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Surface degradation mechanisms of cemented carbide drill buttons in iron ore rock drilling

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ABSTRACT

The wear behavior of cemented carbide rock drill buttons is influenced by many factors, which include the composition and microstructure of the cemented carbide material, the nature of the rock material, and the conditions of the rock drilling operation. Depending on the type of rock and on the drilling procedure used, the cemented carbide is exposed to substantially differing mechanical and thermal conditions. In the present study, the surface degradation and wear mechanisms of cemented carbide drill buttons exposed to iron ore rock drilling have been characterized based on a combination of high resolution scanning electron microscopy (SEM), focused ion beam cross-sectioning (FIB), energy-dispersive X-ray spectroscopy (EDS) and electron back scatter diffraction (EBSD).

The results show a significant difference in surface degradation and wear between the front and peripheral buttons of the drill bits. While the front buttons display a relatively smooth worn surface with shallow surface craters the peripheral buttons display a reptile skin pattern, i.e. plateaus, 200–300 μm in diameter, separated by valleys, typically 40–50 μm wide and 15–30 μm deep, The reptile skin pattern is obtained in regions where the peripheral buttons are in sliding contact against the drill hole walls and exposed to high surface temperatures caused by the frictional heating. The results indicate that the reptile skin pattern is related to friction induced thermal stresses rather than mechanical contact stresses, i.e. the reptile skin pattern is formed due to thermal fatigue, rather than mechanical fatigue, caused by the cyclic frictional heating generated at the cemented carbide button/iron ore interface.

1. Introduction

The wear behavior of cemented carbide rock drill buttons is influenced by many factors, which include the composition and microstructure of the cemented carbide material, plus the conditions of the rock drilling operation, such as drilling parameters, drill button geometry and the nature of the rock material. Depending on the type of rock and on the drilling procedure used, the cemented carbide is exposed to substantially differing mechanical and thermal conditions. Under conditions of high mechanical stress and high temperatures, typical for drilling in highly abrasive rocks such as granite, the worn cemented carbide buttons are usually very smooth, with the roughness limited to within the size of individual WC grains. When drilling under conditions of moderate mechanical stress and high temperatures, typical for drilling in low-abrasive rock, such as ores with e.g. magnetite, the surface damage of the buttons usually includes a macroscopic surface wear pattern, commonly referred to as "reptile skin", in an otherwise smooth surface. The crack growth associated to the valleys of the reptile skin pattern eventually leads to catastrophic fracture of the button, unless the cracked surface layer is repeatedly ground off before the cracks grow too deep. So despite the low general wear rate, the wear life of drill buttons becomes severely restricted by the surface cracks. Among the published studies related to the failure and wear of cemented carbide in rock drilling [1–20], just a few have covered the formation of "reptile skin" during iron ore rock drilling [4–7,12,14,15]. Lagerquist [4] and Stjernberg et al. [5] stated that the prevailing mechanical contact conditions do not generate high enough tensile stresses to produce cracking when drilling in low abrasive rock types such as iron ore. Instead, these authors claimed that the reptile skin formation is due to the cyclic heating generated at the cemented carbide button/iron ore interface. Lagerquist [4], Stjernberg et al. [5] and Perrot [7] found the presence of instantly (already after a few meters of drilling) formed thermal cracks in the cemented carbide surface. However, if these cracks are a prerequisite for the formation of the reptile skin pattern is not clear.

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For example, Jonsson [6] did not observe thermal cracks during the initial wear stage of cemented carbide buttons showing reptile skin and Beste et al. [10] claimed that the cracks were not related to the reptile skin pattern. Instead, Beste [15] proposed a point fatigue model for reptile skin formation where the repeated indentation of the cemented carbide surface by rock asperities form the reptile skin without the dependence of thermal effects. Thus, it can be concluded that no consistent explanation of the mechanisms behind the formation of reptile skin patterns exists. Reviews of cemented carbides for rock drilling applications are available in the recent works by Ren et al. [17] and Katiyar et al. [18], which to a large extent refer to the work by Beste et al. [10–14]. In summary, the reviews illustrate the need for a deepened understanding of the behaviour of cemented carbide during the contact between the drill bit button and the rock.

In the present study, a number of worn cemented carbide buttons from drill bits used for Down-The-Hole (DTH) drilling in magnetite rich ore at the LKAB mine in Kiruna, Sweden, have been investigated with respect to the damage and wear mechanisms. State-of-the-art high resolution scanning electron microscopy (SEM), focused ion beam cross-sectioning (FIB), energy-dispersive X-ray spectroscopy (EDS) and electron back scatter diffraction (EBSD) have been used to characterize the dominant degradation mechanism focusing on the mechanisms behind the reptile skin phenomena.

2. Experimental

2.1. Rock drilling

Percussive rock drilling of blast-holes in magnetite ore in the Kiruna mine in Sweden was performed with a Down-The-Hole (DTH) hammer using the Wassara water power technology where water is used to drive the hammer tool. The drill bits used had a diameter of 116 mm and were equipped with 7 front and 10 peripheral cemented carbide buttons (ø 14 mm) with a semi ballistic shape, see Fig. 1. In operation, using a water pressure of 180 bar, the drill rotates at approximately 70 rpm and impacts the iron ore around 65 times/s. Three different drill bits used for 5 m, 100 m and 150 m drilling distance were evaluated.

2.2. Materials

The rock drill bit buttons were manufactured from a WC-Co cemented carbide grade with a composition of 94 wt% WC, 6 wt% Co, mean WC grain size of 2–3 μm and a nominal hardness of HV1 = 1250 kg/mm^2.

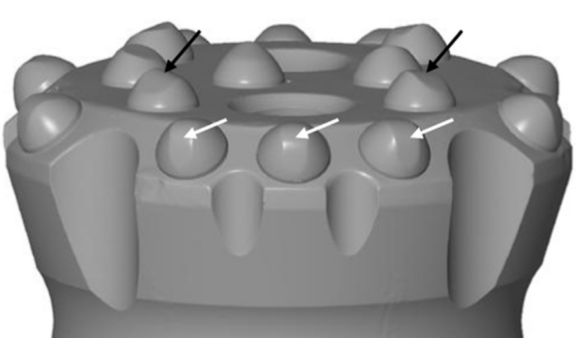

Fig. 1. Schematic showing the drill bit and the drill bit buttons. In the present study, two front buttons (black arrows) and three peripheral buttons (white arrows) were characterized.

2.3. Surface characterization

Representative cemented carbide drill bit buttons, see Fig. 1, were carefully cut out from the drill bit using wire electrical discharge machining. Cross-sections of the buttons were prepared using precision cutting followed by conventional metallographic cutting, grinding and polishing techniques. Local cross-sections were prepared using a focused ion beam (FIB) FEI Strata DB235 system. The surface topography of the drill bits was characterized using 3D optical surface profilometry using a WYKO NT9100 optical profiler. The worn surfaces and cross-sections were characterized using a Zeiss Ultra 55 FEG-SEM equipped with an Oxford Instruments Inca energy dispersive X-ray spectroscopy (EDS) system and an Oxford Instruments HKL Nordlys EBSD detector and Channel 5 software. In order to reveal the presence of any adhered transferred material, the SEM was operated using a relatively low accelerating voltage of 5 kV thus limiting the interaction depth. The FIB cross-sections were imaged using a Zeiss Merlin FEG-SEM, using 3 kV acceleration voltage. For the EBSD samples, a standard colloidal silica suspension (0.04 μm) was used for the final polishing step in order to obtain a surface “free” from preparation induced plastic deformation.

3. Results

3.1. Optical microscopy and 3D optical profilometry

Light optical microscopy of the drill bit used for only 5 m drilling revealed the presence of adhered magnetite (as confirmed by SEM and EDS analysis, not shown here), especially at the outer side of the peripheral buttons. No signs of surface cracks or significant wear were observed after this short drilling on any of the buttons. However, it should be noted that the pronounced transfer of magnetite to the peripheral buttons makes it impossible to detect the presence of any fine cracks in the cemented carbide surface.

The worn surfaces of all buttons on the drill bits used for 100 and 150 m drilling were very smooth. This includes the surfaces of the whole front buttons as well as the top surfaces of the peripheral buttons. The only exception was the outer part of the peripheral buttons, which each displayed a region with a characteristic reptile skin pattern, as illustrated in Fig. 2. This illustrates that the formation of reptile skin is restricted to the regions exposed to the most intensive sliding contact, i.e. those sliding against the wall of the just drilled hole. These regions experience extensive frictional heating and associated high surface temperatures.

Fig. 3 show 3D surface profilometry images and 2D surface profiles of a peripheral button (reptile skin region) and a front button (top region), respectively, from the drill bit used for 150 m drilling. The reptile skin region consists of a number of plateaus separated by down to 15 μm deep valleys. In contrast, the top region of the front button displays a worn surface without the pronounced reptile skin morphology.

It should be noted that the border between the reptile skin region and the surrounding smoothly worn surface is not sharp, but becomes more distinct with increasing drilling distance. Further, the size of the individual plateaus tends to decrease with increasing drilling distance, i.e. the number of plateaus increases, as do the depth of the valleys in the centre of the reptile skin region.

3.2. SEM and EDS analysis of buttons used for 150 m drilling

The SEM micrographs in Figs. 4 and 5 show the characteristics of the reptile skin region on a peripheral button in different

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