International Journal of Rock Mechanics and Mining Sciences 100 (2017) 263–268

Contents lists available at ScienceDirect

International Journal of Rock Mechanics and Mining Sciences

journal homepage: www.elsevier.com/locate/ijrmms

Effects of the skew angle of conical bits on bit temperature, bit wear, and rock cutting performance

Eunhye Kim[a,*], Kerwin Hirro[b], Demetryus Oliveira[a], Andrew Kim[a]

[a] Department of Mining Engineering and Center of Underground Construction and Tunneling, Colorado School of Mines, CO, USA
[b] Department of Civil and Environmental Engineering, Colorado School of Mines, CO, USA

ARTICLE INFO

Keywords:
Skew angle
Cutting tool wear
Excavation
Frictional ignition
Contact mechanism

1. Introduction

Understanding the contact mechanism between a cutting tool and rock is important in mining, drilling, and tunneling industries as the physical contact can cause frictional ignition and bit wear. The heat generated in the rock cutting process can be a precursor to frictional ignition, which can potentially ignite methane (CH_4) gas, leading to explosions as occurred in the 2010 explosion at the Upper Big Branch Mine in West Virginia.[1,2] Therefore, friction mitigation is critical for improving mining safety.[3]

Additionally, understanding the bit wear is crucial for preventing financial losses and saving project budgets by reducing bit replacement. Many factors are taken into account in cutting tool wear as the physical contact mechanism between a tool and rock varies with the properties of the rock, tool, and working conditions (cutting speed, line spacing, depth of cut, etc.), significantly affecting the bit wear process.[4] Previous studies have reported the importance of predicting operational circumstances related to the wear rate of cutting tools.[5] In addition, other studies demonstrated that tool wear typically is mainly determined by the mechanical and thermal interactions that occur between a tool and rock.[6] Some theories have been further developed to account for the bluntness of the tool.[7] Some of the main parameters in these theories are the cutting geometry parameters such as the cutting depth and the angles of the cutting tools.[8,9] However, not much work has been reported in quantifying the relationship between wear and cutting machine performance.

Skew angle is an important parameter when cutting materials such as rock, wood, and metal.[10] Many researchers have studied the effect of the skew angle of conical bits on bit rotation because understanding the bit rotation is important for extending bit life. Bit rotation can allow the bit to maintain its shape and can even re-sharpen the tip.[2,11–16] The skew angle in rock cutting is defined as the angle between the projection of the bit axis on rock surface and the line of cut. However, in contrast to the number of studies done on bit rotation, very few studies on skew angle have been reported regarding friction mitigation and bit wear,[16] even though understanding the effects of skew angle on frictional ignition and bit wear are critical for workplace safety and productivity.

The skew angle of conical bits can significantly change the physical contact mechanism between a tool and rock, affecting bit temperature, bit wear, and rock cutting performance. In a previous study,[16] the effect of skew angle on bit temperature increment was tested with four bit types of different weights. Bit weight can influence the physical contact between a tool and rock by changing the normal, cutting, thrust, side, and shear forces. For this reason, in this paper four bit types with the same weight were used to investigate the effects of skew angle on rock cutting performance. Thus, our results demonstrate the effects of skew angle more precisely without contributions from bit weight.

In this study, we explored the effects of skew angle not only on the temperature of bit tips (as a function of the tip surface area) but also on bit wear and rock cutting performance. The results of this study provide insightful information for designing cutting bits with safer and more wear-tolerant shapes, significantly contributing to improving the safety and productivity in the mining and tunneling industries.

* Corresponding author.
E-mail address: ekim1@mines.edu (E. Kim).

https://doi.org/10.1016/j.ijrmms.2017.11.006
Received 12 September 2016; Received in revised form 23 March 2017; Accepted 9 November 2017
Available online 15 November 2017
1365-1609/

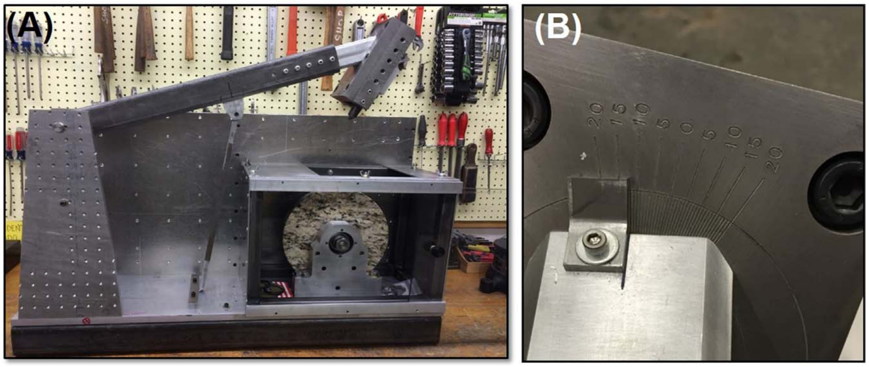

Fig. 1. The frictional ignition test machine with the rock wheel (A) and the protractor such as gage aid (B). The skew angle of the cutting tools was adjusted using the protractor such as gage aid.

2. Materials and methods

2.1. Design and fabrication of the testing machine

An advanced rock friction machine was designed and fabricated (Fig. 1). In the advanced cutting machine, the steel base frame was installed to reduce the amount of vibration throughout the machine while it was running. A granite rock wheel (10 in. in diameter) on the friction machine was prepared with a water jet machine. The granite wheel was mounted on a shaft equipped with heavy-duty ball bearings as previously described.[16] The rock friction machine was designed by considering the three critical angles – clearance, contact, and skew angle – in Fig. 2 as described. For a continuous miner or longwall shearer, the rotation axis is the centerline of the cutting drum. For each cutting test, a cutting bit was mounted in the bit housing on the lever arm. The housing was rotated to adjust the skew angle of the bit, and a protractor like gauge aided in absolute precision when measuring the skew angle (Fig. 1). Tests were performed at skew angles of 0°, 6°, 12°, and 18°.

2.2. Engineering of cutting tools

The weight of four bit types (S1, S2, B1, and B2) used in the previous study varied from 558.8 to 1133.2 g.[16] To more precisely assess skew angle effects on bit wear, rock excavation performance, and bit temperature than in that previous study, each of the four bit types was machined with the same weight because bit weight can significantly affect normal, cutting, shear, side, and thrust forces (Fig. 3 and Table 1). Because the weight of S1 was the lightest (~ 539 g), all bits were machined to ~ 539 g (± 2 g of deviation) (Table 1).

2.3. Experiment, data collection, and analysis

The granite wheel was mounted on the rock cutting machine, and the cutting bit was placed near the top of the rock wheel at a specific skew angle. The rock cutting test was performed under ~ 672 m min^{-1} of cutting speed for 5 min, and the depth of cut after the experiment was ~ 2 mm. The rock cutting was performed with a single bit for each test, so line spacing was not applicable in this study. Water was not applied during the cutting tests to examine the effect of skew angle on bit temperature without interference from water cooling effect. The bit temperature was recorded with a 50-Hz infrared (IR) camera to estimate the temperature of the bits. A full set of tests was performed with four bit types of the same weight, 4 different skew angles (0° to 18° in 6° steps), and 6 repetitions for each condition. To avoid the artificial increases in bit temperature due to successive friction tests, after each test the tested rock wheel and cutting bit were replaced with a cool-downed rock wheel and bit (~ 25°). Data were analyzed with programs specific to the IR camera used (Fig. 4). Bit wear and rock excavation performance were estimated from the loss of bit and rock weights, so bit and rock weights were measured before and after each of the tests.

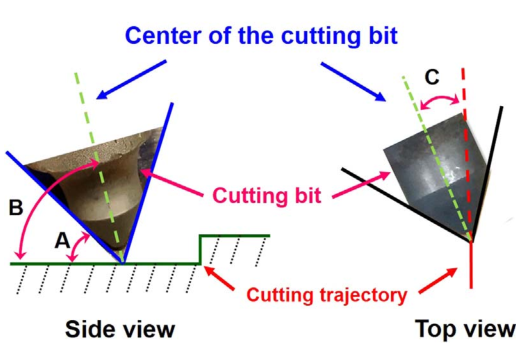

Fig. 2. Cartoon images for the critical angles of a cutting bit. A: initial clearance angle, B: attack angle, and C: skew angle.

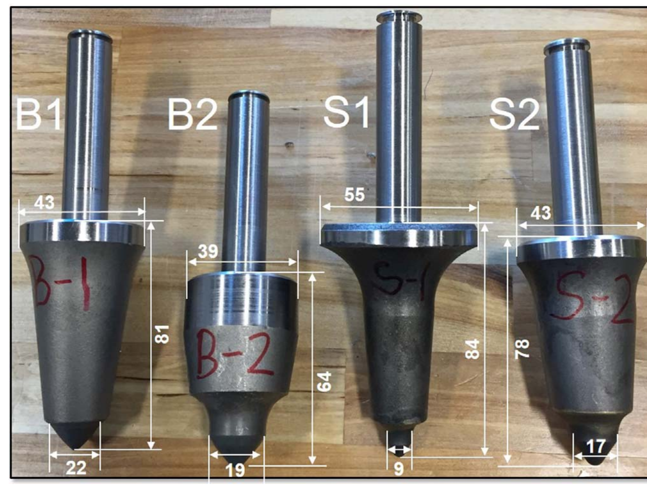

Fig. 3. Engineered conical cutting bits within ± 2 g of deviation. B1: BETEK coal cutting bit; B2: BETEK rock cutting bit; S1: Sandvik coal cutting bit; and S2: Sandvik rock cutting bit. Unit is millimeter (mm).

Table 1
The weight, tip angle, and tip surface area of engineered cutting tools used in the experiment. All bits were engineered to 539 g within ± 2 g of deviation. The values of the bit tip angle and the tip surface area were obtained from our previous paper.[16]

Cutting tools	Weight (g)	Tip angle (°)	Surface area (cm^2)
S1	538.1	60.6	1.2
S2	540.2	69.3	2.5
B1	540.3	79.5	3.2
B2	540.3	79.9	4.3