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Mechanical and Microstructural Characterization of Carbon Nanofiber–Reinforced Geopolymer Nanocomposite Based on Lunar Regolith Simulant

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Introduction

Background

- The preparation of geopolymer based on lunar regolith is a feasible method for lunar pavement construction. While cementitious materials are considered quasi-brittle and need to be reinforced. Carbon nanofibers (CNFs) are beneficial nanomaterials for reinforcement, which is effective in cement-based materials.

Research gaps

- Effect of CNFs on geopolymers based on lunar regolith simulant.
- The reinforcement mechanism of CNFs.

Research aims

- A novel ball milling method for CNFs dispersion was proposed and evaluated. The mechanical and microstructural properties of CNF/geopolymer nanocomposites synthesized with three different contents of CNFs were characterized.

Materials and methods

Materials

- BH-1 lunar regolith simulant was used in this study.
- The alkali activator used was 8 mol/L sodium hydroxide (NaOH) solution prepared by mixing NaOH particles with distilled water.
- The CNFs were 50-200 nm in diameter and 1-15 μm in length.

Dispersion Method

- The CNFs and BH-1 were mixed and milled together in a horizontal ball mill for 60 min. The CNF content was 0%, 0.1%, 0.3% and 0.5% by weight of BH-1 and denoted as BF0, BF1, BF3 and BF5, respectively.

Testing Methods

- Mechanical properties: three-point bending test and uniaxial compression test at 1, 3, 7 28 d.
- Microstructural characterization: SEM; MIP

Results and discussion

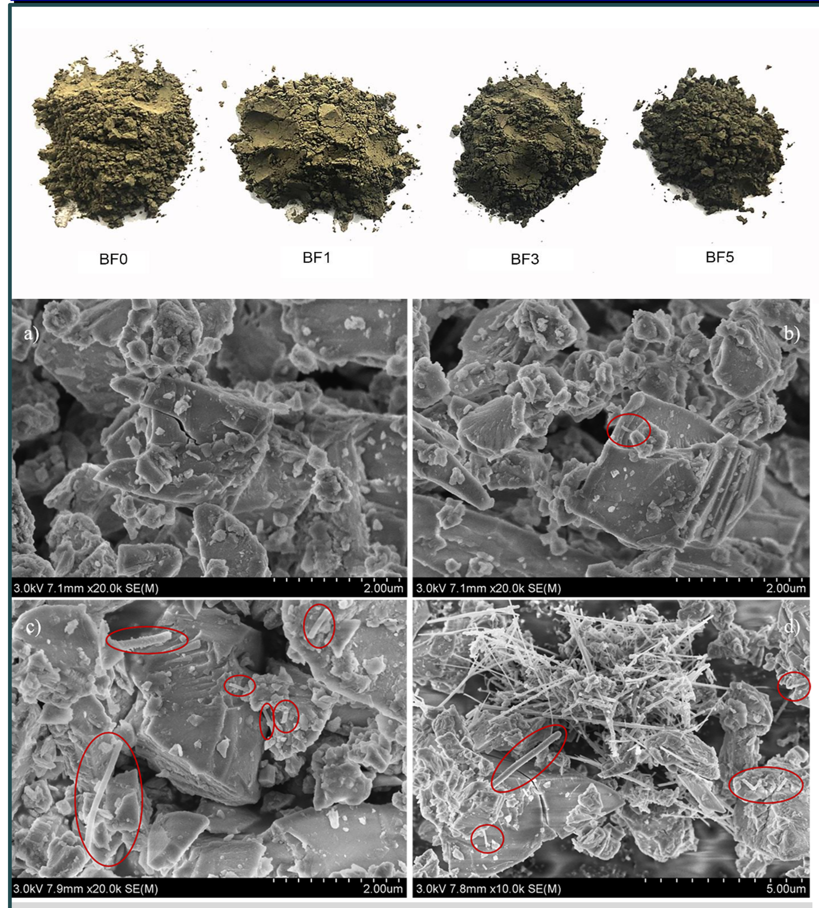

Fig.1 Macroscopy and SEM images of (a) BF0 (b) BF1 (c) BF3 and (d) BF5 powders.

Dispersion of CNFs

- The color changes dramatically from light to dark with increasing CNF content. For BF1 and BF3, the CNFs can be observed with apparent morphology in the form of individual fibers and with uniform distribution. However, evident agglomeration was observed in BF5.
- The ball-milling dispersion method was feasible and practical when the milling amount of CNFs did not exceed 0.3%. At a higher content the CNFs were more easily entangled.

Mechanical Properties

- BF1, BF3, and BF5 improved 28-d flexural strength by 26.1%, 34.8%, and 26.1%, respectively.
- MSE was the reciprocal of the mass ratio of the summed materials forming 1 MPa of strength, calculated by : $\eta_m = \left(\frac{(m_{SH}+m_{CNF})\times 100}{m_{BH}\times f}\right)^{-1}$
- MSE values of the 28-d flexural strength of BF0, BF1, BF3, and BF5 were 0.24, 0.30, 0.31, and 0.29, respectively.

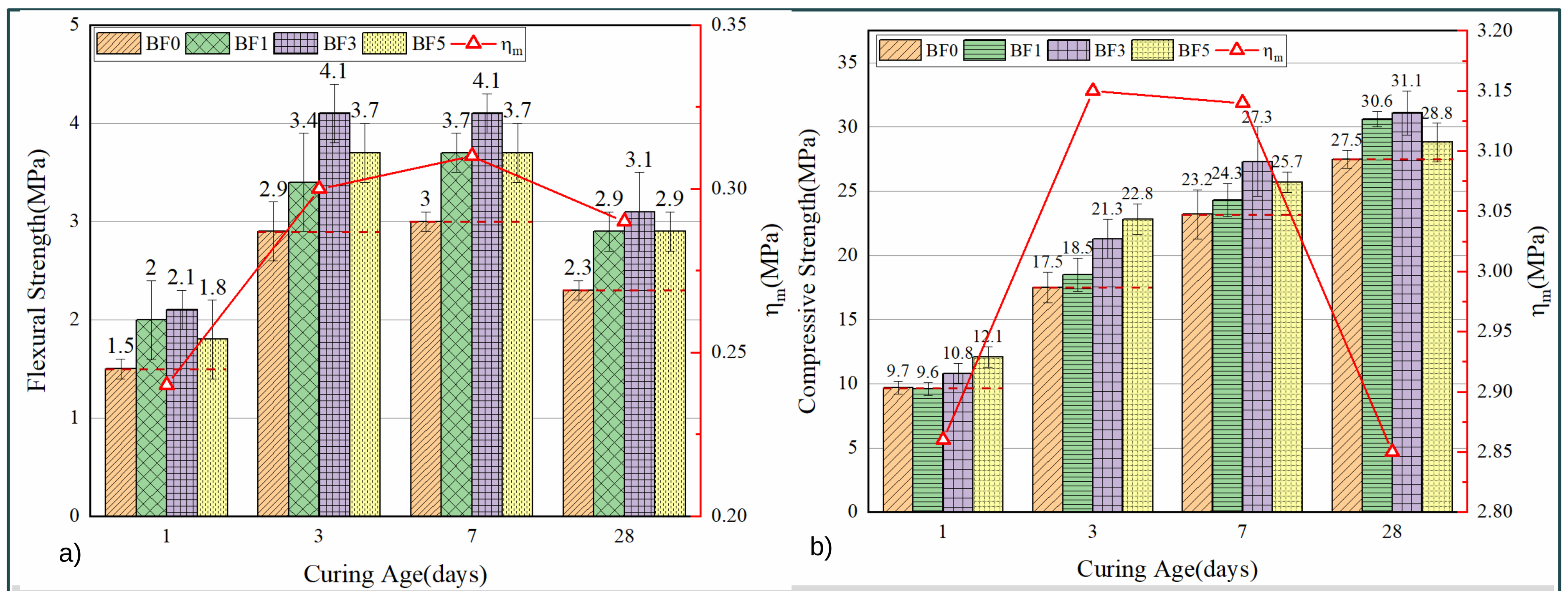

Fig.2 (a) Flexural strength and (b) compressive strength of geopolymer nanocomposites at 1, 3, 7 and 28 d and mass strength efficiency of 28-d strength.

- 7-d compressive strength of BF0, BF1, BF3, and BF5 was 84.3%, 79.4%, 87.8%, and 89.2%, respectively, of that at 28 d.
- The BF1, BF3 and BF5 geopolymer nanocomposites reinforced 28-d compressive strength by 11.3%, 13.1%, and 4.7%, respectively.
- MSE values of the 28-d compressive strength of BF0, BF1, BF3, and BF5 were 2.86, 3.15, 3.14, and 2.85, respectively.

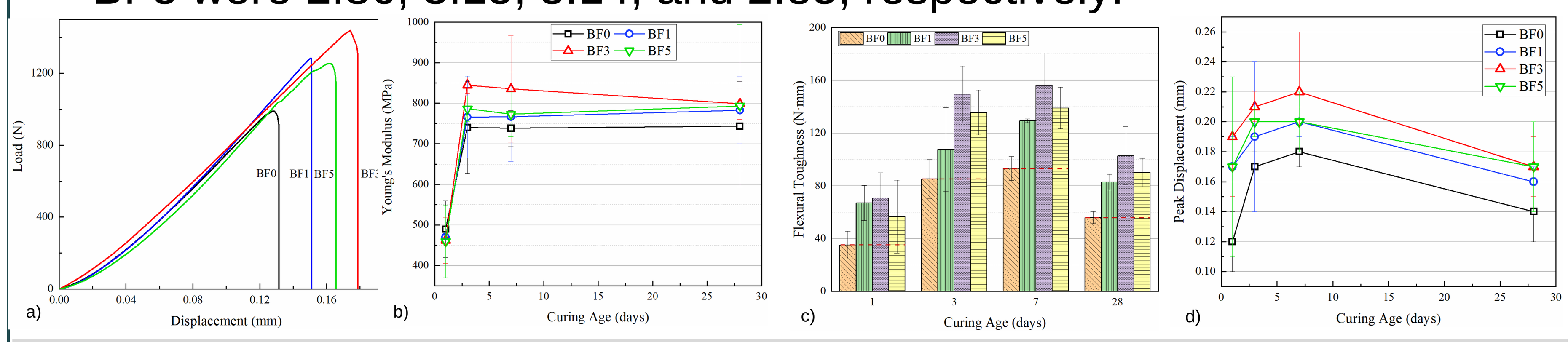

Fig.3 (a) Load-deflection curves of 28-d geopolymers, (b) Young's modulus, (c) flexural toughness and (d) peak displacement of 1-, 3-, 7-, and 28-d BF0, BF1, BF3, and BF5.

- Peak load, peak displacement, and the area between the curves and the x-axis increased significantly in load-deflection curves.
- BF3 was the optimal group, with 7.5%, 83.9%, and 21.4% increase in Young's modulus, flexural toughness, and peak displacement at 28 d.

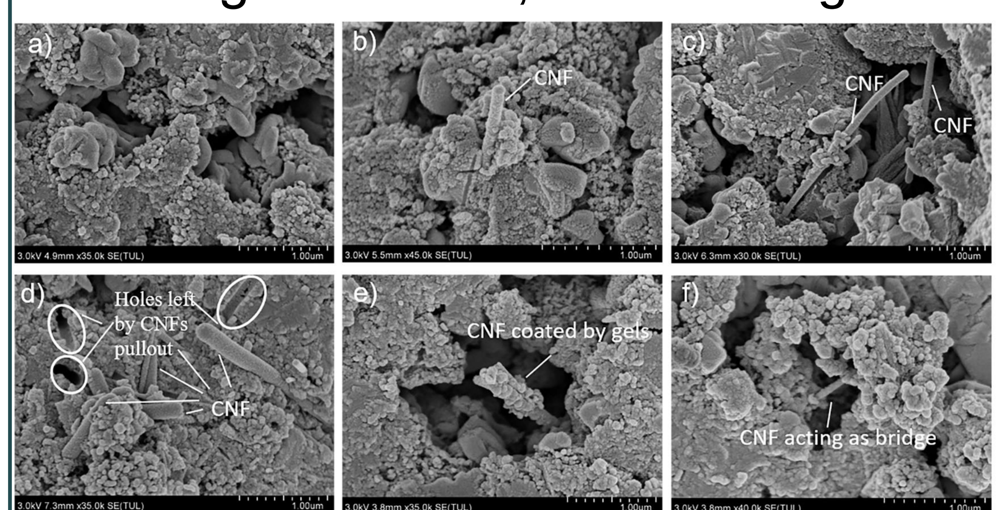

Fig.4 SEM images of CNFs' different effect.

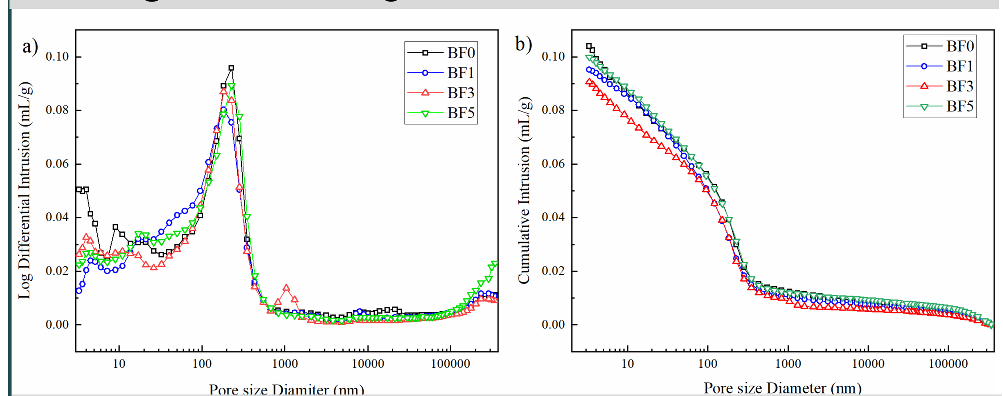

Fig.4 SEM images and MIP test results for 28-d BF0, BF1, BF3 and BF5 geopolymers.

Microstructural Analysis

- CNFs in geopolymers bonded effectively with the geopolymer matrix, filled the cavities and bridged the microcracks in nanoscale. Extra nucleation sites were provided to form geopolymer gels that improve hardness and pore structures of nanocomposites.
- Relative to BF0, porosity of BF1, BF3, and BF5 decreased 7.3%, 10.7%, and 4.4%, respectively, corresponding to compressive strength at 28 d.

Conclusion

The dispersion method of ball-milling CNFs together with lunar regolith simulant has potential because it was shown to be simple and effective. The addition of CNFs in different amounts can prominently reinforce the mechanical properties of geopolymer nanocomposites based on lunar regolith simulant to different degrees, especially in flexural strength and flexural toughness. CNFs play a nucleation, bridging, filling, and pulling role in the geopolymer.

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