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High-hardness alloy substituted by low hardness during drilling and cutting experiments of conical pick

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1. Introduction

Protective seam mining is the most effective and economical method for the regional prevention of coal and gas outbursts.[1–3] The protective seam is a somewhat thin, to extremely thin, coal seam with a high dirt band rate and hardness. It greatly increases the speed and efficiency of protective seam mining compared with conventional methods and equipment by utilizing a coal auger.[4] However, it was found that the conical picks used in coal auger drills tended toward failure from severe wear when cutting or drilling high-hardness coal and rock, which limited further improvement of the mining speed and efficiency.[5,6] To improve the lifetime and to reduce the wear failure rate of conical picks, many scholars have investigated and studied the cutting performance and wear characteristics of conical picks.

The most comprehensive and accepted theories are those of Evans[7–10] for chisel picks and conical picks and those of Nishimatsu[11] for chisel picks, which led to a better understanding of the coal and rock cutting process. Egon[12] studied the relationship between pick wear and the cutting force in the cutting process in both laboratory and field conditions. Hurt[13] studied the pick life and cutting efficiency under controlled experimental parameters using a boom tunnelling machine test rig. Tiryaki[14,15] researched the relationships among the rock properties and the specific cutting energy and cutting forces in the linear cutting of sandstones. Zhang[16] established an auger coal mine pressure mathematical model and provided the transmission efficiency. Fu[17,18] built finite element models of single-pick drilling and cutting of coal to study the load characteristics of a point-attack pick and the influence of the pick's operating angle on the aiguille's load. Bilgin[19] carried out full-scale laboratory linear cutting tests and obtained the relationships among the cutter force, the theoretical force and the specific energy values. Jiang[20–22] utilised a testbed to perform rock cutting experiments and investigated the dynamic characteristics of rock cutting load time series and fragment size distributions in rock cutting. Gao[23] established a theoretical model and a vertical fracture model of a rock cutting fragments to predict the peak cutting force of conical picks in the rock cutting process. Loui[24] developed a two-dimensional, nonlinear, finite element simulation model for progressive rock failure to understand the mode and sequence of rock failure under a drag pick cutter. Dewangan[25,26] investigated the different wear mechanisms that cause a worn-out surface by using FE-SEM and EDS and observed the presence of coal/rock material and their respective concentrations in the selected area of the worn-out surface using EDX spectra.

The above research provides the references for this study, but the literature regarding the influence of the installation parameters on the cutting performance and the wear characteristics is still limited. Therefore, drilling and cutting experiments of a single conical pick were conducted under laboratory conditions. The influences of the installation parameters on the cutting performance and wear characteristics of the conical pick were analyzed to determine the optimal installation angles that could not only satisfy the demand of protective seam mining but also effectively reduce pick wear.

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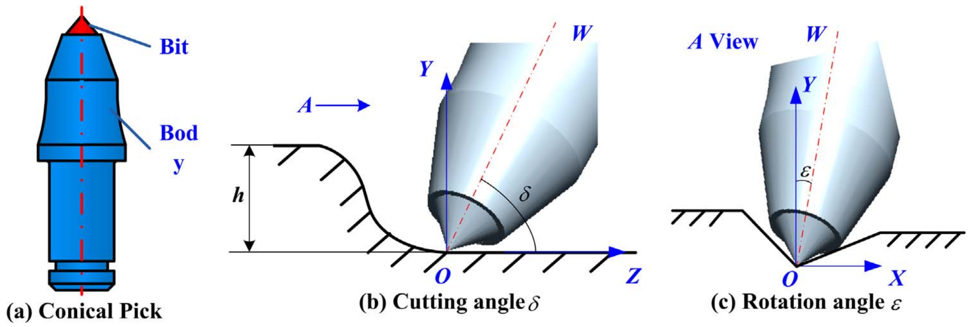

Fig. 1. Conical pick and operating angle.

2. Structure of cutting head and conical pick

The U43KL/C22 pick was selected as the test pick shown in Fig. 1(a). The body material is high-quality structural alloy steel with modulation processing (e.g. 40CrNiMo, 35CrMnSi, 42CrMo and 40Cr). The hardness of the pick body reaches HRC 38–42 after thermal treatment processing, and the mechanical properties satisfy the pick standard of a coal mining machine. The bit material is cemented carbide with high hardness, wear resistance, toughness and impact resistance (e.g., YG13C, YG11C and YGSC).[29] The bit material is YG8 or YG8C, and the bit is welded at the body front by a 105# manganese copper solder when the conical pick cuts high-hardness coal and rock. The installation angles of the conical pick in the coal auger are expressed by the cutting angle δ and the rotation angle ε,[27,28] which are shown in Fig. 1(b) and Fig. 1(c). The cutting angle δ is the acute angle between the pick axis and the tangent movement locus of the pick. The rotation angle ε is the acute angle between the pick axis and the vertical plane of the drill axis in which the pick tip is located.

3. Experimental materials

A large number of test coal walls are needed to reach the actual wear effect in drilling and cutting experiments because cemented carbide and high-quality structural alloy steel. This method takes a long time and is infeasible in laboratory conditions. Therefore, high-hardness alloy materials were substituted by low-hardness alloy materials based on the actual material hardness requirements of the pick bit and the body. The Brinell hardness of the bit material in the actual conical pick is HB399, and the Brinell hardness of the body material is HB361. The actual alloy material of the test pick bit was substituted by the structural alloy steel 30Mn2 (Brinell hardness is HB206), and the actual alloy material of the test pick body was substituted by the structural alloy steel 20Mn2 (Brinell hardness is HB187). The bit and body material hardness ratio of raw and exprimental material is 1.937 and 1.930, and the raw and exprimental material hardness ratio of bit and body is 1.105 and 1.102.

The hardness ratio of the raw materials between the bit and the body is close to that of the experimental material. Moreover, the hardness ratio between the test coal wall and the natural coal wall was required to be near that of the ratio between the raw and the experimental material to ensure experimental accuracy, which meant that test results may be similar to actual results. The compressive strength of natural coal is approximately 32 MPa and the average ash content of natural coal is 15.8%. Therefore, the compressive strength of the test coal wall was made to be approximately 16.5 MPa. The coal wall samples with 100 mm high cylinder and 50 mm diameter were made on the basis of different ratios of sand, water and 525# cement.[30] Uniaxial compression experiments of the coal wall samples were carried out to obtain the compressive strength, and the results showed that the samples, with the ratio of sand, water and 525# cement was 1:2:0.36, was nearly equal to the test requirement (16.44 MPa). Therefore, the test coal walls were constructed according to this ratio.

4. Experimental method and process

The relationships among the cutting force, the wear severity and the installation parameters were obtained by drilling and cutting experiments using test picks that were made of low-hardness materials. Using the ordinary cutting head of a coal auger could result in a higher expense for processing and installing; therefore, the ordinary cutting head was substituted by a cross-cutting head to save on the cost of experiments shown in Fig. 2.

The cross-cutting head not only ensures that cataclastic coal does not accumulate in the cutting hole but also can be conveniently processed and installed. The four cross blades were used in the experiments, and each cross blade was welded with four pick pedestals with different installation angles. The installation angles and the corresponding numbers of test picks are shown in Table 1.

The cutting testbed for a single pick is shown in Fig. 3. Before the experiment, the 16 test picks were cleaned, dried, and weighed, and their weights were recorded. The 1st test picks were installed in the corresponding positions on the cross blade. The testbed was propelled forward by a thrust cylinder until the distance between the 1st test pick and test coal wall was 10–20 mm.

The cutting torque was acquired within 10 s after the cutting started. The motor provided rotary motion for the cross blades, and the rotating speed was 60 rpm. The thrust cylinder provided feed movement for the test picks, and the feed speed was 0.23 m/min. The test pick drilled and cut into the test coal wall and finished the cutting motion with the combined action of two movements. After finishing the drilling and cutting experiments with low-hardness test picks, the 1st actual conical test pick with installation parameters (δ=38, ε=25) was installed in the test bed, and the experiment was conducted. The experiment took 6 h and aimed to illuminate the

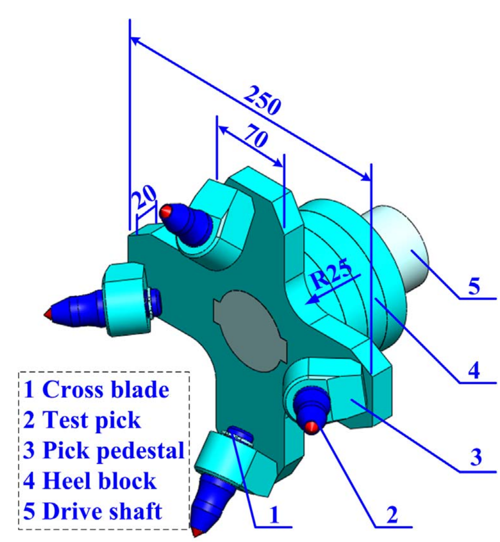

Fig. 2. Structure of the experimental cutting head.