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Failure Characteristics of Sandstone with Different Water Content

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Abstract

In order to study the influence of water content on the failure and deformation characteristics of sandstone, the indoor compression test and numerical simulation of sandstone under different conditions were carried out. The results show that with the increase of water content, the peak strain increases and the peak strength decreases. With the increase of water content, the transverse and longitudinal strains of rock samples gradually increase. This conclusion can provide reference for the safe construction of underground engineering in water-rich areas.

Keywords

Sandstone; Water Content; Failure Mode; EDEM.

1. Introduction

Water has always been the main cause of natural disasters, such as rockburst, water inrush and large deformation, which are closely related to water intrusion. Moisture content has a great weakening effect on rock strength, so it is necessary to study moisture content for sandstone failure mode, peak strength and internal crack evolution, which plays a vital role in the development of Weilai underground engineering in China[1, 2].

2. Test and Simulation

2.1. Establishment of Numerical Model

EDEM is an advanced discontinuous medium program software based on discrete element method. It can be used to study the fracture problem of rock-like materials which are essentially particle aggregates, and can reflect the crack evolution characteristics and failure mechanism of the medium under stress conditions. The EDEM rock model is ideally combined by a set of particles, and the size distribution of the particles allows the simulation of geometric inhomogeneity, which is an advantage over the continuum model. The Hertz-Mindlin with bonding (HMB) model is included in the EDEM software. As shown in Figure 1, the two particles are connected by a bond to produce strength.

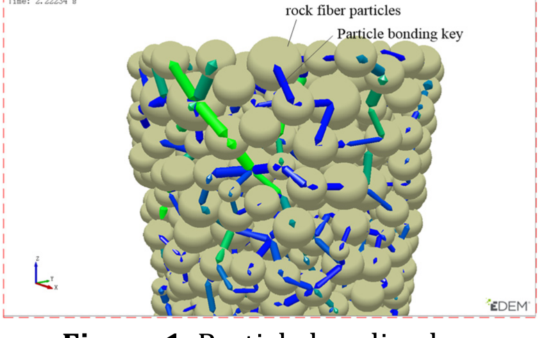

Figure 1. Particle bonding key

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The biggest difference between EDEM and PFC discrete element software is that gravity accumulation can be simulated when particles accumulate, which makes the numerical simulation stress-strain curve obtained by simulating uniaxial compression fit the reality to the greatest extent, and can also well reflect the curve in the initial compaction stage. Based on the particle flow theory, the EDEM program is used to simulate the failure process of rock samples under uniaxial compression. First, a numerical analysis model that is completely consistent with the size of the sandstone sample is generated in the program. The model is composed of particles, and the four sides are constrained by setting walls. Based on the Hertz-Mindlin with bonding (HMB) contact model of EDEM software, the model particles are bonded to produce strength. After completion, the side wall is deleted, and the loading process is simulated by giving the top wall motion rate. The numerical model establishment process is shown in Figure 2. The loading speed is the same as that of the physical test, which is 0.001 mm / s.

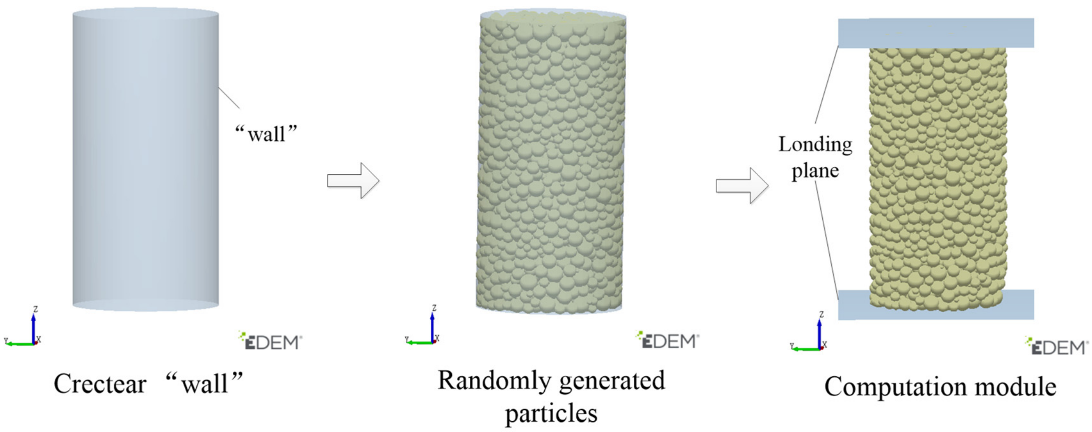


Figure 2. Numerical model establishment process

Using numerical calculation method to simulate rock, the main controlling factors of the results are compressive strength and Poisson 's ratio. Figure 3 shows the comparison between the stress-strain characteristics obtained from the test and the EDEM simulation results. EDEM simulation results show that the peak strength of the material is 52.2 MPa and the elastic modulus is 11.078 GPa. Similarly, the peak strength of the rock material obtained by the test is 48.835 MPa and the elastic modulus is 6.418 GPa. The results show that the deviation between the test and numerical analysis in terms of strength is about 36 %, and the elastic modulus is different.

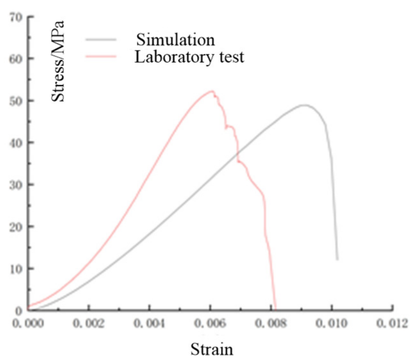


Figure 3. Sandstone laboratory test and numerical simulation stress-strain curve

EDEM has a particle contact model JKR, which simulates particle water content by adding energy to the particle surface. After several tests, it was finally determined that the no slip contact model was used in the dry state, the natural state Surface Energy was 10 J/m^2, and the saturated state Surface Energy was 20 J/m². The Hertz-Mindlin with JKR action mode and surface energy setting interface are shown in Figure 4.

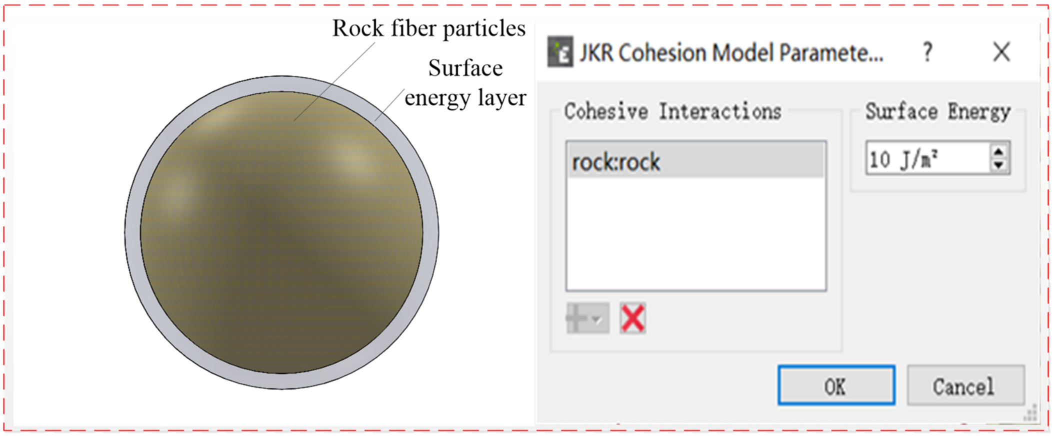
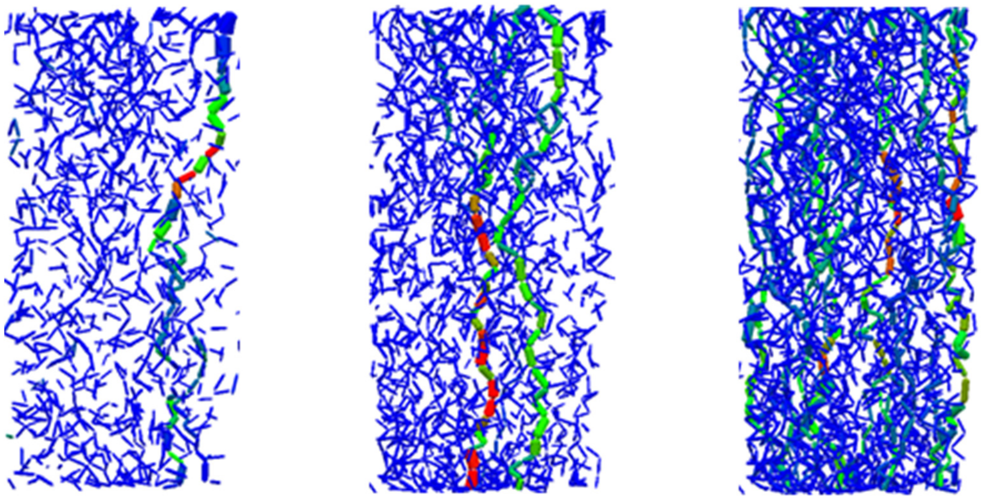


Figure 4. Particle surface energy and related parameter settings

2.2. Numerical Simulation Results Analysis

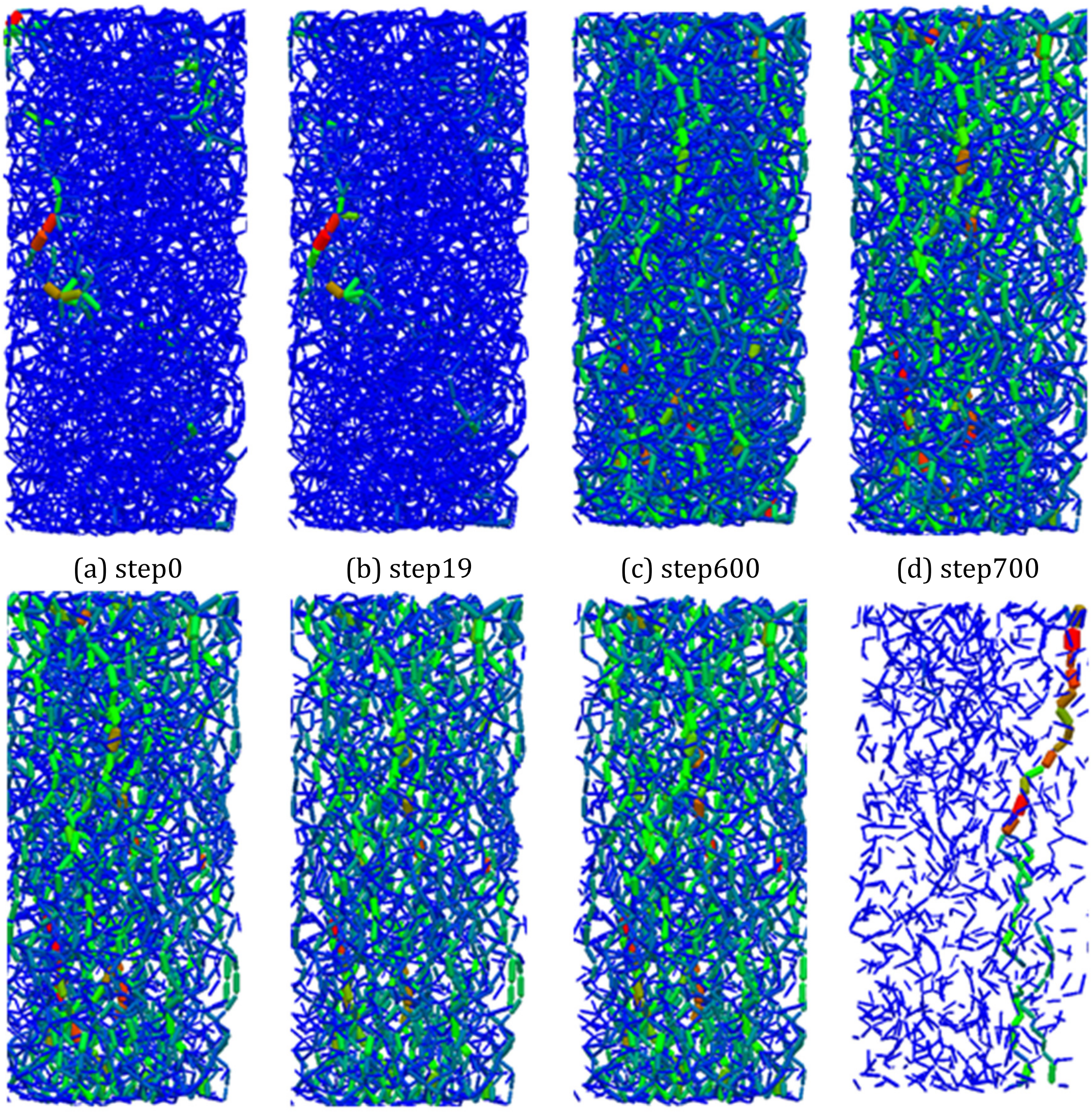
Figure 5 shows the crack distribution of rock samples with different water content. As shown in Figure 5(a), the crack is a penetrating shear crack when the dry rock sample is destroyed, and the failure form is shear failure. When the rock specimen is destroyed in the natural state (Figure 5a), there are two vertical tensile cracks inside the rock specimen, and the failure mode of the rock mass changes from shear failure to tensile failure. The saturated rock sample is destroyed (Figure 5c). At this time, the tensile cracks of the sample are fully developed, the ultimate performance is typical tensile failure, and the degree of rock fragmentation is more serious than the former. The failure modes of rock samples under different water contents are consistent with the actual situation.



(a) drying (b) nature (c) saturated

Figure 5. Crack distribution of rock samples in different water-bearing states during failure

Figure 6 shows the crack propagation in the whole loading process of dry rock samples. The damage generation of rock model in eight time steps is shown in the figure. The axial stresses applied at each time step are 0,3.2,15.484,22.5,29.982,61.625,77.42 and 60.99 MPa, respectively. In the figure, the blue bond is the initial connection stress, and the green and red bond indicate that the force increases. In the initial stage of step 0 (shown in a), the rock basically has no additional stress bond, and a small amount of stress bond may be caused by the incomplete stability of the particles when the bond is generated. When 600 steps of micro-cracks are generated (shown in c), the force of some bond bonds in the rock mass increases, and there is a trend of connection and penetration. In the 700-step elastic stage (d-f), compared with the previous stage, the number of bond bonds increased significantly, and the cracks appeared small-scale penetration ; at the peak stage of 2200 steps (g), a small number of bond bonds have broken at the edge of the model, corresponding to the peak stress during the loading process.



(a) step0 (b) step19 (c) step600 (d) step700

(e) step1200 (f) step1700 (g) step2200 (h) step2400

Figure 6. Crack propagation in the whole loading process of dry rock samples

Figure 7 is the axial strain change trend corresponding to the peak stress of rock sample test and numerical calculation with different water content. From the diagram, it can be seen that with the increase of water content, the radial strain change trend of rock sample failure in numerical simulation and indoor test is rising. In theory, due to water, the internal cementation of rock sample is weakened, the hardness is reduced, and the plasticity is better. The radial strain should indeed increase with the increase of water content, and the results are consistent. Through careful observation, it can be found that the failure strain values of numerical simulation are higher than those of laboratory tests in each state, which may be related to the fact that Hertz-Mindlin with JKR model only acts on the surface of particles, while in reality water will immerse into the sandstone particles. In addition, it may also be related to the use of compressive strength and Poisson 's ratio as similar criteria for simulation.

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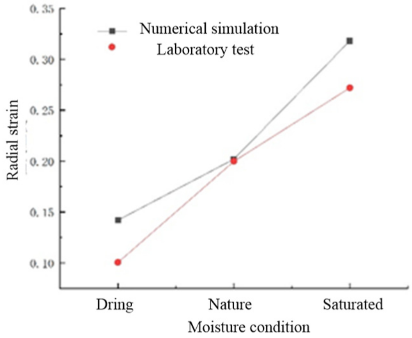

Figure 7. The radial strain at the peak stress of rock specimen in laboratory test and numerical simulation

2.3. Strain Analysis of the Whole Loading Process based on Photoinfor

Figure 8 is the uniaxial compression stress-strain curve of dry sandstone samples. In order to facilitate the subsequent analysis, five characteristic points were selected on the curve, that is, before the peak intensity, 0.30 peak (point a), corresponding to the compaction point of the rock, and 0.85 peak (point b), corresponding to the yield point of the rock ; at the same time, the peak stress peak (point c) is selected ; after the peak intensity, 0.93 peak (point d) and 0.67 peak (point e) were selected.

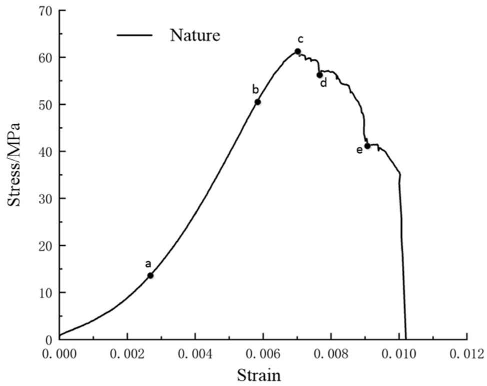

Figure 8. Uniaxial compression stress-strain curve of dry sandstone

Combined with the axial strain cloud diagram of the rock sample, it can be seen that the rock sample exhibits a shear failure mode under uniaxial compression in the natural state, and the shear cracks are symmetrically distributed in the two observation areas of region 1 and region 2.

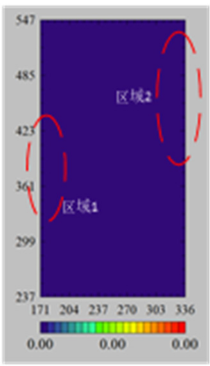

Figure 9. Uniaxial compression stress-strain curve of dry sandstone

The five points correspond to the evolution cloud map of the axial strain field as shown in Figure 10. It can be seen from Figure10 (a) that in the compaction stage (point a), the color of the axial strain field cloud map is relatively consistent, indicating that the rock surface deformation is

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more uniform. This indicates that there is no obvious crack on the rock surface before the peak strength. The results are consistent with the actual rock samples. It can be observed from Figure 10 (b) that when the stress reaches the yield strength, the strain cloud diagram produces a slight strain concentration phenomenon. There are no obvious cracks on the surface of the rock sample, indicating that the strain concentration has not yet reached the level of macroscopic cracks. At the peak strength moment, the range and magnitude of the strain concentration area on the strain cloud map of the rock sample increase. As shown in Figure 10 (c), the visible macroscopic deformation also appears in Region 1 in the actual picture. At 0.93 peak after the peak, the range and magnitude of the strain concentration area on the strain cloud diagram of the rock sample continue to increase, as shown in Figure 10 (d). At the moment of 0.67 peak failure (see Figure 10e), clear deformation localization bands appeared in both region 1 and region 2 of the strain cloud diagram of the rock specimen, indicating that the rock specimen has undergone macroscopic fracture, which is consistent with the actual situation.

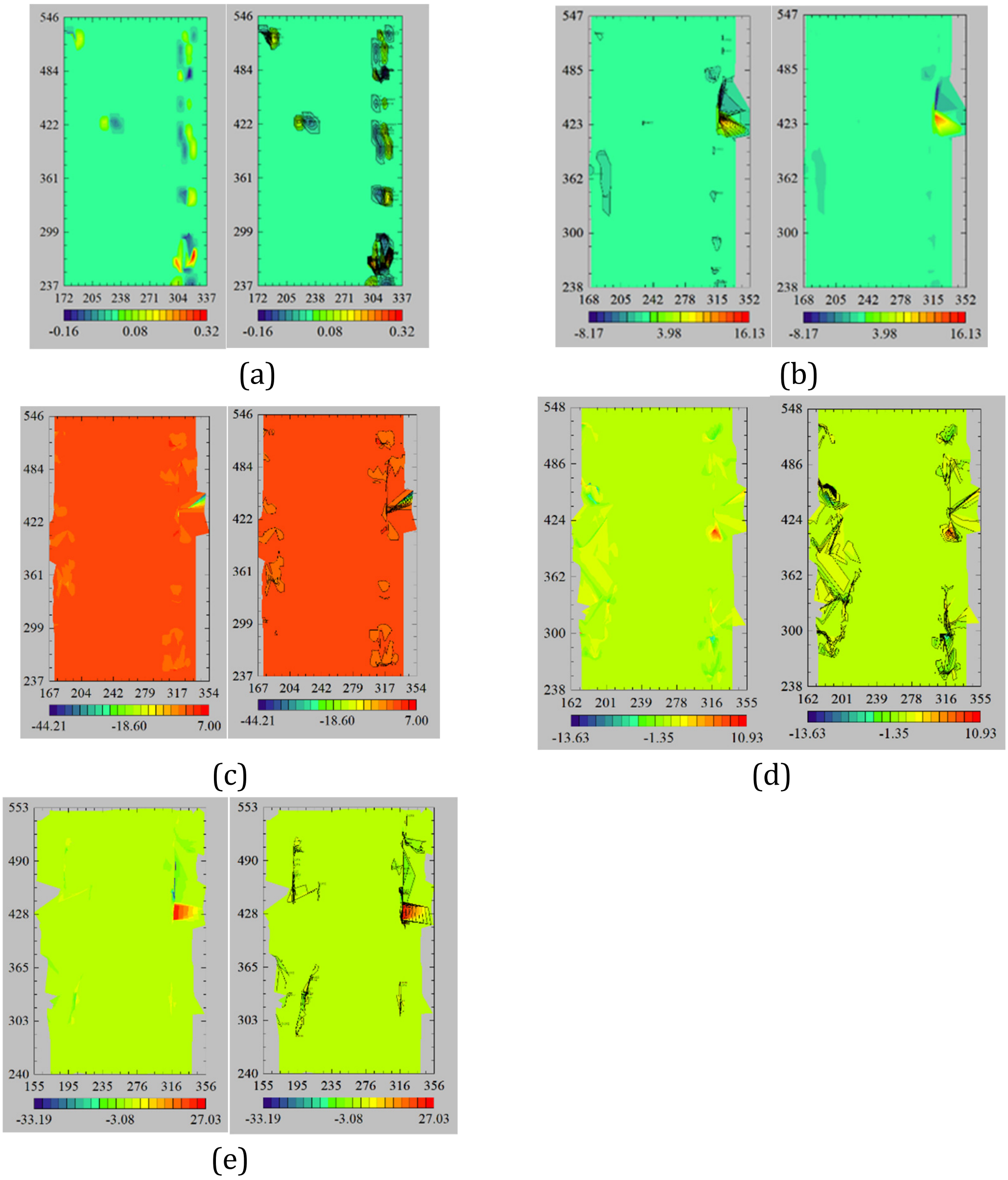

Figure 10. Transverse strain cloud diagram of rock sample loading process

Figure 11 is the radial strain field evolution cloud map of sandstone samples at five typical moments. It can be seen from the figure that before the peak strength (as shown in Figure11a),

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the color of the radial strain field cloud diagram of the rock sample is relatively consistent, indicating that the surface deformation of the rock sample is more uniform. When the peak strength is reached (as shown in Figure11 b), the strain cloud diagram shows a slight strain concentration and the value is small. At 0.93 peak and 0.67 peak after the peak strength(see Figure11dand 11e), the strain concentration phenomenon of the cloud map is further deepened, and the macroscopic fracture area can be seen on the rock sample.

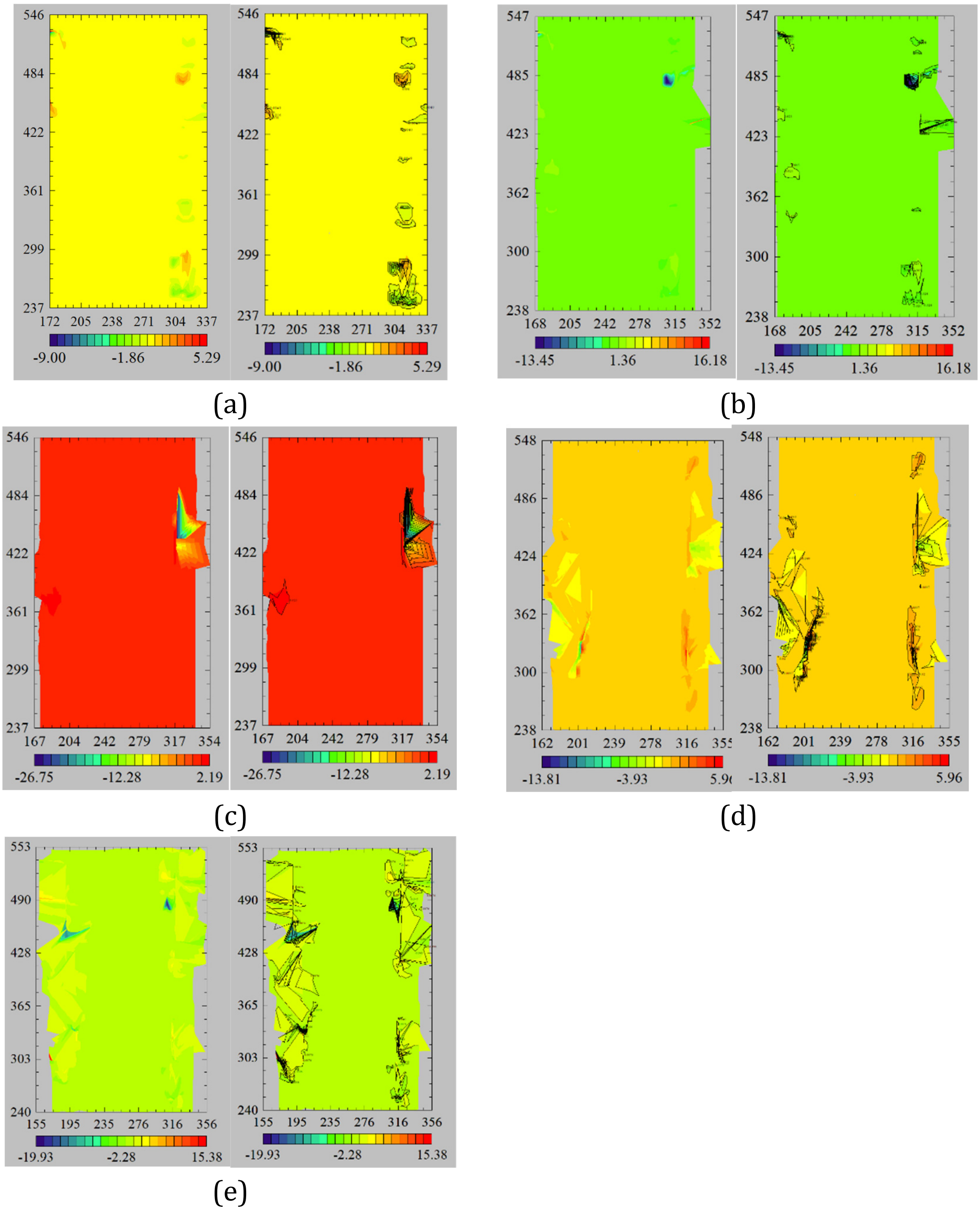

Figure 11. Longitudinal strain cloud diagram of rock sample loading process

3. Conclusion

In this paper, the conventional triaxial tests of sandstone with different water content under different confining pressures are carried out, and the indoor test is simulated by discrete element software to further study the internal influence of water on sandstone failure. The following conclusions are obtained:

(1) Compared with dry sandstone, the peak strength of natural sand sample was 61.27 MPa, which decreased by 16.13 MPa and reached 26.38 %. The peak strength of the saturated sand sample was 52.24 MPa, which decreased by 25.16 MPa and decreased by 48.16 %. The peak strength and yield strength of sandstone decrease with the increase of water content.

(2) Through the comparison of transverse and longitudinal strain nephogram, it is found that the deformation of sandstone with different water content is different at the same loading time. The general trend is that with the increase of water content, the deformation of rock sample increases gradually.

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