5th International Conference on Durability of Concrete Structures
Jun 30–Jul 1, 2016
Shenzhen University, Shenzhen, Guangdong Province, P.R.China

The Promotion of Nano-SiO_2 on the Compressive Strength of Alkali-Activated Materials

Tongtong Zhou, Zonghui Zhou*, Peng Du, and Xin Cheng
Shandong Provincial Key Laboratory of Preparation and Measurement of Building Materials,
Engineering Center of Advanced Building Materials of Ministry of Education, University of Jinan,
Jinan 250022, China

ABSTRACT

Nanomaterial which has high activity is widely used in the modification of cement-based materials due to its physical filling and chemical bonding. This paper mainly studied the influence of nano-SiO_2 on the compressive strength of the alkali-activated materials, using XRD and SEM technology to analyze the mineral composition microstructure of alkali-activated materials, modification effect, etc. The results show that the doping of nano-SiO_2 can enhance the compressive strength of alkali-activated materials. Under the condition of fixed water-binder ratio and alkali content, the optimum dosage of nano-SiO_2 is 4%. When the content is 4%, the intensity of 28 days is increased by 26.81% compared with the blank sample, and compressive strength of 94.93 MPa is reached. By XRD and SEM, we can find a large number of CSH and a certain amount of CH in the sample. The promotion effect of nano-SiO_2 on the alkali-activated materials provides a better support for the application of the alkali-activated materials in reality.

1. INTRODUCTION

Nowadays, with the development of the times, the alkali-activated cementitious material is getting more and more attention. In this paper, alkali-activated cementitious materials with steel slag and granulated blast furnace slag as raw materials, using appropriate activator to stimulate and get a kind of material with cementitious activity. Alkali-activated cementitious materials can effectively make use of industrial waste, and the industrial waste residue can be achieved by the resource and high value. Alkali-activated cementitious material has the advantages of fast curing speed, high strength, good resistance to permeability, and wide raw material sources (Yang, 1996a).

Nanotechnology in the application of building materials can improve many properties of building materials, such as mechanical properties, durability, and compactness. The incorporation of nano-silica can also change the properties of alkali-activated cementitious materials, which may provide a potential for the production of alkali-activated cementitious materials to meet the specific requirements. Alkali-activated cementitious materials, such as silicon aluminum material, nano-SiO_2 doped with alkali-activated materials can improve the compressive strength of cementitious materials. The application of nanotechnology in the field of alkali-activated cementitious materials has certain feasibility and prospect. This experiment mainly studied the effect of different dosage of nano-SiO_2 on the compressive strength of alkali-activated cementitious materials. Through the analysis of the experimental results, the optimal dosage of nanomaterial is 4 wt. % (Yang, 1996b).

2 EXPERIMENT

2.1 Raw materials

The raw materials used in this experiment are steel slag (Ji'nan iron and steel plant), granulated blast furnace slag (GBFS) and nano-SiO_2.

Nano-SiO_2: Xuancheng Jingrui New Material Co., Ltd. Production technical indicators are shown in Table 1.

Table 1. Technical indicators of nano-SiO_2.

Sample	Size (nm)	BET (m^2/g)	Content (%)	pH
Nano-SiO_2	30 ± 5	230 ± 30	≥ 99.5	6–8

2.2 Other reagents

This experiment used the activator with nano-water glass and sodium hydroxide; technical indicators are shown in Table 2.

Table 2. Technical indicators for sodium silicate and sodium hydroxide.

Sample	Molecular formula	Molecular weight	Purity
Sodium silicate	$Na_2O \cdot 3.2\ SiO_2$	254	28%
Sodium hydroxide	NaOH	40	95%

*Corresponding author: Zonghui Zhou, Telephone: +86 13808921072, E-mail address: mse_zhouzh@ujn.edu.cn

2.3 Experimental apparatus

The experimental apparatus includes the glass rod, beaker, paste mixer, paste pot, compressive strength testing machine, and paste mold.

2.4 Experimental method

2.4.1 Preparation of raw materials

Put steel slag into the ball mill grinding for 40 min, followed by a 100 mesh sieve preliminary screening, take the lower part of the screen and then through a 200 mesh sieve segments, taking under the sieve and set aside. The granulated blast furnace slag is bought from market.

2.4.2 Mixture

According to the ratio of 1:1 weigh granulated blast furnace slag and steel slag and the weighing of granulated blast furnace slag and steel slag mixed in the paste mixer mixing for 5 min. At the same time, take an appropriate amount of sodium water glass and sodium hydroxide configurate to 1.0 modulus of water glass liquid soaked in cold water while adding sodium hydroxide, stirring, and cooling to room temperature. The content of nano-silica was divided into four groups according to the content of nano-silica, the nano-SiO_2 content of each group were 0, 2, 4, and 6 wt. % (internal). According to the needs of each group, the amount of nanomaterial is added into the mixture and mixed with granulated blast furnace slag and steel slag for 5 min.

Table 3.

Group	Steel slag (g)	GBFS (g)	Nano-silica (g)
0	250	250	0
2	245	245	10
4	240	240	20
6	235	235	30

2.4.3 Experimental procedure

The mixed raw material mixing in the paste mixer, and in accordance with the water solid ratio is 0.34 (mass ratio), and then mixed with 8 wt. % 1 mode of water glass, referring to GB/T1346-2011 stirring alkali-activated cementitious materials. Then, pour the mixed paste into the 20 mm × 20 mm × 20 mm mold, cure in curing room of 20°C and 95% humidity for 24 h. Determine the compressive strength of 1, 3, 7, and 28 days.

3. EXPERIMENTAL RESULTS AND ANALYSIS

3.1 Strength analysis

From the above, Figure 1 shows that the addition of nanomaterial has an impact on strength of alkali-activated cementitious material, 1-day compressive strength of each sample were 42.23, 51.57, 54.88, and 53.54 MPa, respectively. The 3-day compressive strength were 52.57, 62.4, 69.57, and 59.69 MPa, respectively; 7-day compressive strength were 62.39, 71.35, 82.31, and 63.69 MPa, respectively; and at the age of 28 days, the compressive strength of the sample were 74.86, 85.28, 94.84, and 78.41 MPa, respectively. When the dosage of nano-silica is less than 4%, the more the dosage of nano-silica, the higher is the compressive strength of each sample in all age. Blank strength was 74.86 Mpa, and the compressive strength of the sample with 4% dosage of nano-SiO_2 was 94.93 Mpa.

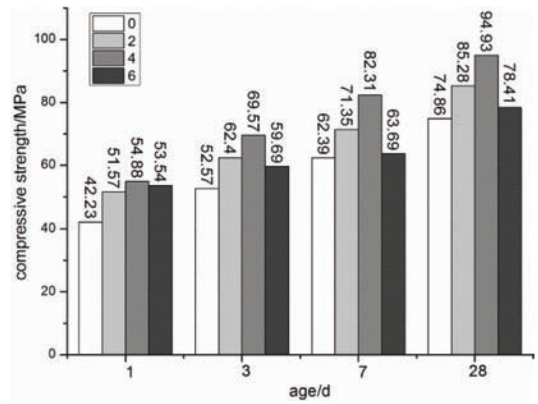


Figure 1. Compressive strength with nano-silica dosage.

By Figures 2 and 3, the compressive strength of each age can be improved. The 1-day compressive strength was improved by 22.12, 29.96, and 26.78% when the nano-silica dosage was 2, 4, and 6%, respectively. The 3-day strength was improved by 18.70, 32.34, and 13.54% when the nano-silica dosage was 2, 4, and 6%, respectively. The 7-day compressive strength was improved by 14.36, 31.93, and 2.08% when the nano-silica dosage was 2, 4, and 6%, respectively. The 28-day compressive strength was improved by 13.92, 26.81, and 4.74% when the nano-silica dosage was 2, 4, and 6%, respectively. It can be seen from Figure 2 that during the dosage of 2 and 6%, the nanomaterials had a promoting effect on early compressive strength significantly; 1-day strength increased rate reached 22.12 and 26.78%, respectively; while the late strength increase compared to 1-day rate of increase was reduced, 28-day compressive strength was increased by 13.92 and 4.74%. When nano-silica dosage was 4%, the early strength and late strength of the sample were significantly increased. When dosage is 4%, samples' 1 and 28 days of strength increased rates were 29.96 and 26.81%, respectively. It can be seen that the dosage of nano-silica has an excellent enhancing on early strength. The improvement effect of the late strength is lower than the early increase rate (Gao et al., 2013).

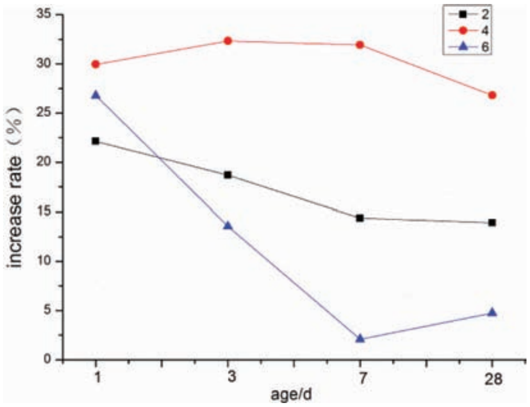


Figure 2. Increase rate with the dosage of nano-silica.

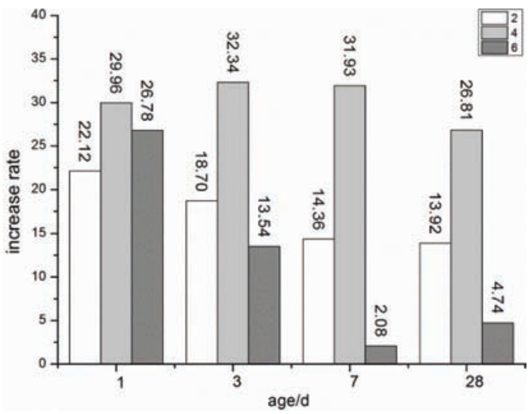


Figure 3. Increase in rate of different ages.

3.2 XRD result analysis

Figure 4 shows XRD patterns for the 28 days of age in different nano-dosage of each sample. The figure shows that alkali-activated cementitious materials after hydration mainly produce CSH and a small amount of $Ca(OH)_2$; RO phase is solid solution phase that basically does not produce hydration. The dosage of nano-silica has no effect on the hydration product categories but only affects the number of hydration products. At the same time, it can be seen that alkali-activated cementitious material hydrated gel-based products. So the difference strength between samples is not affected by hydration to generate new material, but the amount of hydration products (Najigivi, Khaloo, & Rashid, 2013).

3.3 SEM result analysis

The above pictures are SEM of 28-day specimens; a, b, and c represents 0, 2, and 4% dosage of nano-silica, respectively. From the image above, it can be seen that with the increase of the dosage of nano-silica, the amount of CSH gel increased gradually. When the optimal dosage is reached, the largest amount of CSH gel is produced. So the amount of gel is the main factor to improve the strength of the specimen. The more the CSH gel, the higher is the compressive strength.

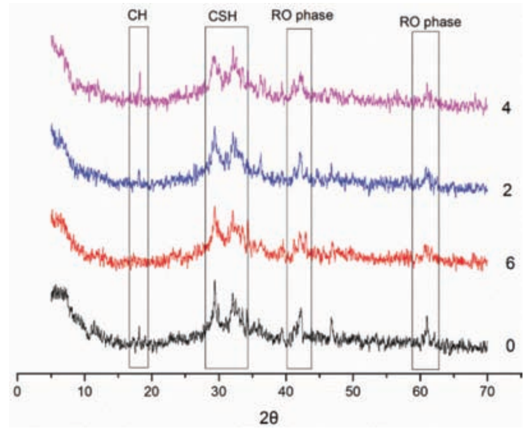
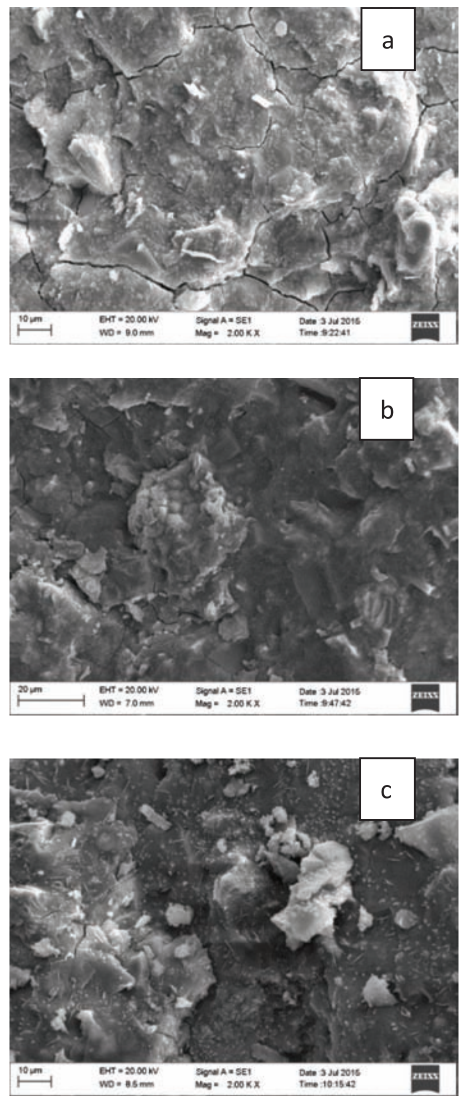


Figure 4. XRD patterns of different nano-dosage.



4. CONCLUSION

1. Incorporation of nano-silica can improve the strength of alkali-activated cementitious materials, possibly because of nano-silica in the

sample hydration, the formation of more CSH gel, reduce the number of harmful holes, making the structure more dense, thereby effectively increasing the effective force area of the sample, and then the compressive strength of the sample is increased (Aly et al., 2012).

2. The optimal dosage of nano-silica on the strength of alkali-activated cementitious materials is 4 wt. %. At the same age, before dosage of nano-silica reaches 4 wt. %, with the increase of nano-content, the compressive strength gradually increased, and also the relationship between the early strength increase rate is proportional to the dosage. When the dosage exceeds 4 wt. %, the compressive strength will gradually decrease. The possible reason is that the optimal amount of the nanomaterial has a certain effect on the porosity, which makes the porosity decrease. At the same time, the dosage of nano-silica into the sample forms more gel, so that the strength of the sample increased. The strength can be reduced when the dosage is over the optimal dosage. The reason is that the amount of nanomaterial is too large, which makes the internal structure non-uniform, resulting in the increase of the number of harmful pore and the decrease of compressive strength (Nazari & Riahi, 2011).

3. Nanomaterials' promoting effect on the early strength is obvious, late effects decreased relative to the early. Possible causes are nano-silica is highly active material; at the early age, alkali-activated cementitious material's hydration rate is lower than nanomaterial hydration rate. Therefore, the incorporation of nano-silica on the early strength of the promotion effect is obvious, but the promotion effect of nanomaterial on the post strength is relatively weak (Aly et al., 2012).

ACKNOWLEDGMENTS

This research was supported by National High-tech R&D Program of China (No. 2015AA034701), Shandong Province Science and Technology Major Project (new industry) (2015ZDXX0702B01), and Shandong Province Science and Technology Development Plan (2014GSF117017). The authors gratefully acknowledge the support of the related units and teachers.

REFERENCES

Aly, M., Hashmi, M. S., Olabi, A. G., Messeiry, M., Abadir, E. F., & Hussain, A. I. (2012). Effect of colloidal nano-silica on the mechanical and physical behavior of waste-glass cement mortar. *Materials and Design, 33*, 127–135.

Gao, K., Lin, K.-L., Wang, D., Hwang, C.-L., Anh Tuan, B. L., Shiu, H.-S., & Cheng, T.-W. (2013). Effect of nano-SiO_2 on the alkali-activated characteristics of metakaolin-based geopolymers. *Construction and Building Materials, 48*, 441–447.

Najigivi, A., Khaloo, A., & Rashid, S. A. (2013). Investigating the effects of using different types of SiO_2 nanoparticles on the mechanical properties of binary blended concrete. *Composites Part B: Engineering, 54*, 52–58.

Nazari, A., & Riahi, S. (2011). The effects of TiO2 nanoparticles on physical, thermal and mechanical properties of concrete using ground granulated blast furnace slag as binder. *Materials Science and Engineering: A, 528*, 2085–2092.

Yang, N. (1996a). Physical and chemical basis of the formation of cementitious materials. *Journal of Chinese Ceramic Society, 24*(2), 209–215.

Yang, N. (1996b). Physical and chemical basis of the formation of cementitious materials. *Journal of Chinese Ceramic Society, 24*(4), 459–465.