바인더젯 3D 프린팅을 위한 TiO_2 입자를 함유한 시멘트 기반 재료의 기계적 성능 및 광촉매 특성 분석

Characterization of mechanical and photocatalytic performance on cement-based materials with TiO_2 particles for binder jet 3D printing

유준성[1] · 리패기[2] · 배성철[3*]
Liu, Jun-Xing[1] · Li, Pei-Qi[2] · Bae, Sung-Chul[3*]

Abstract : The development of advanced 3D printing technologies has opened up new opportunities for customized digital designs in the construction industry. Using nano- and micro-scale additives is expected to improve the performance of cement-based materials in 3D printing. TiO_2 particles have been widely used as reinforcing additives in cement-based materials. Therefore, this study aims to investigate the application of cement-based materials containing multi-size TiO_2 particles in binder jet 3D printing and the effect of different-size TiO_2 particles on the performance of printed samples. TiO_2 particles exhibit an excellent filling effect, which increases the density of the printed samples and promotes hydration, thereby improving the compressive strength of the samples. In addition, larger TiO_2 particles exert more pronounced filling and photocatalytic effects on the resulting samples.

키워드 : 바인더젯 3D 프린팅, 시멘트 기반 재료, TiO_2 입자, 압축강도, 광촉매 특성
Keywords : binder jet 3d printing, cement-based materials, TiO_2 particle, compressive strength, photocatalytic properties

1. Introduction

The application of three-dimensional printing (3DP) in the construction industry is increasing due to its design versatility, the ability to directly transform digital designs into solid structures, faster construction time, easier fabrication of complex structures, and the economic efficiency it brings by reducing material and labor costs. In the construction industry, binder jet 3D printing (BJ3DP) is another available additive manufacturing (AM) method in addition to extrusion 3D printing methods [1]. On the other hand, TiO_2 particles of various sizes have been widely accepted as additives for various products due to their size and large surface area that can confer specific electronic, ionic, and biocompatibility and significantly increase the reaction rate. Among them, the feasibility study of nano-TiO_2 particles (NTPs) in construction building materials has attracted much attention due to the filling and nucleating role of NTPs in gelling materials. Moreover, another reason why researchers are interested in titanium dioxide in various sizes is its ability to induce photocatalytic activity, which can be used to mitigate severe air pollution caused by pollutants such as nitrogen oxides (NO_x) and volatile organic oxides (VOCs). Therefore, in this work, the feasibility of incorporating TiO_2 particles into cementitious materials in the BJ3DP process was investigated to enhance their mechanical properties and endow them with photocatalytic functional activity. The compressive strength, hydration products, and photocatalytic activity of the printed specimens were evaluated.

2. Materials and experiments

Cement-based materials consisting of ordinary Portland cement (CEM I 52.5R), quartz sand, and additives were obtained from CONCR3DE (Netherlands) for preparing the specimens. Moreover, a water-based liquid ink utilized in the printing process was a mixture of a polyether polyol polymer, water, and surfactants (CONCR3DE). Different-sized anatase TiO_2 particles were purchased from Sigma-Aldrich and added to the cement-based materials and the the morphology of the TiO_2 particles was inspected via transmission electron microscopy (TEM, JEM-2100F, JEOL, Japan) and displayed Figure 1. The compressive strengths of printed specimens were

1) 한양대학교, 박사과정
2) 한양대학교, 석박통학과정
3) 한양대학교, 부교수, 교신저자 (sbae@hanyang.ac.kr)

tested after 1, 3, 7, and 28 d of water curing using 5 kN Micro compression machine (Deben, UK). The photocatalytic activity of the printed specimens was evaluated by monitoring the concentration of methylene blue (MB) solution soaked with printed specimens under ultraviolet light (PM-1600UVH, NDT Advance, Japan) irradiation, the solution concentration was measured via ultraviolet−visible (UV−vis) spectroscopy (Genesys 180, Thermo Scientific, USA).

3. Results

Figure 1 shows the morphology of different TiO_2 particles. The size of the three groups of particles varied significantly, and the sizes of particles were summarized by TEM images as well as Image J, which were 8, 110, and 150 nm, respectively. In addition, the TiO_2 particles exhibit spherical and hexagonal disk shapes. The compressive strengths of the printed specimen were shown in Figure 2. For the blank group (specimen without TiO_2 particles), the compressive strength increased with curing time, and the specimens cured in water showed a significant increase in compressive strength after 28 days, from 2.28 MPa d (1 d) to 8.04 MPa (28 d). This increase may be attributed to sufficient water promoting the hydration reaction of the cementitious materials, resulting in more hydration products. For the printed specimens containing TiO_2 particles, the compressive strength increased with increasing TiO_2 content and particle size. Overall, the specimen with 1% 150 nm TiO_2 particles exhibited the highest strength after 28 d of curing in water (28% higher than the blank). The TiO_2 particles facilitated hydration, and these particles filled the voids in the specimen, resulting in a denser microstructure, which in turn increased the compressive strength. For photocatalytic performance, the optimal result of photocatalytic properties was also achieved with the specimen with 1% 150 nm TiO_2 particles due to micro-sized TiO_2 (more than 100 nm) providing a higher surface area to more efficiently adsorb and react with large organic pollutants compared with nano-sized particles [2].

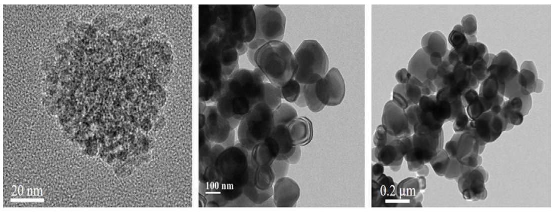

Figure 1. Morphology of the different TiO_2 particles: (a) 8 nm, (b) 110 nm, and (c) 150 nm.

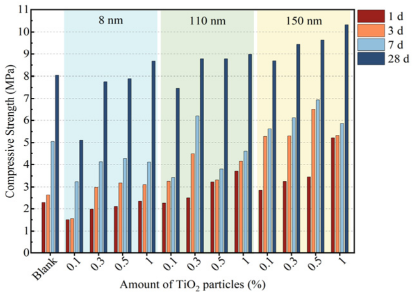

Figure 2. Compressive strength of printed specimens curing in water.

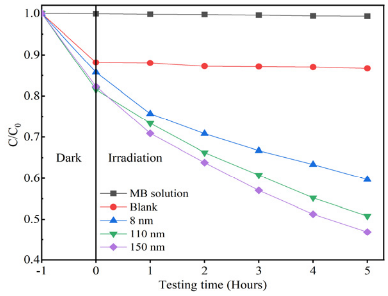

Figure 3. Photocatalytic effect of printed specimens with 1% TiO_2 particles.

4. Conclusion

The feasibility of the use of cement-based materials mixed with nano- to micro-sized TiO_2 particles in BJ3DP technology was verified. The specimens mixed with micro-sized TiO_2 particles exhibited a higher mechanical and photocatalytic performance.

감사의 글

본 연구는 국토교통부/국토교통과학기술진흥원의 지원으로 수행되었음 (과제번호 23NANO-C156177-04)

참고문헌

1. F. Hamidi, F. Aslani. Additive manufacturing of cementitious composites: materials, methods, potentials, and challenges. Construct. Build. Mater. 2019. p. 582-609.
2. A. Folli, I. Pochard, A. Nonat, U.H. Jakobsen, A.M. Shepherd, D.E. Macphee, Engineering photocatalytic cements: understanding TiO_2 surface chemistry to control and modulate photocatalytic performances, J. Am. Ceram. Soc. 2010. p. 3360-3369.