials, SiO_2 nano-particle is the nano-particle with most extensive applications in concrete and HPC due to the high activity and extraordinary high specific area, because of which the pozzolanic activity in concrete can exhibit high level. Furthermore, NS can accelerate the dissolution of tricalcium silicate (C_3S) and generation of calcium silicate hydrate (C-S-H) due to high activity, which

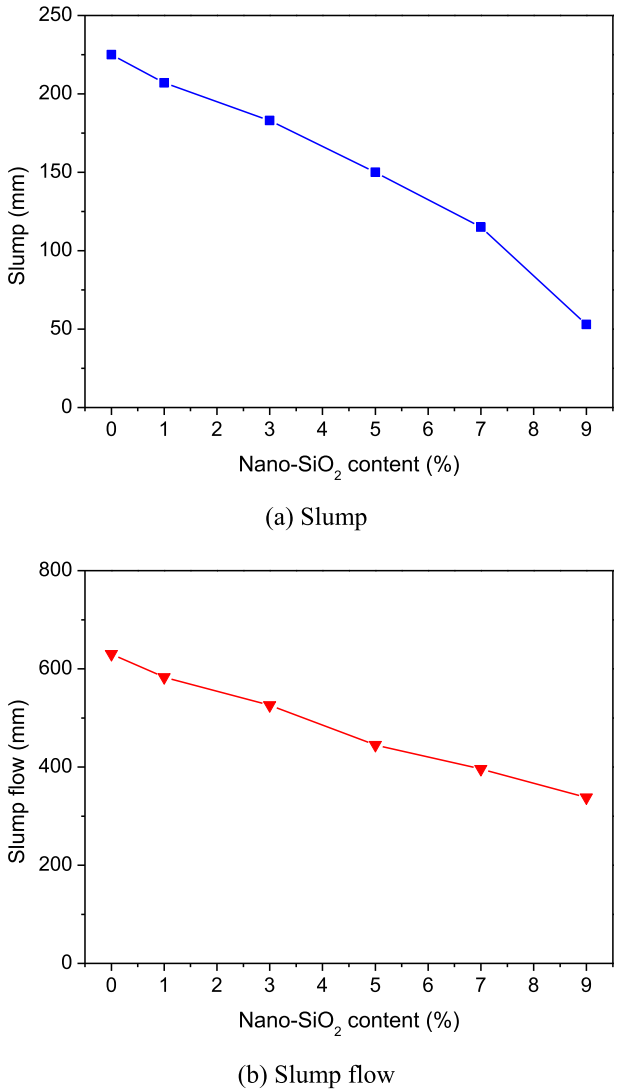

Fig. 1. Effect of NS content on slump and slump flow [27].

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