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Technical Note

Effect of skew angle on main precursor of frictional ignition in bench-scale simulation of excavation processes

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A R T I C L E I N F O

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1. Introduction

Frictional ignition in coal mining usually occurs when the cutting bits of a mining machine drill rocks. This is one mechanism that has been speculated to underlie the phenomena of ignition and explosion. The heat generated in the process of cutting geomaterials can potentially ignite methane clouds and lead to explosions; hence, friction mitigation in the mining industry is crucial for improving mining safety. In recent years, the Massey Mine explosion in West Virginia in 2010, which killed 29 people, has served as an unforgettable reminder that friction ignition can cause disastrous mine accidents when it is poorly controlled.[1] This incident is believed to have been triggered by a spark on the cutting face, which ignited methane clouds and propagated quickly to coal dust. Because water is widely used to suppress friction ignition, this accident suggests that water cannot be a completely reliable countermeasure to prevent mine explosions. Therefore, it is essential to advance new techniques that mitigate the occurrence of friction ignition during mine excavation. To prevent mine explosions and thereby improve mine safety, the mechanisms that underlie friction ignition should be thoroughly understood.

According to friction ignition statistics for Australian and South African coal mines between 1990 and 2010, one to five incidents have been reported nearly every year, with several lives lost in each accident. Some researchers found that 90% of all friction ignition incidents occurring in underground coal mines liberated at least 0.39% of methane gas (CH_4) through their ventilation systems, and claimed there was no significant relationship between gas content and number of friction ignition incidents.[2] In contrast, other researchers reported that friction ignition occurred in coal and gold mines, which could liberate even less methane (between 0.02% and 0.05%) through their ventilation air methane systems.[3]

There are several ignition sources such as chemical reactions, electrical heat energy, mechanical heat energy, and nuclear decomposition.[4] Among them, frictional ignition is one of common mechanical heat energy sources.[4,5] Some researchers have discussed frictional ignition in terms of hot spots[6–9], which were proposed as a potential explosion source caused by frictional abrasion[10] and complex cutting-abrasion phenomena.[11] However, few studies have analyzed contact phenomena such as the formation of hot spots; hence, little understanding of the contact mechanism has been achieved. To minimize spark generation, many engineers have suggested selecting proper shank materials and cutting bit materials. For example, a mushroom shape for bit inserts, 4340 steel for the shank, and tungsten carbide for the cutting bit tip have been widely used in mine excavation.[6–8]

To prevent frictional ignition in mines, its precursors must be thoroughly characterized and evaluated. In discovering the primary cause of frictional ignition, it is important to understanding how the temperature of a cutting tool changes depending on the skew angle between the cutting tool and excavated material.[12–16]

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Some researchers suggested that the contact area of tool-chip is an important parameter in controlling heat transfer into the cutting tool.[17] Thus, a small contact length suggests that a low percentage of the generated heat flows into the tool. Also, temperature distribution and heat partitioning in cutting tools are important factors when designing cutting tools as temperature and heat can influence the performance and lifetime of cutting tools as well as quality of the machined product.[17,18] However, these are beyond the scope of this paper. One interested pursuing this scope could start by reading other papers.[19–24]

For this study, a bench-scale device, which facilitates mechanical contact between a cutting tool and a rock wheel, was used to examine the correlation between the skew angle of a cutting bit and the temperature increment of its tip. The skew angle is an important parameter in excavation processes because an optimum angle is required to increase the lifetime of a cutting bit. However, the effect of the skew angle on the temperature increment—the main precursor of frictional ignition—has not been systematically tested.

In this paper, possible remedies are proposed for reducing or minimizing sparking occurrences by understanding the effect of skew angle on the temperature increment of bit tips as a function of the bit-tip shape. The results provide insight into designing cutting bits with safer shapes, and may contribute greatly to improving safety in the mining industry.

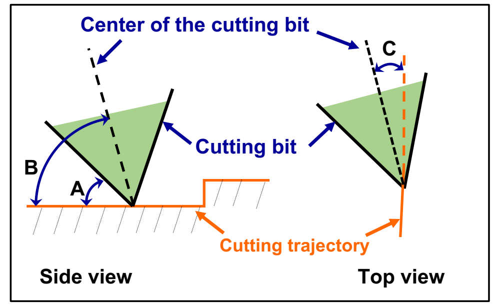

Fig. 2. Schematic diagrams depicting critical angles of conical shape cutting bit. A, initial clearance angle; B, attack angle; C, skew angle.

Fig. 3. Four cutting tools tested for frictional ignition. B1, BETEK coal cutting bit; B2, BETEK rock cutting bit; S1, Sandvik coal cutting bit; S2, Sandvik rock cutting bit.

2. Design and fabrication of testing machine

This study began with the design and fabrication of the frictional ignition-testing machine (Fig. 1). The rock wheel on the machine (10 in. in diameter, 11/8 in. in thickness) was fabricated from a granite countertop, using a water jet machine. The wheel was mounted on a shaft (1 in. in diameter, 18 in. in length) equipped with heavy-duty ball bearings. It was turned by a motor (½ hp torque) connected to the shaft with a sheave and belt arrangement. The speed was controlled by adjusting the sheave size and belt.

The test device was designed by considering the three important angles shown in Fig. 2. The clearance angle (“A” in Fig. 2) is the angle between the physical edge of the bit and the plane struck by the bit. Each of the four bit types tested had a unique clearance angle (Fig. 3). The contact angle (“B” in Fig. 2) is the angle between an imaginary line running through the center of the bit and the plane struck by the bit. As reported by some publications, attack angles of 45° to 50° and a mushroom-shaped cutting bit reduce spark ignition in mines.[25] Therefore, a 45° attack angle and tungsten carbide tips were used, both of which are widely used in mine excavation. The skew angle (“C” in Fig. 2) is the angle between an imaginary plane perpendicular to the direction of cutting and the imaginary line running through the center of the bit. For the test device, the axis of rotation was the shaft on which the rock wheel was mounted. For a continuous miner or longwall shearer, the axis of rotation was the centerline of the cutting drum. For each test, a cutting tool or bit was mounted in the bit housing on the lever arm (Fig. 1A). The housing can be rotated to adjust the skew angle of the bit. Testing was performed at skew angles of 0°, 3°, 6°, 9°, 12°, and 15°. Tip angle, surface area, and weight of cutting tools used in the experiment were measured (Table 1). Tip angles and dimensions were measured from photographic images of the tools by using ImageJ software to calculate the surface area.

3. Procedure for cutting tests

The granite rock wheel was mounted on the testing machine, and the cutting tool was positioned on the granite wheel (near the top) at a specific skew angle. The blasting chamber was lowered to isolate the testing machine. As the chamber of the testing machine was exposed to air, ventilation was not used in this study. Testing experiments were run at room temperature (18–22 °C) for 7.2 s in the short duration test and 200 s in the long duration test while 900- and 30-Hz recordings were made with two different infrared (IR)

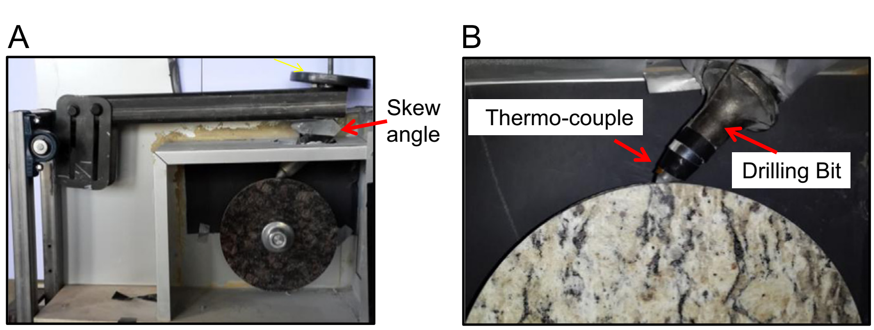

Fig. 1. Frictional ignition test machine with rock wheel (A) and thermo-couple on cutting bit (B).