Study on Force-chain-resistance Network Structure of Pressure Control Granular Material

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Abstract— Based on the good conductive properties of pressure control granular materials, this paper selects a typical pressure control material titanium diboride (TiB_2) as the research object, through the effect of the change of the pressure control resistance value of the particles. Firstly, the force chain structure of particles at different heights was studied by simulation. Then, a method of constructing force-chain-resistance network is proposed, and the rationality of the model is verified by experiments. Finally, the development law of resistance changes with pressure is deeply analyzed, and the structure of force-chain-resistance network effectively combines macroscopic materials and microscopic particles organically, which provides a certain theoretical basis for the resistance response of granular materials with pressure, and provides a reliable basis for its application in the field of electric power.

I. Force chain network

As shown in Figure 1, the distribution of force chains under different pressures is presented respectively. When the pressure is 400 N, the pressure is borne by a small number of particles in the particle system. It can be seen that the force is transferred between several particles in contact with each other to form a similar chain-like structure. The contact force of the upper part of the particles contacted by the moving contact is larger, and the value of the contact force decreases when it is transferred to the lower particles. It conforms to the development law of granary effect. As the applied pressure increases to 5000 N, the contact force gradually transfers to the lower particles, and its value also gradually increases. The contact force of the upper particles is larger than that of the lower particles. The particles are squeezed closer together, making it easier for forces to transfer between them.

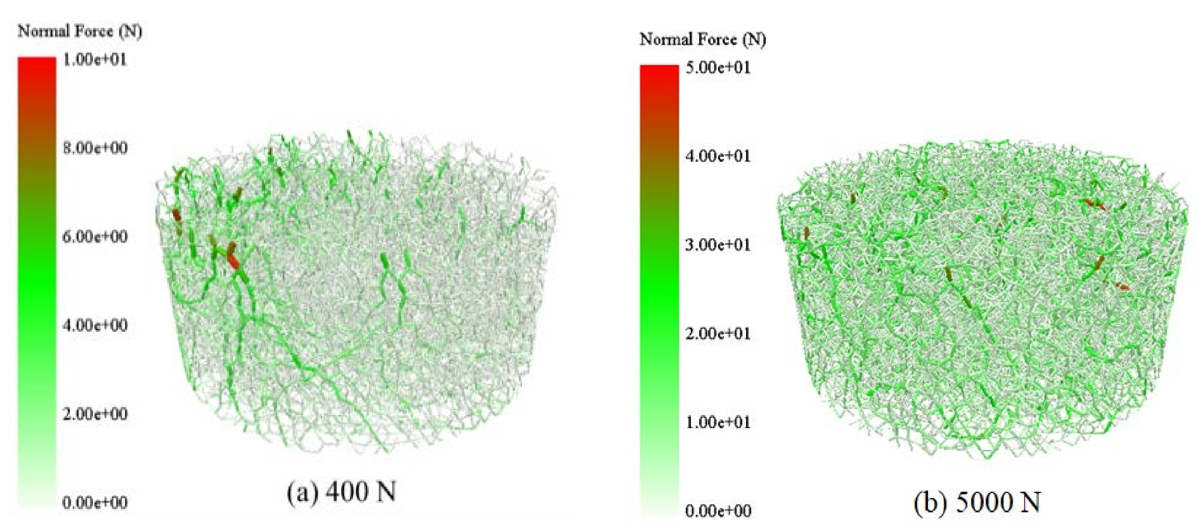

Figure 1. Trend of force chain evolution

II. Transformation of force-chain-resistance network

The main equations are shown in (1) to (4):

$$\frac{\pi D^2}{4}\left(f_{zz}(z)-f_{zz}(z+\mathrm{d}z)-\rho g \mathrm{d}z\right)=\pi D f_s \mathrm{d}z \quad (1)$$

$$\frac{f_{zz}(z+\mathrm{d}z)-f_{zz}(z)}{\mathrm{d}z}=-\rho g-\frac{4\mu K f_{zz}(z)}{D} \quad (2)$$

$$f_0(z)=f_{zz}\mathrm{e}^{z/h} \quad (3)$$

$$R_{\mathrm{j}}=\frac{K_{\mathrm{c}}}{\left(0.102F_{\mathrm{j}}\right)^m} \quad (4)$$

The resistance network is constructed as follows:

- Calculate the strong chain reference value and quantity.
- Scale scaling reduction.
- The contact force of particles at the bottom of the strong chain is the average contact force of particles as a whole.
- Using Equation (3), the contact forces at different positions on the same strong chain can be obtained successively.
- Use Equation (4) to calculate the contact resistance as the series branch and the number of strong chains as the number of parallel branches.

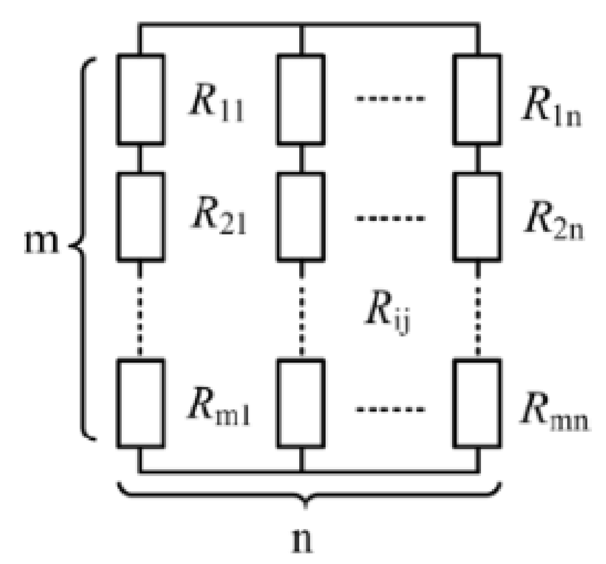

Figure 2. Resistance network.

III. Experiment and Calculation

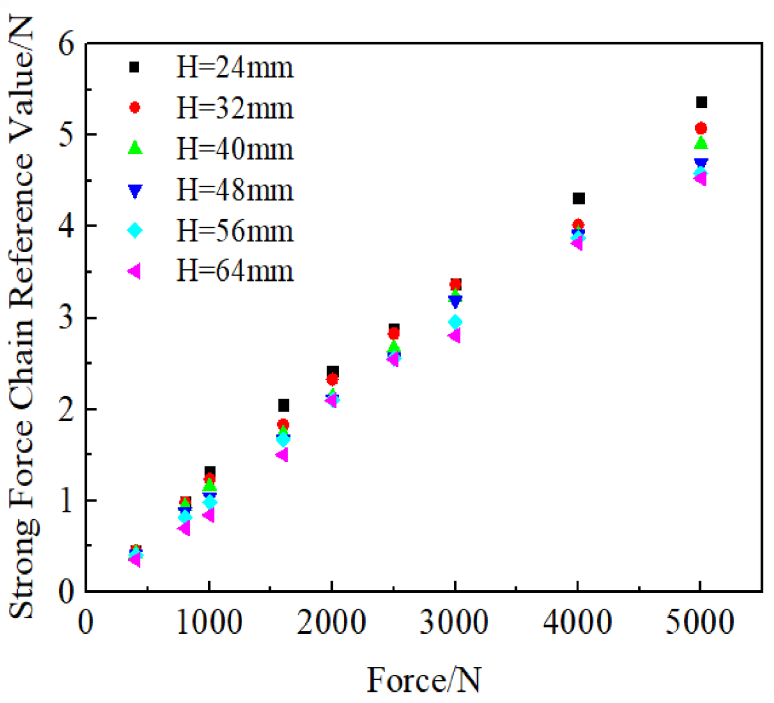

Figure 3. Strong chain reference values at different pressures and heights.

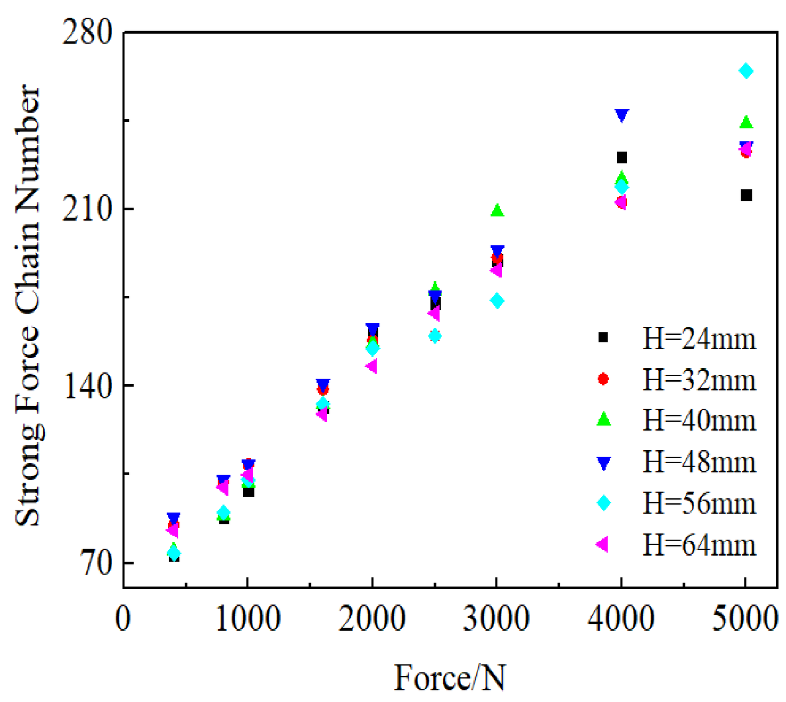

Figure 4. Number of strong chains at different pressures and heights.

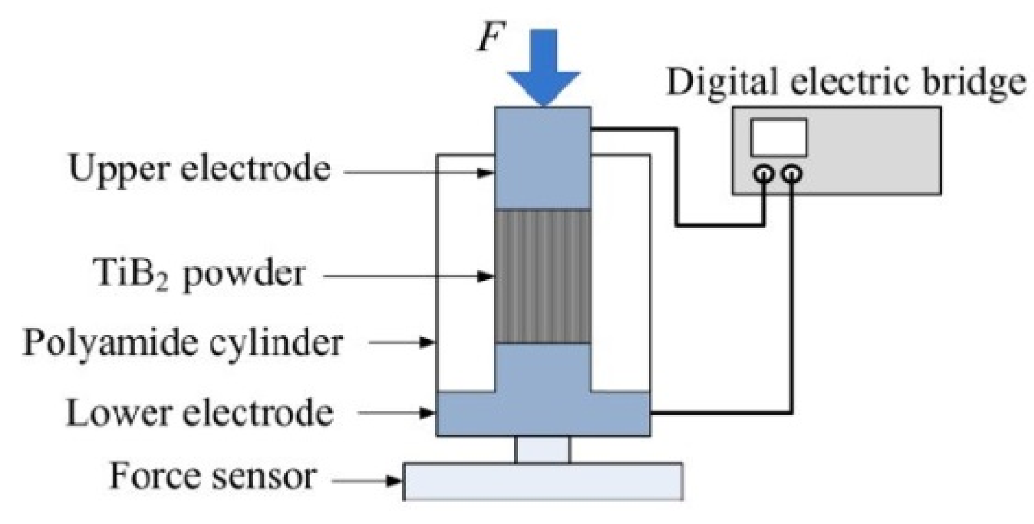

Figure 5. Pressure control resistance value change module test device.

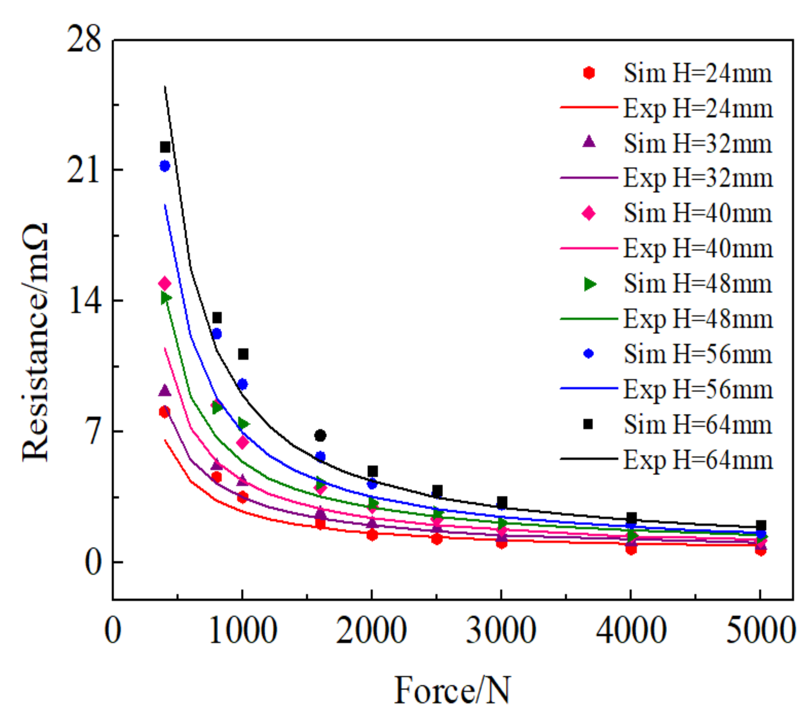

Figure 6. Results contrast.

IV. Conclusions

- TiB_2 particles have good oxidation resistance, and there is no insulating oxide film on the surface of the particles. Therefore, the change of the resistance of the particle system is caused by the change of the force chain structure of the particle system and the change of the contact resistance between particles.
- In the force chain network, the strong chain plays the main supporting role and bears most of the principal stress, so only the strong chain can be considered for the resistance network. Contact resistance is related to the conductive path, and force chains can be thought of as "conductive chains", where strong chains mean shorter conductive paths.
- A method for constructing force-chain-resistance network is proposed. The model is found to be in good agreement with the experimental results, which verifies the feasibility of the model. The reason why the resistance varies with the pressure is explained, and the structure of force-chain-resistance network effectively combines macroscopic materials and microscopic particles. It can be used as a variable resistance in fault current limiting or DC breaking applications.