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Short communication

Pitting mechanism of cemented carbide tool in the early stage of rock drilling

Xiaofeng Yang *, Shijing Wu, Yong Kang, Xiaochuan Wang, Re Xia

School of Power and Mechanical Engineering, Wuhan University, Wuhan 430072, China

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A B S T R A C T

Surface pitting affects the working life of cemented carbide tools. The pitting mechanism of the cemented carbide tool in the early stage of rock drilling is investigated. Experimental results showed that the surface pitting appears in the cemented carbide tool as soon as the rock drilling begins, and the high concentration of heat on the tool surface in the early stage of rock drilling induces flash temperature. The models of flash temperature and thermal stress of the cemented carbide tool in rock drilling are established. Mechanical analysis indicates that the pits on the surface of the cemented carbide tool in the early stage of rock drilling are not formed by the scratching, fatigue, and crushing of the rock material. And thermal analysis shows that thermal stress is the major cause of the pitting on the surface of the cemented carbide tool in the early stage of rock drilling, for the thermal stress induced by flash temperature on the tool surface is much higher than its mechanical stress. Experimental results also show that most of the surface pits occur at the junction of the WC phase and the Co phase due to the thermal stress.

1. Introduction

Due to its advantages such as high hardness, toughness and reasonable price, cemented carbide is the most common material in mining tools [1]. There have been lots of studies in the literature focusing on the failure mechanisms of cemented carbide tool in rock drilling, and wear is considered the main surface damage mode of the cemented carbide tool in rock drilling [2]. Montgomery stated that the chief wear mechanism is fatigue microspalling of the carbide surface related to the blows [3]. Larsen-Basse reported that the wear of cemented carbide tool is a process of abrasion of Co and WC skeleton breakage [4]. Beste and Jacobson investigated the wear of cemented carbide rock-drill bits, and five kinds of material removal processes were proposed to explain the wear mechanism [5]. Bailey and Perrot pointed out that the extrusion of binder phase Co was an important mechanism of surface wear of cemented carbide tool in mining [6]. Lagerquist suggested that wear was related to the thermal fatigue crack propagation between Co layers and adjacent WC grains [7]. Reptile skin is also a common surface damage in rock drilling by cemented carbide tools. Jonsson reported that reptile skin on hot bits could be a result of thermal fatigue under the coolant [8]. And corrosion of Co was found in the valleys of reptile skin [9]. But there is still no consistent agreement on the origin of wear. Recently, it was found that surface pitting of the cemented carbide tool appears in the early stage of rock drilling which could accelerate the surface loss and be the potential origin of wear and other surface damage [10]. However, the sudden appearance of pitting has not been reasonably explained so far.

In the present paper, the pitting mechanism of the cemented carbide blades in the early stage of rock drilling is investigated. Based on rock drilling experiments and temperature tests, mechanics and thermal analysis of the cemented carbide tool are conducted. Then, a new view of the origin of surface damage of the cemented carbide in rock drilling is presented.

2. Experimental procedure

The drill bit is 20 mm in diameter, the blade size is 5 mm × 5 mm × 10 mm, and the rake angle of the bit (θ) is 30°. The cemented carbide blade material for the rock drilling is of five kinds in the YG series: YG2 (98% WC, 2% Co), YG4 (96% WC, 4% Co), YG6 (94% WC, 6% Co), YG8 (92% WC, 8% Co), and YG10 (90% WC, 10% Co). The surface characteristics of the blades were examined by a scanning electron microscope (SEM), and the result shows that the surface of the samples is in acceptable quality (Fig. 1).

The mechanical properties of the cemented carbide and the rock material measured are presented in Tables 1 and 2. The drilling experiments were performed at usual working conditions with the feed speed of 10 mm/s and rotation of 90 rpm. All the experiments were performed for 0.1 s. The interface temperature between the rock and the cemented carbide blade was measured by a VarioCAM 9100 infrared-charge coupled device with a sampling frequency of 50 Hz. The surface investigations of cement carbide blades were performed with a Tescan Vega II LMU scanning electron microscope.

3. Results and discussion

3.1. Mechanics analysis

Neither obvious scratch trace nor fatigue crack morphology was found in the SEM images of the samples surface. But SEM microscopy

* Corresponding author. Tel.: +86 13971526161; fax: +86 27 68774906.
E-mail address: xfyang@whu.edu.cn (X. Yang).

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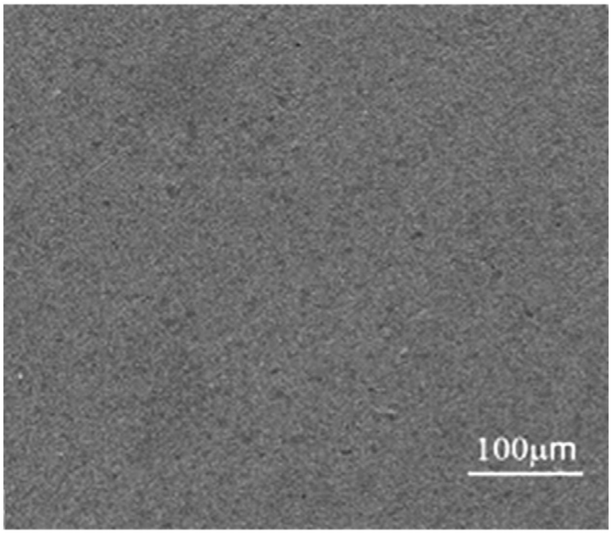

Fig. 1. Surface of the blade prior to drilling (YG6).

revealed a lot of pits in all test samples (Fig. 2). Moreover, the pits were irregular with different sizes.

Both the hardness and compressive strength of cemented carbide material are higher than those of the drilled rock. In the view of statics, the pits on the tool surface could not be induced by the pressure of the rock in such a short time. And in the view of kinetics, the stress on the tool in the drilling process is higher than that in the static pressure condition and is given as [11]:

$$\sigma_f = \frac{2}{m+1}\tau\frac{\cos\phi}{1-\sin(\phi-0.75\theta+22.5)}a + \frac{\pi^3}{\sqrt{3}}nb\rho_c\delta^3 \quad (1)$$

where τ is the shear strength of the rock, ϕ is the shear angle of the rock, θ is the rake angle of the tool, m is the stress coefficient ($m = 11.3–0.18\theta$), a is the area of contact surface, n is the rotation, b is the feed speed, ρ_c is the rock density, and δ is the radius of the drill bit. According Eq. (1), the value of σ_f is about 200 MPa. The strength of the cemented carbide material σ_0 is higher than 1 GPa, so the pits in the blade surface could not be impacted by the rock under the experimental condition ($\sigma_f < \sigma_0$) in such a short time. Therefore, the pits on the surface of the cemented carbide tool in the early stage of rock drilling are not formed by the scratching, fatigue, and impacting of the rock material. Traditional interpretations of the surface damage of cemented carbide drill have difficulty reasonably explaining the rapid appearance of the surface pitting.

3.2. Thermal analysis

The heat generated by the drilling process provides a new approach to explain the pitting of the cemented carbide blade. Rock is a kind of brittle material and it is crushed into powder instead of continuous chip in metal cutting. Rock fracture happens randomly in a very short time and the heat release in rock drilling is a discontinuous concentration and outbreak process [12–15].

Table 1
Mechanical and thermal properties of the cemented carbide material.

Cemented carbide	Hardness (HRA)	Bending strength (MPa)	Thermal conductivity (W/mk)
YG2	93	1200	88
YG4	91.5	1300	83
YG6	90	1450	79
YG8	89	1500	75
YG10	87.5	1520	72

Table 2
Mechanical and thermal properties of the rock material.

Compressive strength (MPa)	Shear strength (MPa)	Shear angle (°)	Density (10^3 kg/m^3)	Thermal conductivity (W/mk)
150	15	65	2.6	2.4

The temperature rising rate reflects the concentration extent of heat released in the interface. Fig. 3 shows the temperature rising rate of the interface drilling with different Co content blades in 0.1 s after the drilling begins. All results in the experiments have shown a high temperature rising rate in the interface of the rock and the cemented carbide tool. It also indicates that there is extremely high concentration of heat released on the surface of the cemented carbide tool in the early stage of rock drilling.

Most of the drilling heat is transformed from the mechanical energy of the drill bit, so friction is the main heat resource in the contact surface of the rock and the cemented carbide blade. The power of friction is given by

$$w = \mu p_0 v \quad (2)$$

where μ is the friction coefficient, v is the friction velocity, and p_0 is the pressure intensity which is given as

$$p_0 = \frac{p}{s_0} \quad (3)$$

where p is the pressure and s_0 is the geometric area of the contact surface. So the average heat flux in the friction surface q_0 is simplified as

$$q_0 = w = \mu p_0 v. \quad (4)$$

From Eq. (4), the heat flux can be related to the friction coefficient. However, the friction coefficient is different in the random process of rock fracturing, providing the conditions for the heat concentration. High temperature also appears with the appearance of heat concentration which would impact the surface of the tool material.

3.3. Surface temperature

Normally, the average temperature of the friction surface is obtained as [16,17]

$$T = \frac{1.6\eta q_0}{\rho c v}\sqrt{\frac{\rho c v l}{k_1}} \quad (5)$$

where ρ is the density of the cemented carbide material, c is the specific heat of the cemented carbide material, k_1 is the thermal conductivity of the cemented carbide material, l is the width of heat resource, and η is the proportion of the heat assigned to the cemented carbide tool. η is given by

$$\eta = \left[1 + \left(\frac{k_2}{k_1}\right)\left(\frac{k_1}{\rho c v l}\right)^{\frac{1}{2}}\right]^{-1} \quad (6)$$

where k_2 is the thermal conductivity of the rock.

In actual rock drilling, the local actual temperature in different areas is not the same as the average temperature. In the microscopic view, the actual friction surface of the cemented carbide blade is uneven, and there are a lot of micro asperities. The actual contact area between the tool and the rock material s_a is lower than the geometric contact area s_0. In this paper, the coefficient of surface contact ω is defined to