

Influence of Penetration on Cutting Performance During TBM Tunneling

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Abstract

Tunnel boring machine (TBM) is one of the important methods for tunnel construction, And the penetration has an important influence on the cutting performance of the cutter, which affects the efficiency of tunnel boring. Therefore, for the effect of penetration degree on cutting performance, a model of tool cutting was established in the form of ABAQUS finite element simulation, and the tangential force, normal force and specific energy during cutting were analyzed at different penetration. The results show that the rolling force and normal force increase with the increase of penetration degree, and the increasing trend of rolling force is more obvious than normal force, while the consumed specific energy decreases significantly with the increase of penetration.

Keywords

TBM; Penetration; Rolling Force; Normal Force; Specific Energy.

1. Introduction

TBM tunnel is superior to the drilling and blasting tunnel [1]. The hobbing tool deployed on the TBM cutter is a key component of rock breaking in tunneling [2]. The hob is an important rock-breaking tool on the cutter of tunnel boring equipment, and the study of the interaction between the disk-shaped hob and the rock is of great significance for analyzing the rock-breaking mechanism of the disk-shaped hob, guiding the cutter design and improving the tunneling performance [3].

As an important parameter in tunnel boring, the penetration degree affects the force state of the cutter. In order to further improve the tunneling performance, the impact of penetration on the cut-ting performance of the hob in tunneling is analyzed, so that the appropriate penetration parame-ters can be selected to improve the tunneling performance.

2. ABAQUS Finite Element Modeling

2.1 Material Parameter Setting

Table 1. Mechanical properties of rock sample

Mechanical properties	Granite
Uniaxial compressive strength (MPa)	101.5
Tensile strength (MPa)	8.1
Young's modulus (GPa)	12.5
Friction angle (°)	66
Density($kg \cdot m^{-3}$)	2548

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The hob cutting analysis is a complex nonlinear dynamic response process with complex nonlinear problems of geometry, material and contact [4]. Therefore, the finite element software ABAQUS, which is good at solving nonlinear problems, was selected to establish the hob cutting model.

The D-P model in ABAQUS is well suited for analyzing rock materials. During the simulation, the material properties of granite are assumed to be isotropic, homogeneous, and have continuous, small deformation material properties. The mechanical properties of the rock sample are listed in Table 1.

2.2 Model Establishment

The hob model was selected from 17in normal section disk hob. The rock model size is 1000mm×160mm×150mm. C3D8R (linear reduction integral) is used and the rock mesh is encrypted in the contact area between the hob and the rock, and the rock model is divided into 224070 elements and 238680 nodes, all of which are linear hexahedral cells.

The interaction between the tool and the rock is selected as face to face contact, with the blade face as the main body and the upper part of the nodal region of the rock from the face. For the interaction properties, the friction factor of 0.2 is chosen for the tangential behavior and the penalty function is used as the friction equation, and the hard contact is chosen for the normal behavior. The motion constraint equation is chosen as penalty contact, and the slip equation is chosen as finite slip.

Related studies reported that the effectiveness of rock breaking by hobbing is not influenced by the hobbing cutting speed [5]. Cho et al. [6] found that the dependence of rock breaking ratio energy consumption on cutting speed was also weak. However, as the speed increases, the calculation time becomes shorter, thus improving the calculation efficiency. Therefore, in this simulation, the rotation angle speed of the disc hob is set to 2.3 rad/s and the linear translation speed is set to 200 mm/s.

The five boundary surfaces of the rock are fixed. The rock breaking model is shown in Figure 1.

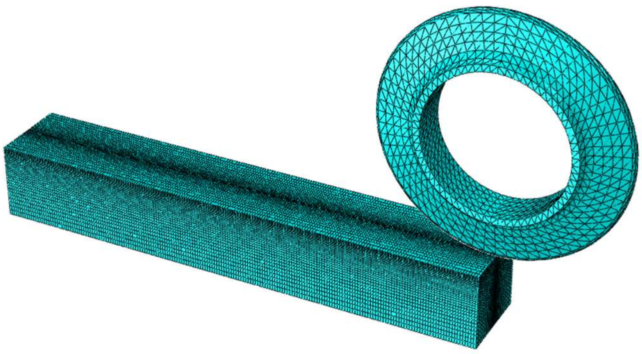

Figure 1. Hobs break rock model

3. Literature References

An important indicator reflecting the rock breaking efficiency of the hob is the specific energy.

The smaller the energy, the less energy consumed by the hob cutting unit volume of rock, the higher the efficiency of rock breaking. The calculation method is as follows:

$$S_E = \frac{F_R \times L}{V} \tag{1}$$

Where SE is the specific energy,unit is MJ/m3;FR is the average rolling force,unit is kN;L is the cutting length of the rock cut by the hob,unit is mm;V is the volume of rock fragments produced in the rock breaking process, unit is m3.

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Different penetration degrees have different effects on the cutting performance during full-section tunnelling. The different penetration degrees have different effects on the cutting performance during the full section boring process, thus affecting the speed and efficiency of the boring. In the established cutting model, change the penetration of the hob, set the penetration depth of cut to 2mm, 2.5mm, 3mm, 3.5mm and 4mm respectively for hob cutting simulation. Taking the penetration degree of 4 mm as an example, the cutting process is shown in Figure 2, and the output of tangential force, normal force and specific energy change under different penetration degrees.

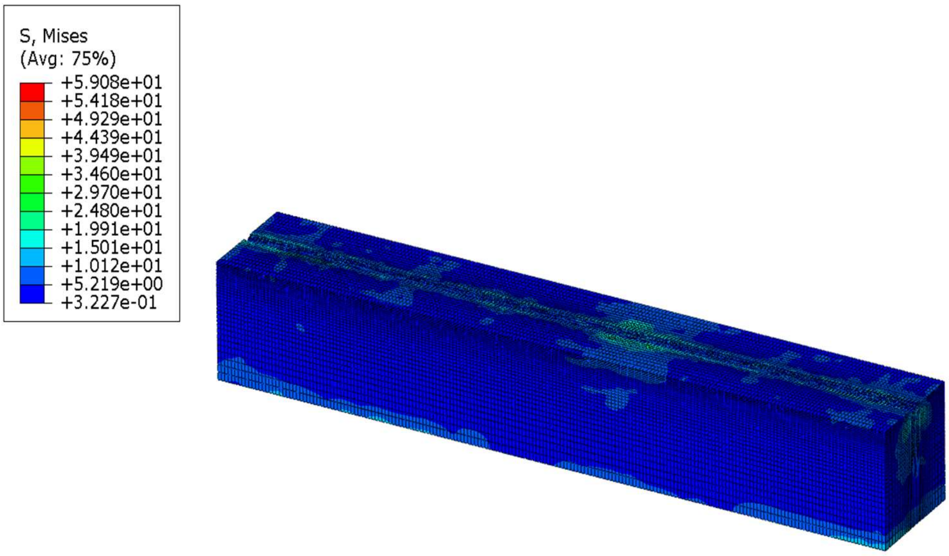

Figure 2. Rock fragmentation at 4mm penetration

The analysis of the rolling force and normal force during the cutting process, in the variation of tangential force and normal force at different penetration degrees is shown in Figure 3. From Figure 3, it can be seen that the rolling force and normal force both increase approximately linearly with the in-crease of penetration. When the penetration degree is small, the resistance encountered during the rolling forward of the hob is small, with the increase of penetration depth, the resistance of the hob gradually increases, so it needs a larger rolling force and normal force to ensure the quality and efficiency of rock crushing. Although the rolling force and normal force both increase with the depth of penetration, they have different growth rates. As the penetration depth increases, the growth rate of rolling breaking force is greater than the growth rate of normal force.

In the process of increasing penetration, as the depth of cut increases, the greater the thrust required for the tool to perform rock breaking. At the same time, the contact area between the side of the hobbing tool and the rock layer gradually increases, resulting in greater side friction. Therefore, the cutting force in the normal direction gradually increases. In the process of breaking the rock, the more work is required to break the rock formation with large penetration, the more torque is required for the tool, causing an increase in the rolling force.

The specific energy consumed by the hob during rock breaking was analyzed, and the specific energy fitting curve shown in Figure 4 was obtained.It can be seen from Figure 4 ,that the specific energy tends to decrease with the increase of penetration. This indicates that during the process of increasing the penetration depth of the hob, a larger cutting force and the volume of the broken rock are generated. The ratio of cutting force to rock breaking volume gradually decreases, thus reducing the specific energy required for cutting, which is conducive to improving the digging efficiency.

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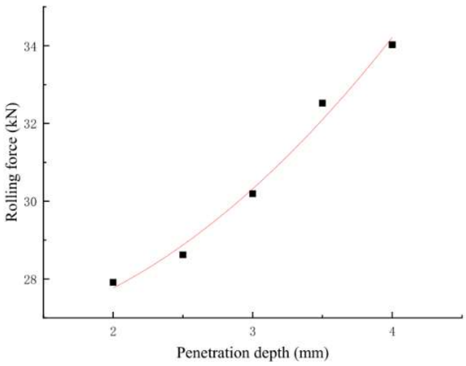

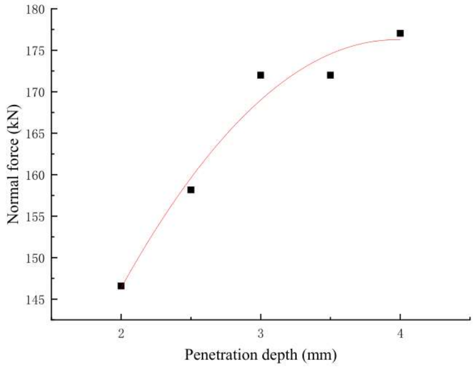

(a) Fitting curve of average rolling force (b) Fitting curve of average normal force

Figure 3. Fitting curve of average rock breaking force under different penetration

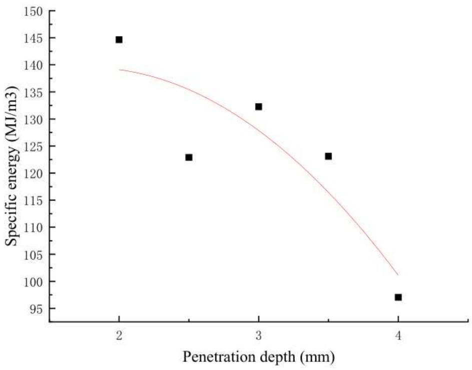

Figure 4. Specific energy fitting curve

4. Conclusion

The penetration depth has a significant effect on the breaking force during the hobbing linear cutting breaking process with the increase of penetration, the rolling force and normal force tend to increase. The growth rate of rolling breaking force is greater than the growth rate of normal force. And the specific energy consumed tends to decrease significantly. This shows that increasing the penetration is beneficial to reduce the consumed specific energy and improve the digging efficiency. At the same time, the value of penetration cannot be increased infinitely, the increase of cutting force is not conducive to the tool life, and it is easy to cause tool wear. Therefore, the penetration degree selection should be reasonably set according to the working conditions to improve the efficiency of TBM tunneling.

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