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Simulations of Shearing Behavior of Magnetorheological Fluids in an Oblique Magnetic Field

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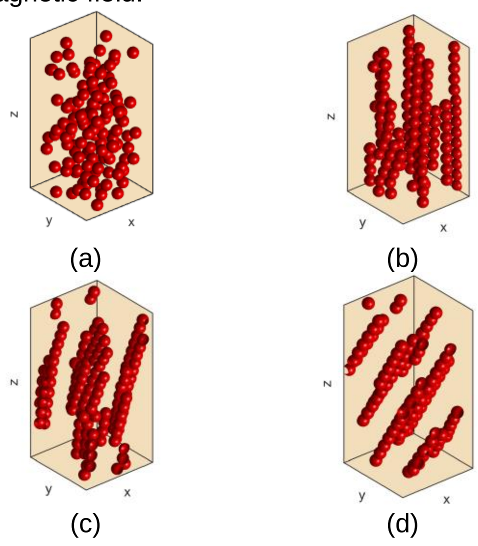
1. Introduction

Particle-level simulation is an effect method to study the microstructure of magnetorheological fluid. In this paper, the particle-level 3D simulation based on DEM was carried out to investigate the shearing behavior of magnetorheological fluids in an oblique magnetic field. The stable chain-like structure without shearing process, the steady shear stress tensor and the angular connectivity were systematically investigated. It was found that the stable chain-like structure showed good agreement with the direction of magnetic field. The stress tensor and the angular connectivity showed significant differences with various tilt angles of magnetic field.

2. Analysis of the simulation results

Figure. 1 shows the snapshots of stable chain-like structures under different magnetic field, where the direction of magnetic lines locates in the z-o-y plane, but with an inclination angle between z axis.

It should be known that the initial location of magnetic particles is the same in these simulations, as shown in Figure. 1(a). It can be seen from Fig.1 that the chain-like structures show significant differences under various tilt angles. The direction of chain-like structure is the same as the direction of magnetic field.



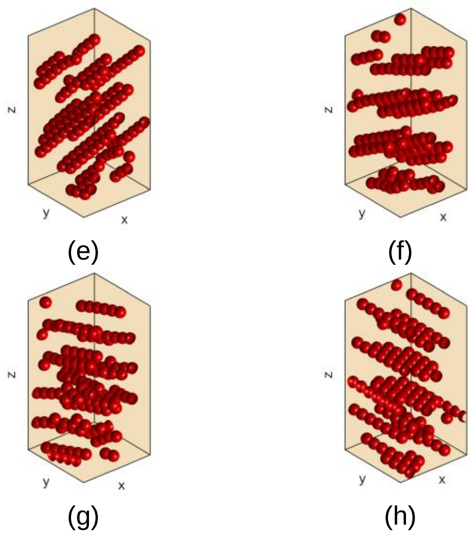


Fig.1 Snapshots of chain-like structures under different magnetic field. (a) initial location. (b) 0° . (c) 15° . (d) 30° . (e) 45° . (f) 60° . (g) 75° . (h) 90° .

The reason of the different chain-like structures is that the magnetic particles are magnetized along the direction of magnetic field.

After the stable chain like structure formation is finished, the steady shearing process was carried out with shear rate $\dot{\gamma} = 1000\ \mathrm{s}^{-1}$. The shear direction is in the positive direction of y-axis. Figure. 2 show the stress tensor as a function of shear strain under different tilt angle of magnetic field.

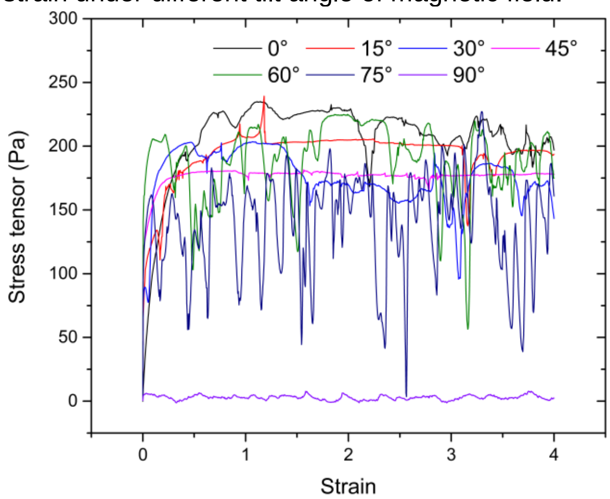


Fig.2 Stress tensor as a function of strain

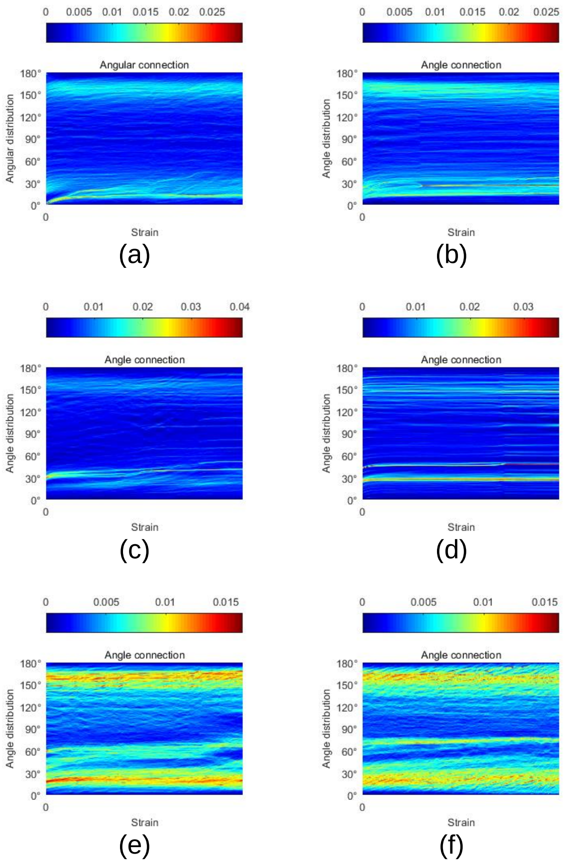
It can be seen from Fig. 2 that the stress tensor fluctuates within some range in each case. But the curve of stress tensor fluctuates gently when the tilt angle is no more than 45° , conversely, the curve of stress tensor fluctuates violently when the tilt angle is 60° or 75° . And when the tilt angle comes to 90° , the stress tensor is almost zero, which means that there is no magnetorheological effect.

The study of stress tensor reveals that the shear behavior of magnetorheological fluids is different in different oblique magnetic fields. Also, it is known that the shear behavior of magnetorheological fluids is related to the microstructure of magnetic particles. Therefore, to further understand the reason causes such differences, the angular connectivity of magnetic particles is investigated, which is calculated as

$$C(\theta) = \frac{1}{N}\sum_i \frac{n_i(\theta)}{N-1} \quad (0 \le \theta < \pi)$$

where N is the total number of magnetic particles, θ is the angle between the positive direction of z axis (the magnetic field direction) and the vector joining the centers of the two particles, and $n_i(\theta)$ is the number of the particles whose centers are located in the range of θ and $\theta + d\theta$ of particle i.

Figure. 3 shows the evolution of angular connection $C(\theta)$ as a function of strain.



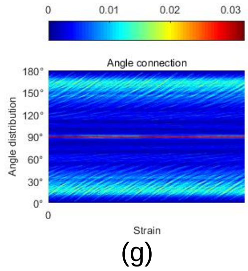


Fig.3 The evolution of angular connection as a function of strain (a) 0° . (b) 15° . (c) 30° . (d) 45° . (e) 60° . (f) 75° . (g) 90° .

The evolution angular connection is able to reflect the microstructure change as the strain increase. It can be seen that the chain like structure begin to gradually tilt in the beginning of shear process when the tilt angle of magnetic field is no more than 45° , corresponding to the gentle fluctuation of stress tensor. However, the change of microstructure is disorderly when the tilt angle is 60° or 75° , and the microstructure is almost no change when the tilt angle is 90° .

Acknowledgment

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