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Reconstructed method of porous sandstone and mechanical properties research

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Abstract. Based on the statistic theory and image processing technology, a three-dimensional reconstructed model of pore structure for sandstone is established. On the basis of the model, the numerical simulation experiment is carried out to analyze the influence of pore structure parameters (pore size, shape and porosity) on the deformation, stress distribution and failure distribution of sandstone under the splitting load. The research results show that the effect of void morphology on the damage of sandstone is obvious. With the change of the pore shape from the ellipsoid to the sphere, the fracture zone of the splitting disc is increased and more dispersed. With the pore shape is changed from sphere to ellipsoid, the maximum stress along the Y direction is firstly decreased and then increased. When the pore size increases, the failure mode becomes a single tensile failure from an induced-tension-shear failure, and the maximum stress along the Y direction is decreased. But the influence degree is weakened with the increase of the pore size of the model. Along with the increase of the porosity, the maximum stress along the Y direction is increased, therefore, the sandstone is easy to damage. But the degree of influence decreases with the increase of pore size. The results reveal the influence of the parameters of the pore structure on the mechanical properties of rock, which provide some reference for the study of the effect of pore structure on the rock physical mechanical properties.

1. Introduction

Rock is a kind of natural porous material, and there are a large number of different sizes of the pores in the rocks, and the pores directly affect the physical, mechanical and chemical properties of rocks. Such as strength, elastic modulus, permeability, electrical conductivity, wave velocity, particle adsorption capacity and rock reservoir capacity. Understanding and quantifying characterization of the influence of pore structure on the mechanical properties of rocks is very important for solving practical problems in petroleum, geology, mining, metallurgy, civil engineering and water conservancy projects.[1-6]

In recent years, domestic and foreign scholars made effects on make the reconstructed model and developed considerable researches on the influence of internal rock pore on its macroscopic physical and mechanical properties. ZuoJian-ping and other scholars used image analysis technique to analyse the phenomenon of the three point bending microscopic destruction test of the different depth basalt[7]. Yang Yongming and others adopted similar materials to simulate similar porous rocks, and analyzed the failure mechanism of rock and the changes of its pore structure[8]. Vernik and others studied the relationship between porosity with compressive strength and shear strength of sandstone, and presented the empirical relation model[9]. Clavaud J B and others analysed the effects of different

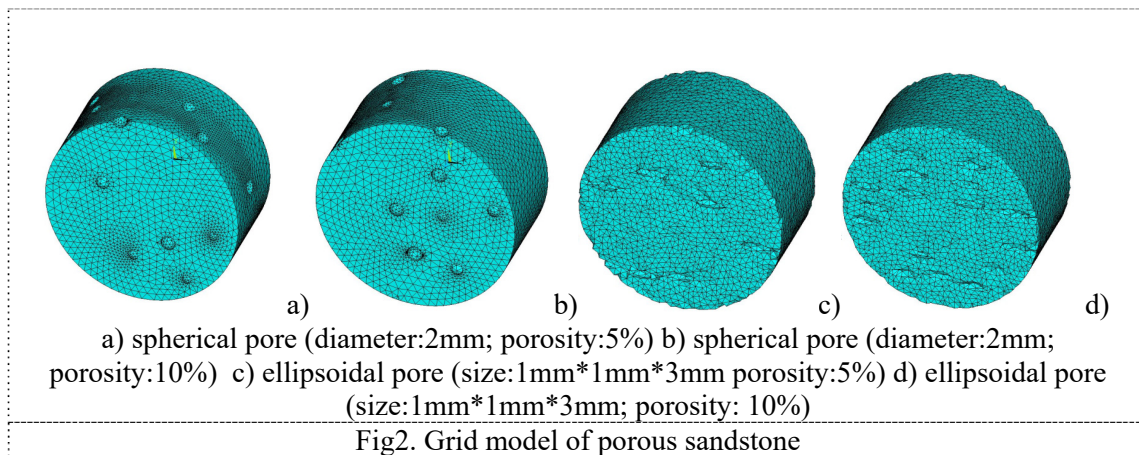
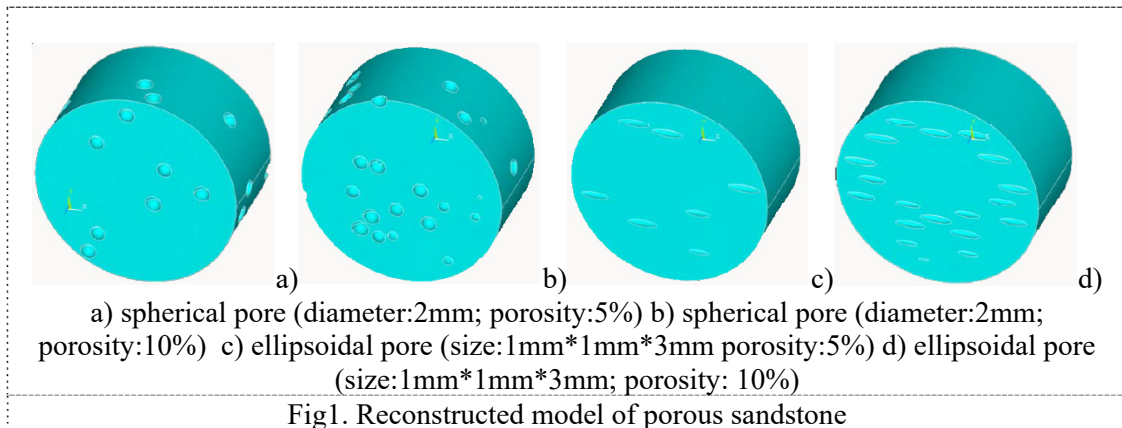


rock pore geometry structure on permeability anisotropy, and found closed relationship in sandstone permeability anisotropy with sandstone inherent bedding[10]. Smith T M and others studied the properties of low porosity and low permeability sandstone, and got the conclusion that the influence of the pore geometry on the elastic modulus of sandstone is more than that of the porosity when the porosity is lower [11]. Palchik and others built a classical model to predict the coupling effect of porosity, elastic modulus and grain size on the uniaxial compressive strength of sandstone under high porosity soft sandstone[12]. M.S.Patserson and others found the trend of the transition of rock about brittleness and ductility with the confining pressure[13]. Ju Yang and others developed and verified the LBM method based on the CT image of pore structure of sandstone [14]. Li Xibing and others made split hopkinson pressure bar experimental study on the granite samples with circular and square holes, and obtained the characteristic parameters of the nuclear magnetic porosity and nuclear magnetic resonance images of granite samples[15]. Above researches revealed the macroscopic influence of pore structure on physical mechanics of rock in some extent. However, it is complex and different for pore structures of natural rocks distributed in different spans. At present, above researches lacks enough understanding toward the influence mechanism of pore on mechanical properties of rock, especially for the influence of pore shape and size on stress distribution, strength, deformation, and fracture of the rock.

In this paper, the statistic principle and image processing techniques are used to establish a three-dimensional reconstruction model of porous sandstone. On this basis, this paper makes a numerical simulation experiment for the splitting of porous sandstone and analyzes the influence law of pore size, shape, and porosity on internal stress field distribution, strength, deformation and fracture of sandstone, revealing the influence mechanism of pore structure on macroscopic mechanical property of rock. This paper provides a reference for the research on revealing the internal relationship between pore structure and mechanical properties of rock.

2. The three-dimensional reconstructed model of porous sandstone

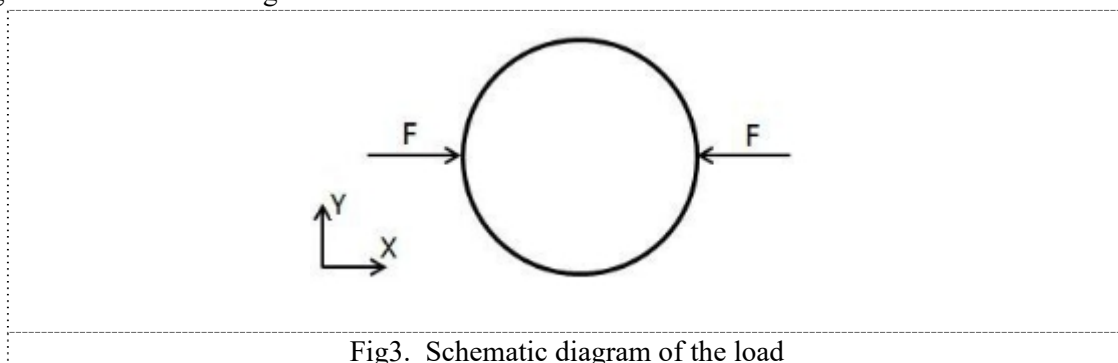
In this paper, we utilizes the statistic principle and images processing and other methods to establish a three-dimensional pore model. On this basis, this paper makes a numeric simulation test for the separation of pore stone. The three-dimensional pore model is reconstructed according to the following steps: according to distribution characteristics of natural sandstone pore position, it can be known that pore obeys to uniform distribution [16]. At first, the statistic principle is used to generate a random number sequence meeting uniform distribution as the space position of pore. Secondly, the finite element analysis software is used to establish the preliminary corresponding model. Then, we divide the model net with the image processing technology in the image processing software. Finally, we import the restructure 3D pore structure into the finite element analysis software. Natural rock is a kind of complicated heterogeneous pore material. Its macroscopic mechanical property, deformation and fracture are correlated with the number, size, shape, distribution and connectivity and other factors of pore. Changing any factor may cause change in the mechanical properties of rock. To analyze the influence of one factor, therefore, this paper makes a research on the influence of pore shape, size and porosity on macroscopic mechanical property, deformation and fracture mechanism of rock by individually changing the pore shape, size and quantity in the model on the premise of maintaining basic mechanical properties basically unchanged. In total, two kinds of porosity and pore shape are designed. At the same time, four kinds of pore diameter are designed for spherical pore, and 2 kinds of pore diameter for ellipsoidal pore. Specific parameters are shown as follows: the porosity includes 5% and 10%. The pore shape includes sphere and ellipsoid. The diameters of spherical pore are 1mm, 2mm, 3mm and 4mm respectively, and the sizes of ellipsoidal pore are 1 mm*1 mm*2 mm and 1 mm*1 mm*3 mm respectively. As an example, Figure 1 gives the spherical pore model (diameter: 2mm; porosity: 5%, 10%) and the ellipsoidal pore model (size: 1 mm*1 mm*3 mm; porosity: 5%, 10%). Geometric dimensions of the model: 50mm (diameter) × 25mm (height). Figure 2 gives a relevant grid model divided.



3. The numerical simulation experiment of the reconstructed model under the splitting load

3.1 The mechanical parameters of sandstone and boundary conduction

This paper takes sandstone as the research object. According to the measured values of the mechanical parameters of sandstone, we determine the parameters of the model as following. The matrix is Mohr Coulomb material model with tensile strength of 1.17MPa and the shear modulus of 7.0GPa, bulk modulus of 26.9GPa, sticky cohesion of 27.2MPa, and internal friction angle of 30 degrees. We use the split loading method, the uniformly distributed load is applied to the both side of the model. Figure 3 gives the schematic diagram of the load.

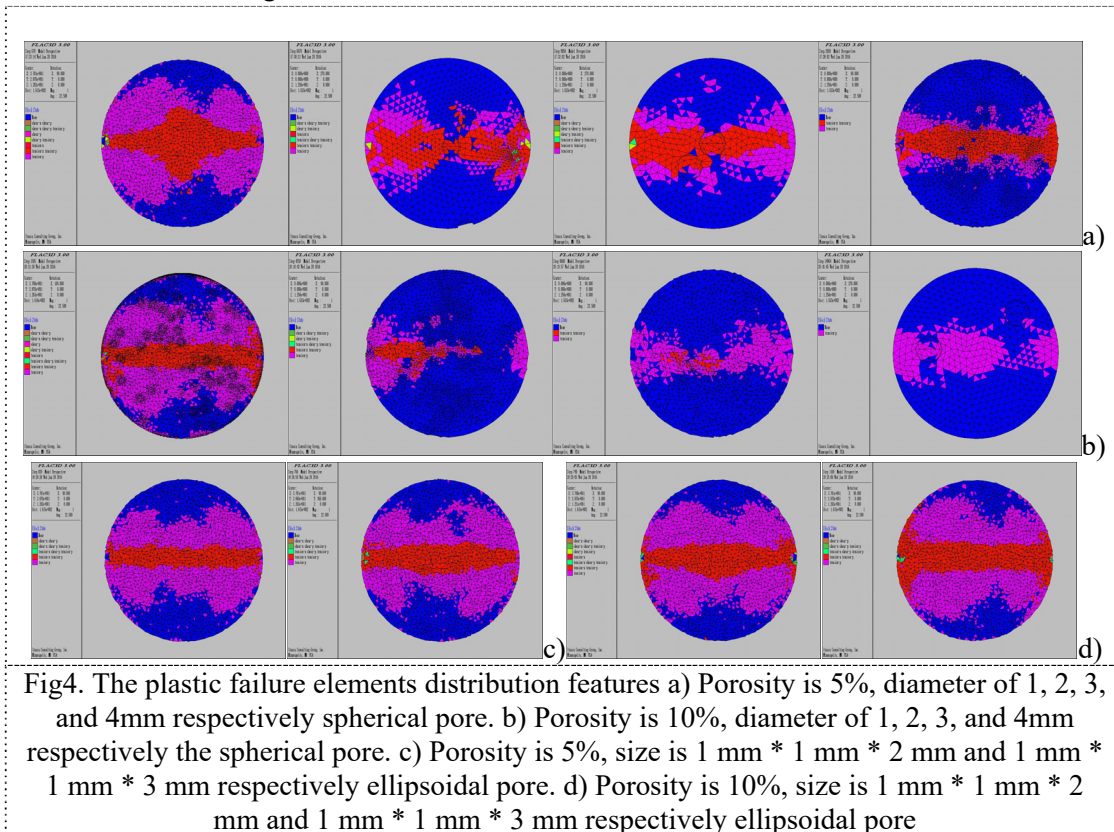


In order to realize the numerical analysis of FLAC3D, we introduce the model divided into grid in FLAC3D by self-made program. So we can make the numerical calculation of splitting loading

experiment on the 8 spherical pore models and the 4 ellipsoidal pore models and give the results of the numerical calculation which are carried out for basis of subsequent analysis.

3.2 The influence of pore parameters on the damaged elements

This paper analyzes the influences of the pore shape, size and porosity on the characteristics about plastic component distribution when the models are destroyed. Plastic failure distribution unit connected as shown in Figure 4.



The above results show that when the porosity is 5%, for the spherical pore models with the diameter of 1 mm, 2 mm and 3 mm, the failure mode is induced-tension-shear failure. When the porosity is 10 %, for the spherical pore models with the diameter of 1 mm, the failure mode is induced-tension-shear failure. When the porosity is 10 %, for the spherical pore models with the diameter of 2mm and 3 mm, the failure mode is single tension failure. For all models of 4 mm diameter, the failure mode is single tensile failure. For all models of ellipsoidal pore, the disc in the plastic transfixion area is very close to a straight line. For the models of spherical pore, the pore numbers are decreased with the increase of pore diameter, and the degree of stress concentration is decreased. Thus failure mode from induced-tension-shear failure changes into a single tensile failure, and the damage form is simplification. For the models of ellipsoidal pore, because the ellipsoidal pore has long axis, the models are easy to damage along the long axis when they are loaded by external effect. Thus the disc in plastic transfixion area is very close to a straight line. On the premise of keeping the same porosity, with the change of pore shape from ellipsoid to sphere, the number of the pore is increased and the place of distribution is relatively uniform, thus the fracturing areas are increased and more diffuse.

3.3 The influence of pore parameters on the maximum tensile stress

Meanwhile, we also analyze the influences of the shape, size and porosity of the rock pore on the stress in vertical direction of the load when the pore models are damaged. Figure 5 shows the curve relationship between the maximum stress and the pore size for spherical pore models. Figure 6 shows the curve relationship between the maximum stress and the pore size for ellipsoidal pore models. Figure 7 shows the stress field distribution. At the same time, we extract the maximum tensile stress σ_y , we analyze the influence of the pore parameters on the maximum tensile stress. And we use the 1 mm diameter spherical pore as special ellipsoidal pore that the long axis and short axis is also 1 mm.

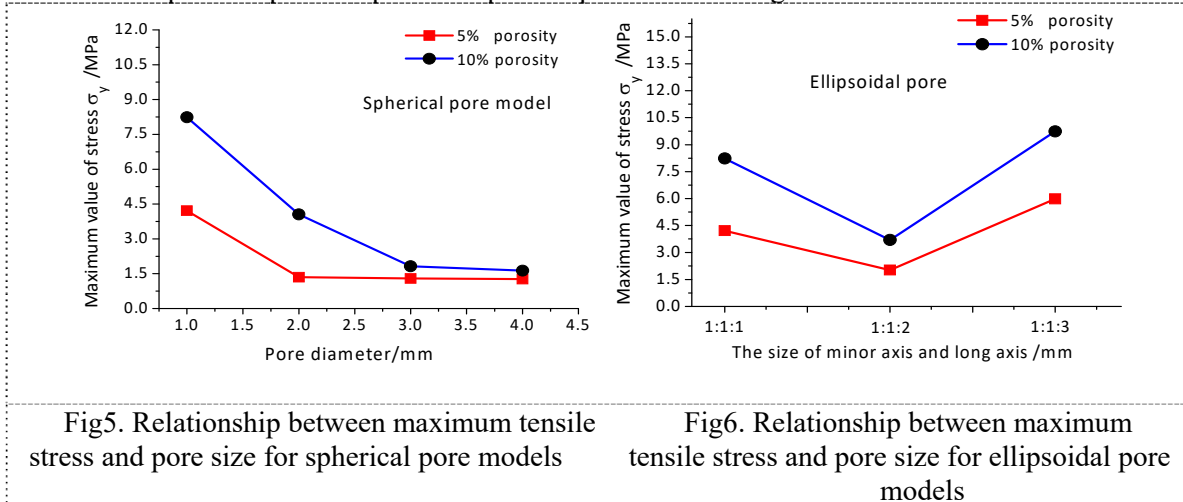


Fig5. Relationship between maximum tensile stress and pore size for spherical pore models

Fig6. Relationship between maximum tensile stress and pore size for ellipsoidal pore models

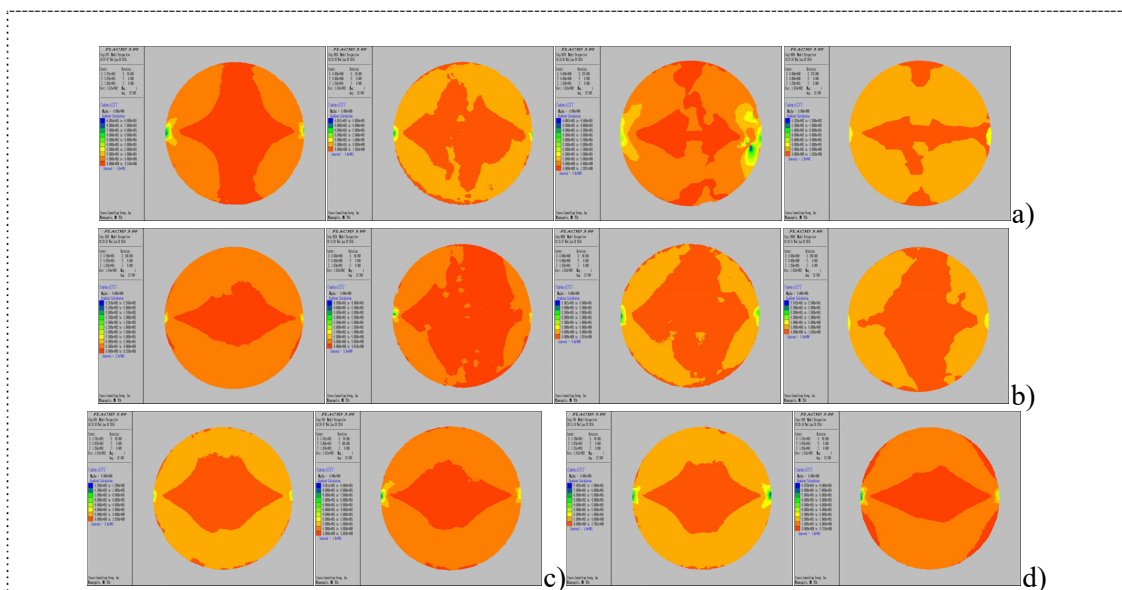


Fig7. The stress σ_y distribution of pore models a) the porosity is 5%, diameter respectively 1, 2, 3, and 4 mm spherical pore. b) the porosity is 10%, diameter of 1, 2, 3, and 4 mm respectively the spherical pore. c) the porosity is 5% respectively, the size is 1 mm * 1 mm * 2 mm and 1 mm * 1 mm * 3 mm ellipsoidal pore. d) the porosity is 10% respectively, size is 1 mm * 1 mm * 2 mm and 1 mm * 1 mm * 3 mm ellipsoidal pore

According to the models of stress distribution, the center of all models is damaged by the tensile stress and the pore shape has a significantly influence on the distribution of tensile stress. The

ellipsoidal pore is easy to be destroyed along the direction of the long axis when it is damaged by the external force and the plastic transfixion area is very close to a straight line. Therefore, the tensile stress areas of the ellipsoidal pore model are mainly focused on the horizontal center line of two sides, there is no obvious extension. And the tensile stress areas of the spherical pore model have a different degree of expansion, even one part of the tensile stress areas are close to the upper and lower boundary region of the model.

According to the curve about the maximum stress along the Y direction, we can see: for the porosity is 5% and the diameter of 1 mm, 2 mm, 3 mm and 4 mm spherical pore models, the maximum stress values along the Y direction are 4.21 Mpa, 1.35 Mpa, 1.29 Mpa and 1.26 Mpa. For the porosity is 10% and the diameter of 1 mm, 2 mm, 3 mm and 4 mm spherical pore models, the maximum stress values along the Y direction are 8.23 Mpa, 4.05 Mpa, 1.82 Mpa and 1.63 Mpa. When the porosity is 5%, the maximum stress values of the ellipsoidal pores that long axis and short axis are 1 mm * 1 mm * 2 mm and 1 mm * 1 mm * 3 mm along the Y direction are 2.02 Mpa and 5.98 Mpa. When the porosity is 10%, the maximum stress values of the ellipsoidal pores that long axis and short axis are 1 mm * 1 mm * 2 mm and 1 mm * 1 mm * 3 mm along the Y direction are 3.70 Mpa and 9.73 Mpa. Comparing the spherical pore models which have the same porosity and shape, we can find that: as the pore diameter increasing, the number of pore decreases, so the stress concentration phenomenon reduced. Thus the maximum stress value of the model along the Y direction is decreased, and with the increase of model size, pore less quantities are become less, the influence degree of the pore diameter to the maximum stress value is decreased. Comparing the spherical pore models which have the same size and shape, we can find that: as the porosity increasing, the number of the pore increases, so the stress concentration phenomenon is obvious. Thus the maximum stress value of the model along the Y direction is increased. With the increase of model size, the additions of the number decrease relatively, thus the influence degree of the pore porosity to the maximum stress value is decreased. For ellipsoidal pore model, pore shape has a significant influence on the maximum stress value of the model along the Y direction. From the spherical pore get into the ellipsoidal pore, the pore volume increases, the number of pore decreases, thus the maximum stress value of the model along the Y direction decreases. But as the irregular degree deepening, the ellipsoidal model is easy to be damaged along the long axis, the maximum stress value increases along the Y direction. Thus we can conclude that the maximum stress value of the model along the Y direction decreases firstly then increases with the change of the pore shape from the sphere to the ellipsoid.

4. Conclusions

This paper uses the methods of statistic principle, image processing technology and correlation analysis software to reconstruct the porous rock model. Based on the three-dimensional model of the porous rock, we make the numerical simulation experiment on the rock of the deformation and failure under the condition of splitting. By changing the characteristic function of pore shape, pore size and porosity, we analyze the influence on the failure path, stress distribution and stress value. The results show that:

(1) The effect of the pore shape on the failure of the model is significant, which is related with the irregular degree of the model. Under the premise of keeping the porosity and the pore size unchanged, the failure region of the disk splitting is increased and more dispersed with the change of the pore shape from the ellipsoid to the sphere. In the same premise, the maximum stress along the Y direction is decreased firstly then increased with the change of the pore shape from the sphere to the ellipsoid.

(2) Under the premise of keeping the pore shape and the pore size unchanged, when the porosity increases, the maximum stress along the Y direction is increased, and the model is easy to destroy. However, with the increase of the size of the model, the influence of the porosity on the failure of model is weakened.

(3) Under the premise that the porosity and the pore shape unchanged, when the diameter of the pore increases, the failure mode is changed from the induced-tension-shear failure to the simple tensile failure. The failure mode is simplified. And the maximum stress along the Y direction is decreased,

and the failure is weakened. What's more, with the increase of the size of the model, the influence of pore size on the failure of the model is weakened.

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