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Editorial

Investigation and Application of Fractals in Civil Engineering Materials

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Fractals is a new branch of nonlinear science that was established in the 1970s, focusing on irregularities, haphazard phenomena and self-similarities in nature. In recent years, fractal theory has been widely utilized in many fields. Civil engineering materials, such as rock and soil materials, concrete, composite materials, etc., are widely used and indispensable in our society and economy. Civil engineering materials are not limited to these conventional materials listed above and may also include new materials, e.g., 3D-printed materials, geopolymers, and other innovative, sustainable materials [1]. It has been proven that the microstructures of civil engineering materials present fractal features on some scales. In addition, some important macro-properties of civil engineering materials such as cracking behavior and mechanical properties can be characterized by various fractal dimensions.

The Special Issue, "Investigation and Application of Fractals in Civil Engineering Materials", focuses on the investigation and application of fractal theory in civil engineering materials. This Special Issue gathers fourteen papers regarding fractal studies on civil engineering and construction materials, including geotechnical engineering, cement-based materials, fiber-reinforced materials, geopolymer materials, soil materials, cracks and fractures, etc.

An overview of these papers is given as follows.

Coal and rock dynamic disasters occur frequently in deep coal mining. In the work conducted by Liu et al. [2], the uniaxial compression acoustic emission (AE) tests of bump-prone coal under various loading rates were carried out, and the mechanical properties, AE spatiotemporal evolution, and spatial fractal characteristics were analyzed. The results indicate that the uniaxial compressive strength is positively related to the loading rate, and the elastic modulus increases while the loading rate decreases. The spatial evolution of AE events of coal samples under various loading rates is the same. The AE spatial fractal dimension ranges from 2.1 to 2.9. There exist some differences in fractal dimension evolution at various loading rates.

Soil drying cracking is a major problem in engineering science. In Zhao et al.'s [3] work, fractal dimension is proposed to characterize the drying cracking characteristics of composite soil by adding recycled waste brick micro-powder. Their results show that the fractal dimensions of the soil samples added with recycled waste brick micro-powder of different contents increased over time, and the ones of the soil samples without recycled waste brick micro-powder were larger than those of the soil samples with recycled waste brick micro-powder. With the increase in the content of recycled waste brick micro-powder, the maximum fractal dimension decreased from 1.74 to 1.45, fractal characteristics of the cracks gradually changed from complex to simple.

Fractal theory can be used to describe the formation and development of the fracture network and to characterize its structure. In Zhao et al.'s [4] work in this Special Issue, the fractal dimension, equivalent hydraulic conductivity (K), and equivalent non-Darcy coefficient of the fracture network are calculated, and the influence of the fractal dimension on K is studied. The results indicate that the fractal dimension of the fracture network has a sizable effect on K; with the increase in size, the fractal dimension of the fracture network undergoes three stages: rapid increase, slow increase, and stabilization.

Yang et al. [5] investigated the fractal characteristics of the desiccation cracking of soil under different substrate contact and permeability conditions. The crack morphology under different spacings was also analyzed quantitatively using digital image processing technology. They found that the fractal dimensions of three soil substrate contact conditions (grease, geomembranes, and geotextiles) were between 1.238 and 1.93. When the crack network on the soil surface stops developing, the fractal dimensions under the three experimental conditions are 1.88, 1.93, and 1.79, respectively.

Zhang et al. [6] analyzed the effect of municipal solid waste incineration fly ash (MSWIFA) content on the mechanical performance and pore structure of geopolymer mortar by conducting compression and mercury intrusion porosimeter (MIP) tests. The results showed that the compressive strength of geopolymer mortars decreased while the total pore volume and total specific surface area of mortars increased with the increase in MSWIFA content. The pore structure in the mortars showed scale-dependent fractal characteristics. All fractal curves were divided into four segments according to the pore diameter, namely, Region I (<20 nm), Region II (20–50 nm), Region III (50–200 nm), and Region IV (>200 nm).

To analyze the relationship between the gas entrainment by carbon nanotube (CNT) dispersion and mortar strength, Guo et al. [7] employed data obtained from strength and micropore structure tests of CNT dispersion-modified mortar. The fractal dimensions of the pore volume and pore surface, as well as the box-counting dimension of the pore structure, were determined by the box-counting dimension method and the Menger sponge model. Their results showed that the complexity of the pore structure could be accurately reflected by fractal dimensions. Moreover, the gray correlation between the fractal dimension of the pore structure and strength of the CNT dispersion-modified mortar exceeded 0.95, indicating that the pore volume distribution, roughness, and irregularity of the pore inner surface were the primary factors influencing the strength of CNT dispersion-modified mortar.

In Chen et al.'s [8] study, porous alumina was prepared via a sacrificial template method using alumina as the matrix and starch and carbon fibers as the pore-forming agents. A fractal model based on the measured MIP data was used to calculate and evaluate the fractal dimension (D_s) of porous alumina. Their results show that the pore size distribution of porous alumina was double-peak when the content of the pore-forming agent was 20, 30, or 50 vol.%. The D_s values decreased with an increase in the pore-forming agent content. Furthermore, D_s was negatively correlated with porosity, most probable pore size, and median pore diameter and positively correlated with the bending strength of porous alumina.

Fang et al. [9] investigated the effects of the contents and ratios of the pore-forming agents (graphite) and the aspect ratios of carbon fiber (CF) on the microstructure, mechanical properties, pore size, and pore-size distribution of the porous alumina ceramics. In addition, the surface fractal dimension (D_s) of porous alumina ceramics was evaluated. Their results reveal that, with the increase in the content of the pore-forming agent, the porosity of the samples gradually increased to a maximum of 63.2%. The pore structure of the porous alumina samples showed obvious fractal characteristics. D_s was closely related to the pore structure parameters.

Wang et al. [10] produced porous alumina by using 30 vol.%, 50 vol.%, and 70 vol.% of carbon fibers and graphite as pore formers. Their findings revealed that the porous alumina's pore structure and morphology varied with the volume content of the pore formers and their shapes. The porosity and pore size of the porous alumina increased with the increase in carbon fiber content because the carbon fiber was unfavorable to the densification of the initial billet before sintering. The pore structure of the porous alumina samples showed prominent fractal characteristics, and its D_s decreased with the increase in the pore former content. The samples' D_s was highly negatively correlated with the pore structure parameters and was positively correlated with the flexural strength.

The resistance of face slab concrete to permeability is the key factor affecting the operation and safety of CFRDs. In Wang et al.'s work, the influences of fly ash dosages on the permeability property of face slab concrete were investigated. Their results illustrate that: (1) The incorporation of 10–50% fly ash raised the average water-seepage height (D_m) and the relative permeability coefficient (K_r) of the face slab concrete by about 14–81% and 30–226% at 28 days, respectively. At 180 days, the addition of fly ash improved the 180-day impermeability by less than 30%. (2) The permeability of face slab concretes is closely correlated with their pore structures and D_s.

In Wang et al.'s work, the effects of fly ash with four dosages on the drying shrinkage, autogenous shrinkage and the cracking resistance of face slab concrete were studied. The findings demonstrate that the incorporation of 10–40% fly ash could slightly reduce the drying shrinkage by about 2.2–13.5% before 14 days of hydration, and it could reduce the drying shrinkage at 180 days by about 5.1–23.2%. Moreover, the D_s of face slab concrete is closely related to the concrete pore structures. The D_s of face slab concrete at a late age increases from 2.902 to 2.946 with the increasing of the fly ash dosage. The pore structure and D_s are closely correlated with the shrinkage of face slab concrete.

Li et al. [11] studied the surface cracking and fractal characteristics of calcium carbonate whisker-reinforced cement pastes subjected to high temperatures. They reported that at 400 °C, the surface crack area, length, and fractal dimension of cement pastes specimen increases from 0 to 35 mm^2, 100 mm, and 1.0, respectively. When the temperature is above 900 °C, the calcium carbonate whisker (CW) and other hydration products in the specimen begin to decompose, causing the surface crack area, length, and fractal dimension of the cement paste specimen to increase from 0 to 120 mm^2, 310 mm, and 1.2, respectively. Compared with the length and width of cracks, the area, and fractal dimension of cracks are less affected by the size and shape of the specimen.

Peng et al.'s study collects and evaluates thermodynamic data at 25 °C and a pressure of 0.1 MPa and establishes the hydration reaction model of magnesium phosphate cement (MPC) pastes. The result shows that a small magnesium–phosphorus molar (M/P) ratio is beneficial for the formation of main hydration products. After the porosity comparison, it can be concluded that the decreasing of M/P and W/B ratios helps reduce porosity. In addition, the fractal dimension D_f of MPC pastes is positively proportional to the porosity, and small M/P ratios as well as small W/B ratios are beneficial for reducing the D_f of MKPC pastes.

In Li et al.'s [12] study, the relationship between steel corrosion and the fractal dimension of concrete surface cracks is investigated. Reinforced concrete prisms with steel bars of different diameters and with different corrosion rates were evaluated. High-resolution images of cracks on the surfaces of these specimens were captured and processed to obtain their fractal dimensions. Finally, a relationship between the fractal dimension, steel bar diameter, and the corrosion rate is established. The results show that the fractal dimension is associated closely with the corrosion rate and steel bar diameter.

It is expected that the collected 14 papers may help to inspire new ideas and provide a basic guide for researchers who want to study civil engineering materials in terms of fractal theory. The purpose of this Special Issue is to promote the deeper and wider investigation and application of fractal theory in civil engineering and material science.

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