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Research on Tooth Profile of Insert Gear Hob of Disc-like Cone-bit

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Abstract

Disc-like cone-bit is a new kind of compound drill, cone tooth is widened and set horizontally on cone tooth basing on the traditional PDC- cone composite bit. making the bit move smoothly and longitudinal vibration is small, this can obviously alleviate the bad effect of longitudinal vibration of cone on PDC teeth, at the same time, improve the working condition of roller bearing. A new type of disc cutter tooth shape is proposed through the in-depth study of different tooth profile in this article, the rock-breaking efficiency of new teeth is compared with that of common wedge-shaped teeth and conical teeth through experiments to evaluate the new tooth profile. This article carries out three kinds of tooth profile of rock damage simulation and obtains different vibration conditions of three kinds of tooth shape under the same loading conditions to present some reference for subsequent tooth profile optimization.

Keywords

Composite bit; disc cutter tooth; cone vibration.

1. INTRODUCTION

PDC- cone bit is a new kind of composite bit developed and successfully used in recent years, Compared with ordinary cone bit, it can drill efficiently in tight shale, uneven layer and other difficult formations. However, the rock breaking mode of the impact crushing of the roller will seriously shorten the life of the bearing and cause abnormal failure of the PDC teeth. This chapter finds that the crushing work of the new teeth is equal to that of the ordinary wedge-shaped teeth and cone-shaped teeth under the same loading through the single-tooth vertical compression experiment of the new teeth and the ordinary wedge-shaped teeth and the cone-shaped teeth, and the comparison of fracture efficiency of teeth can be obtained from this chapter. At the same time, it is found that the vibration of the new tooth shape is better than that of the other two tooth shapes[1].

2. DESIGN AND MACHINING OF HOB TEETH

To guarantee rock to form circular continuous fracture groove and teeth should be designed to be wide. At the same time, teeth should be designed to be sharp and have good machinability to ensure that teeth are cleaved into rocks. The meaning of tooth parameters is shown in figure 1, the specific parameters of teeth are shown in table 1, and the processed teeth are shown in figure 2.

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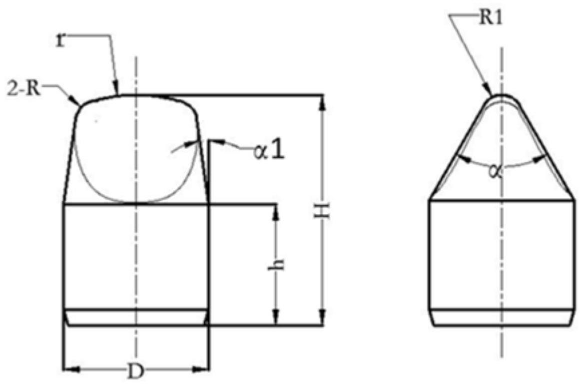

Figure 1. The specific parameters of teeth

Table 1. Main parameters of disc teeth

Tooth shape code	D	H	R	h	H-h (tooth high)	α-tooth angle (°)	α1 (°)	R1	r
CX1421R17	14	21.5	2	11	10.5	59.35	8	1.75	25
CX1219R15	12	19	1.5	10	9	59.35	8	1.5	25
CX1015R15	10	15	1.5	8	7	61.26	8	1.5	25

Figure 2. Processed teeth

3. SINGLE TOOTH EXPERIMENT

The experiment was carried out under normal temperature and pressure with single tooth static load. Single tooth press experiment, the standard pressure sensor is connected to the hydraulic universal test machine, the hob tooth is connected to the pressure sensor by a clamp(referred to as the tooth seat), the pressure is transmitted to the hob tooth through the sensor so that it acts on the rock(as shown in figure 3). The pressure load and displacement of the teeth were collected and recorded during the experiment, after the loading experiment, the geometric information of crushing pit was measured [2-4].

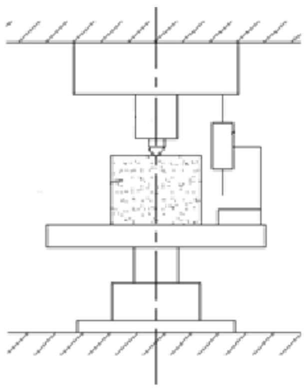

Figure 3. Hydraulic universal test machine

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3.1. The Experiment Acquisition

The crushing specific work is calculated by measuring the crushing pit on the rock for many times, the crushing specific work is the work consumed per unit crushing volume of the rock. The crushing work per unit volume is calculated by single tooth compression experiment [3, 4]. Specifically, in the process of the static pressure of a single tooth into the rock, the load-displacement curve was recorded by the sensor, calculating W, the work done by the tooth during the brittle crushing process from the moment the tooth was pressed into the rock under the action of load, let f (h) be a function of load F and H, the depth of the tooth pressed into, then

$$W = \int_0^{h_{max}} f(h)\, dh \tag{1}$$

After unloading, the volume V of the crushing pit can be measured, and the crushing work Av per unit volume in this process can be obtained

$$A_V = \frac{W}{V} \tag{2}$$

Through the above description, AV can be used as a quantitative evaluation criterion for the efficiency of tooth fragmentation. According to the above equation, the smaller AV is, the higher the rock-breaking efficiency is, and the larger AV is, the lower the rock-breaking efficiency is. Figure 4 shows the crushing pit of a new type of hob tooth in limestone.

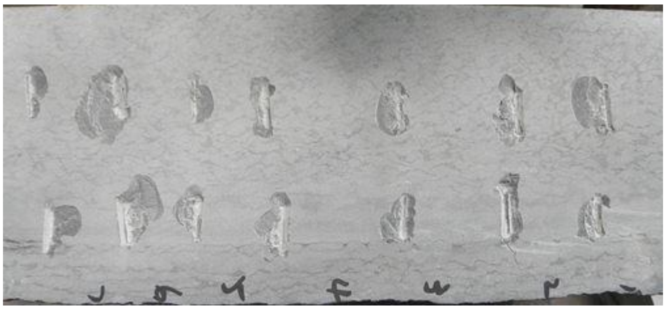

Figure 4. A crushing pit of a new type hob tooth in limestone

Table 2 lists the collection data and statistical calculation results of three kinds of teeth respectively in beibei limestone for vertical compression experiments.

Table 2. Crushing specific work of different tooth types

Tooth type	chisel teeth	Conical teeth	The new tooth (addendum angle 90°tooth thickness 3)	addendum angle 90° tooth thickness 4	addendum angle 90° tooth thickness4.5	addendum angle120° tooth thickness3	addendum angle 150° tooth thickness3
Depth of crushing pit/mm	1.84	2.67	2.20	2.29	2.33	1.79	2.13
Volume of crushing pit / mm^3	189.13	368.50	255.10	286.23	415.71	159.54	209.22
Specific work of crushing A (J/mm^3)	0.0671	0.0487	0.0665	0.0761	0.0946	0.0873	0.0882

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3.2. Contrast of Rock Breaking Energy Efficiency

In order to more directly compare the rock-breaking efficiency of different tooth types, the tooth efficiency coefficient Z is introduced, taking the wedge-shaped teeth as the reference tooth type and ratio of crushing is A_0, the tooth efficiency coefficient of the three tooth types is Z.

$$Z = \frac{A_0}{A}$$

Table 3. Rock breaking specific efficiency and tooth efficiency coefficient of three tooth types

Tooth type	chisel teeth	Conical teeth	New tooth	1	2	3	4
Tooth effect coefficient Z	1.000	1.378	1.009	0.8817	0.7093	0.7686	0.7608

The tooth efficiency coefficient Z above reflects the efficiency of different tooth types on limestone, the larger Z is, the higher the rock-breaking efficiency will be, with the increase of tooth tip angle and tooth thickness, the rock-breaking efficiency of new tooth types will be lower and lower. Rock breaking efficiency is the highest when the tooth tip Angle is 90° and tooth thickness is 3 °.The design optimization direction of the subsequent tooth profile is to make the teeth sharper on the basis of ensuring the tooth strength.

4. SIMULATED ANALYSIS

The new teeth, wedge-shaped teeth and conical teeth with the highest rock-breaking efficiency in hob tooth profile were selected for the simulation analysis of single-tooth transverse scraping limestone [5-8].

4.1. Modelling

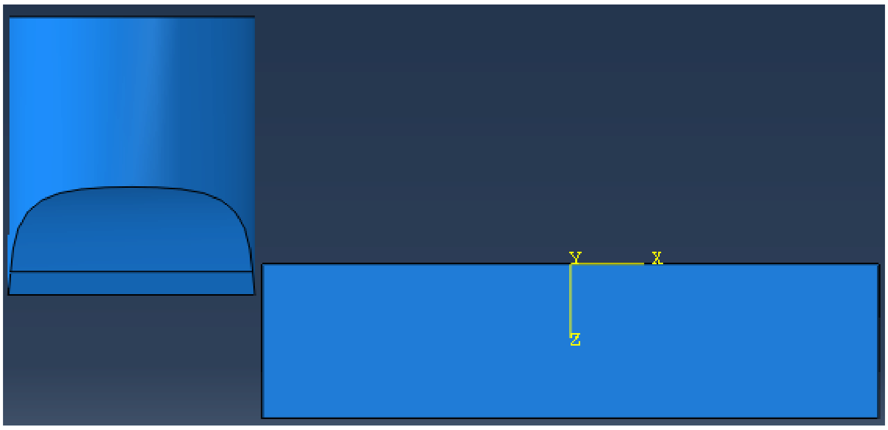

Figure 5. Interaction model between new tooth profile and rock

The following assumptions are made in the model:

1). The surface of the rock is flat, so as to compare the effect of tooth breaking.

2). The tooth is broken at a certain speed.

3). Rock breaking of single tooth is considered only.

4.2. Define Material Properties

The tooth does not undergo plastic deformation during scraping, and the tooth is regarded as an elastic body, and just defining the modulus of elasticity and poison’s ratio. Rock breaking adopts D-P yield criterion.

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4.3. Contact Attribute Definition

The tooth is in face-to-face contact with the rock.

4.4. Interpretation of Result

The cutting depth was 2mm and the three kinds of teeth were analyzed by finite element method, adopting lateral and horizontal rock breaking along the positive direction of the X axis and the displacement vibration diagram of the midpoint of the tooth tip along the Y and Z axes. According to the finite element, the following figure 2 is obtained:

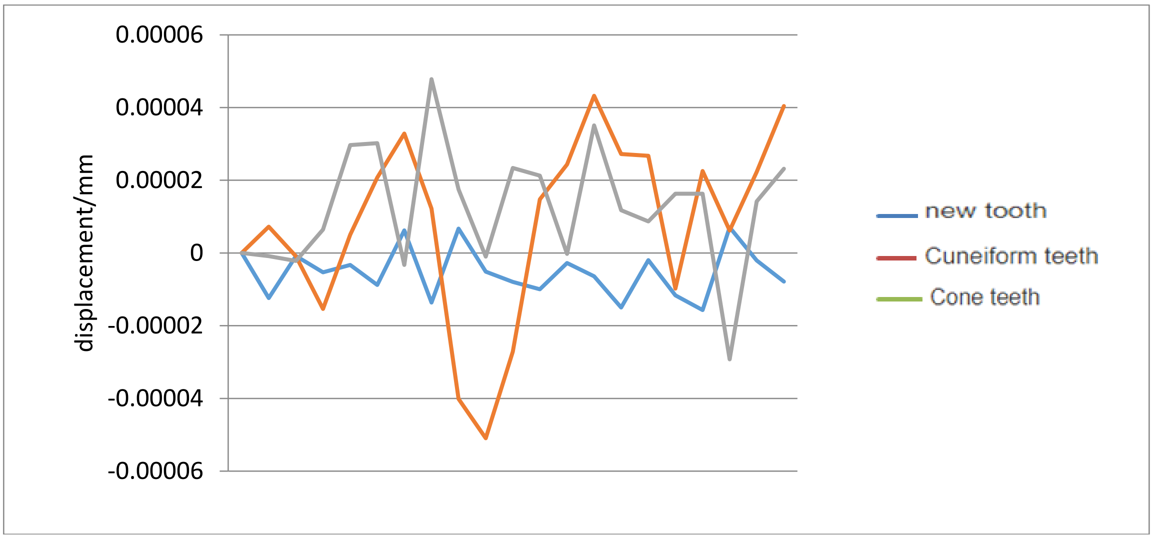

Figure 6. The displacement vibration diagram of the midpoint of the tooth tip along the Y axis

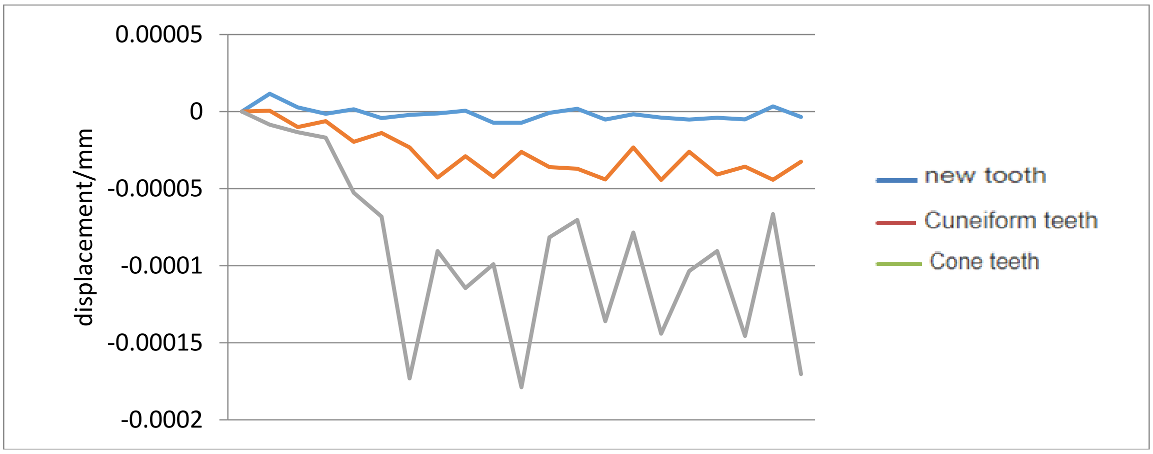

Figure 7. Displacement vibration diagram of the center point of tooth tip along the z-axis

It can be seen from the figure that the vibration in the cutting process of new tooth profile is obviously smaller than that of wedge teeth and conical teeth, and the more stable cutting can effectively reduce the impact on PDC teeth, and significantly alleviate or even eliminate the adverse impact of longitudinal vibration of cone on PDC teeth in the roller-pdc hybrid bit.

5. CONCLUSION

The rock-breaking efficiency of new tooth type is studied, and the rock-breaking efficiency of new tooth type is compared with that of traditional wedge-shaped teeth and cone-shaped teeth.

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This paper only compares the efficiency of limestone fracture. The actual stratum is complicated, but the experiment of single tooth pressing into limestone can provide certain theoretical basis for the efficiency of rock breaking and the optimization of new tooth type.

At the same time, the simulation analysis of transverse scraping between the new tooth type and the traditional tooth type further verifies the advantages of the new tooth type over the traditional tooth type in the rock breaking process. It is beneficial to extend the service life of the drill bit and reduce the drilling cost.

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