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FAILURE ANALYSIS OF CARBIDE TWIST-DRILL BIT FOR SMALL-SCALE GRANITE DRILLING

ANALIZA NAPAK KARBIDNEGA SVEDRA ZA IZDELAVO MANJŠIH IZVRTIN V GRANIT

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This paper deals with a failure analysis of WC-Co carbide-based twist drills used for small-scale granite drilling. A bench-top drill was used for this study. The aim of the study was to analyse a simulated in-situ rock-drilling operation normally carried out in mines. After a drilling time of 15 minutes, the drills were examined using scanning electron microscopy. On macroscopic observation, both cutting edges of the drills showed slight signs of abrasion, but these were not significant. The chisel edge was also abraded and showed some macroscopic abrasion marks. The electron micrographs showed various signs of decomposition at the micro and nano levels, including cracks in the WC grains, cavities in the grains, Co-binder erosion and some heavy abrasion marks. In addition, some parts of the carbide grains were covered with a thin layer of rock. The wear analysis is an important approach to understanding exactly the damage behaviour of the tool so that the material composition can be changed to avoid premature tool failure.

Keywords: carbide twist-drill bit, granite, wear, cemented carbides, scanning electron microscope

V prispevku je prikazana kritična analizo napak svedra iz karbidne trdine WC-Co, ki je bil uporabljen za vrtanje granita. Študija zajema vrtanje na laboratorijski ravni, saj je bil uporabljen namizni vrtalni stroj. Namen je bil analizirati vrtanje kamnin, ki se običajno izvaja v rudnikih. Po času vrtanja petih minut smo svedre kritično analizirali z vrstično elektronsko mikroskopijo. Pri makroskopskem pogledu sta imela oba rezalna robova svedrov manjše odrgnine, ki niso bile pomembne. Rob dleta je bil tudi poškodovan na makro ravni. Slike z elektronskim mikroskopom so razkrile različne pojave obrabe na mikro in nano ravni, ki vključujejo razpoke v zrnih WC, votline v zrnih WC, erozijo veziva Co in nekatere sledi odrgnin. Poleg tega so bili nekateri deli karbidnih zrn prekriti s tanko plastjo kamnin. Analiza obrabe je pomemben pristop za pravilno razumevanje obnašanja orodja pri poškodbah, tako da je mogoče sestavne materiale spremeniti, da se prepreči prezgodnjo okvaro orodij.

Keywords: spiralni sveder iz karbidne trdine, granit, obraba, karbidne trdine, vrstični elektronski mikroskop

1 INTRODUCTION

The twist drill is the most common type of drill used in practise today. It consists of a cutting point at the tip of a cylindrical shaft with helical flutes; the flutes act like an Archimedean screw and transport the cuttings out of the bore hole. Twist drills are generally used for drilling smaller holes. Wear is one of the main factors in the failure of drill-bit components. For example, they are used to drill through rock surfaces and create a hole that is filled with explosives. After the explosion, the coal bed comes to the surface and the coal cutting is done. The roller cone drills for large-scale mining mainly contain cemented carbide as buttons or pointed inserts. The cemented carbide WC+Co, which is also known as "Widia", is produced by the powder-metallurgy process. The WC has a hexagonal lattice (HCP), while the Co binder has a face-centred-cubic crystal lattice (FCC). At this point, the authors would like to point out that Co has a hexagonal, close-packed structure at temperatures below 417 °C, but when used as a binder, the dissolved components of WC can cause the structure to remain face-centred cubic at room temperature.[1] WC is very hard and provides wear and abrasion resistance, whereas the Co binder provides adequate toughness and chipping resistance. The result is a material that has fracture resistance, hardness, abrasion resistance, stiffness and toughness. Typically, WC+Co is used in the form of inserts, like buttons, cone tips, radial tips, inverted V tips, etc., into the hardened steel body parts. Various grades of cemented carbides are produced according to WC grain size and cobalt content. Usually, the grain size of the WC grains is between 1 µm and 10 µm, and the volume of cobalt content is 3–20 φ/%.

For large-scale mining into rock, roller cone drills made of cemented carbide buttons are preferred over other shapes. Some of the rock drilling tools are shown in **Figure 1**. Rock drilling is basically performed by the brittle fracturing technique because of the huge irregularities in the rock properties. The rock is crushed and fractured to drill holes. In mining, both underground and open pit, there are many critical geological and working conditions, such as irregular quartz content in the rock, corrosive chemicals and high heat due to continuous cut-

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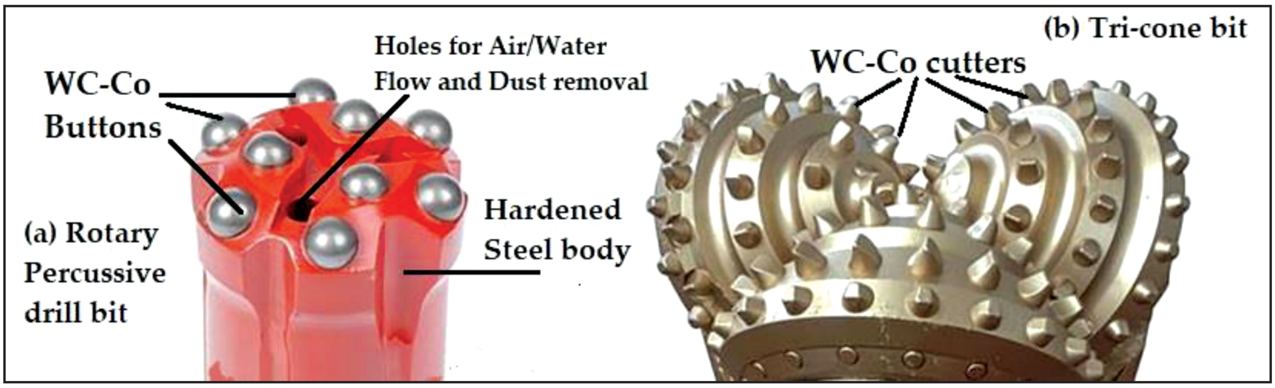

Figure 1: a) Rotary percussive drill bit with WC-Co buttons inserted by brazing method,[2] b) Tri-cone bit with WC-Co cutters[3]

ting. Under these conditions, the service life of the tool is limited. The operating conditions cannot be changed, but the properties of the tool can be improved. Therefore, over the past two decades, various research has been carried out to change or improve the material components of the tool so that the wear can be reduced.

To analyse the wear of cemented carbides, both types of analyses, i.e., laboratory work and in-situ mining operations, have been carried out in the past. For drilling rocks under in-situ conditions, two types of drills, namely percussion drills and rotary percussion drills, have been used extensively. Conical and radial shaped picks were also used for the linear cutting of rocks. As the cemented carbide is mainly used as inserts, they were extracted from the steel body for further micro-level observation under a microscope.[2] Based on the appearance, wear phenomena such as abrasion in WC grains, surface cracks, reptile skin, penetration, covering and intermixing of the rock into binder phase, Co degradation, corrosion of individual grains, crushing and removal of WC grain particles were mainly reported.[2–5] The tools used for coal mining were also subjected to wear testing. The heavy machinery such as continuous miner, roadheader and shearer are used for underground coal mining. Cutting tools such as conical picks, radial picks and forward-attack picks are mainly used for cutting coal. Research has also identified similar wear mechanisms in these bits as in rock drills. A detailed list of the wear phenomena observed in cutting tools is shown in a flow chart (**Figure 2**).[6,7]

Many research works in the laboratory prove that different cemented carbide grades are affected differently under the same working conditions. Mainly the tribological properties of the cemented carbides have been analysed.[8–11] With the change of grades, the mechanical properties also change rapidly. It was observed that the hardness of the cemented carbide increases with a decrease in the WC grain size. The grain size is generally kept in the range 0.1 μm to 10 μm with the Co content varying from 3 *w*/% to 20 *w*/%.[12] Ultrafine WC particles of less than 0.1 μm have also been used.[13,14] Cha et al.[15] analysed cemented carbides with WC – 10 *w*/% Co by changing the WC grain size and HCP/FCC phase ratio of the Co binder. The cemented carbide with 4 μm

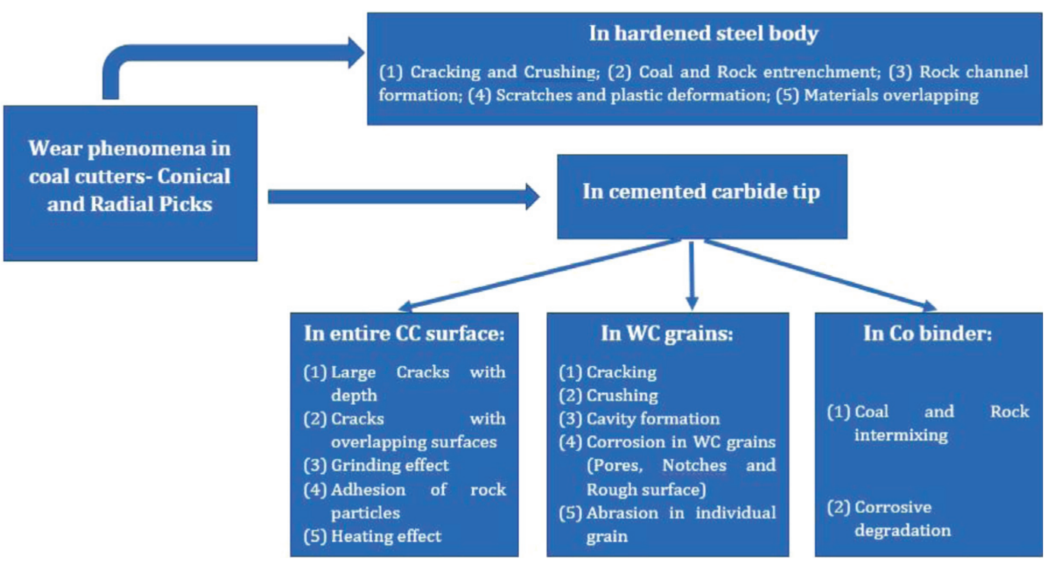

Figure 2: Flow chart showing detailed wear phenomena in coal cutters

WC grains had a hardness of 1200 HV. This value was increased to 1900 HV by reducing the grain size to 300 nm. When the HCP/FCC phase ratio was increased, the fracture toughness also increased.[15] Okamoto et al.[16] showed experimentally that the cemented carbide with large WC grain size (20-30 μm) had higher ductility than the finer-grained WC.[18] Saito et al.[17] concluded that the wear rate of cemented carbides increases with increasing WC grain size and increased Co content. Pirso et al.[12] concluded that in a dry wear test, the cobalt binder is removed first, followed by fragmentation of the grain boundaries and finally crushing and fragmentation of the WC grains. Angseryd et al.[18] analysed the cemented carbide drill buttons for wear. The experimental procedure consisted of a rotating rock with a lathe, additional abrasives were fed against the tool. Both dry and wet wear tests were performed by adding other abrasives such as Al_2O_3 and SiC. The samples were found to show wear phenomena such as cracking and fragmentation in WC grains and Co depletion along with rock adhesion.

Failure analysis of any tool is a fundamental approach to observe and analyse the exact way of wear. Based on this, the properties of the tool can be improved according to the requirements of the working environment, so that certain wear phenomena can be avoided, and the service life of the tool can be increased.

The present work deals with a small-scale rock drilling process under laboratory conditions to analyse the wear phenomena in cemented carbide tools. For this purpose, a cemented carbide-based drill (with a 10 *w*/% Co content) was used to drill a granite sample on a bench drill. After a certain period of drilling, the drill was examined for signs of wear. The wear mechanisms were investigated using electron microscopy. A detailed explanation of each type of wear is given in this paper.

2 EXPERIMENTAL PART

The experimental work is discussed in detail in an earlier paper.[19] A WC -10 *w*/% Co twist drill was used for this work. The lengths of the shank and the body of the drill were 60 mm and 25 mm, respectively. The outer diameter of the drill bit including the edges is 8 mm. It was used to drill granite rock samples with a size of (98 × 98 × 25) mm^3. The bench drill was used to drill the rock sample. The total time for drilling was 15 min to drill 5 holes in one sample. The spindle speed was 1425 min^{-1}. During operation, water was supplied to cool the tip of the drill. After the experiment, the tip of the drill was cut off so that it could be viewed in the field-emission scanning electron microscope (FE-SEM), JEOL JSM-7610FPlus. The experimental setup, the tool and the rock sample are shown in **Figure 3**.

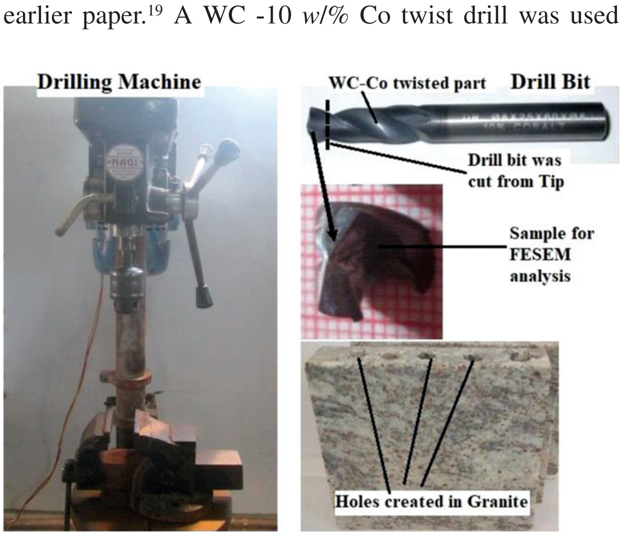

Figure 3: Experimental set-up

3 RESULTS AND DISCUSSION

3.1 General

As shown in **Figure 3**, the tip of the bit was cut-off from the body so that the upper part of the tip can be observed by FE-SEM. As the tip contains two lips and a chisel edge, some grinding marks and blunt lip edges can be seen above the tip in the macro view. After an observation, five main types of wear were found on the tool, namely:

- Cracks on WC – minor and severe,
- WC crushing,
- Cavity formation on WC,
- Co binder intermixing and degradation,
- Granite-layer formation.

3.2 Cracks

Cracks were observed in the WC grains. There were two types of cracks: minor and severe. Minor cracks can be seen at high magnification in **Figure 4**. The presence of hard quartz in the granite is responsible for the abrasive damage to the WC grains. When the drill was rotated around its own axis and at the same time the thrust

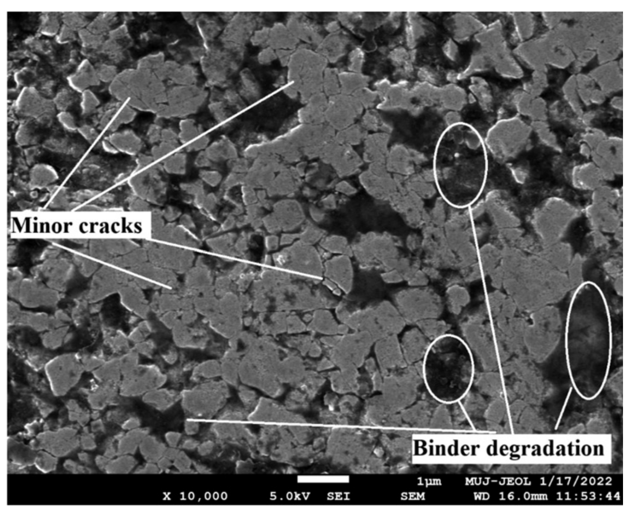

Figure 4: Minor crack generation in WC grains

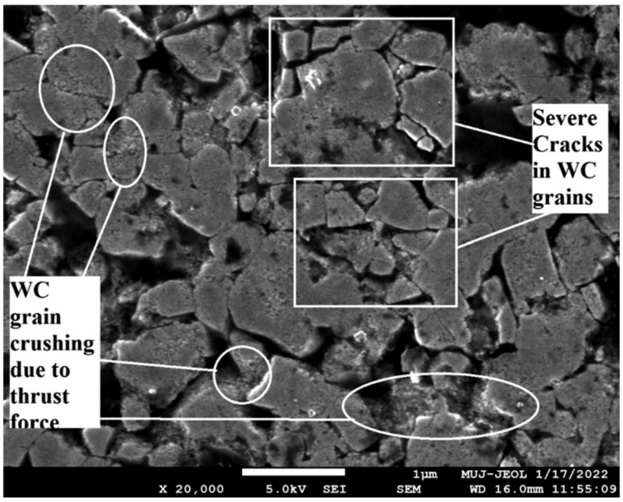

Figure 5: Severe cracks and Crushing of WC grains

was downwards, the abrasion phenomena of the rock increased as soon as the thrust increased. Therefore, cracks appeared in the individual WC grains. Small cracks are the first sign of wear in cemented carbide. As soon as the impacts and abrasion progress, the minor cracks are initially enlarged before a new grain comes into contact. The minor cracks become larger, i.e., both the length and the width of the crack increase. This is called a severe crack. It can also be said that the intergranular boundaries dissolve. At this stage, the adjacent bonding metal is also forced out. Severe cracks can lead to tool damage if the operating parameters are not controlled. Severe cracks are indicated by the white rectangles in **Figure 5**.

3.3 WC grain crushing

The crushing phenomenon is an important stage where severely cracked WC grains begin to disintegrate into fragments. This is due to heavy impact or repeated abrasion on already-cracked parts. The crushed WC grains cannot remain intact for long. The powdered grains lose their original position as the further drilling or cutting progresses. The crushed and fragmented WC grains can be seen in the elliptical areas in **Figure 5**. The severe cracks can also be seen within the white rectangles.

3.4 Cavity formation

Cavity is another type of wear that follows the crushing and fragmentation of the grains. **Figure 5** shows that the crushed WC grains still adhere to the original grain. The fragmented WC particles should not stick there for a long time. Therefore, when a strong thrust force is applied during the drilling process, the fragmented WC grain particles are removed from the cemented carbide, leaving the original position empty. This empty space is characterized as a cavity in the WC grains. The cavity formation is shown in **Figure 6** (in the black circles). During the drilling process, these cavities are sometimes filled with rock particles. This filling cannot last long because there is no proper bond between the rock and the WC grains. Therefore, the cavities eventually remain until the end of the tool's life.

3.5 Granite-layer formation

This is a general wear phenomenon that can be observed in any type of tool. Since the drill was used to drill granite, the fine granite particles cover a large part of the WC-Co. These covered parts cannot be removed easily; thorough polishing is required to remove them. During the drilling process, water was directed onto the contact point between the tool and the workpiece. The drilled granite powder mixed easily with the water. When the mixture of water and granite powder comes into contact with the tool tip, the water evaporates and the granite powder sticks to the tip because the tool tip is

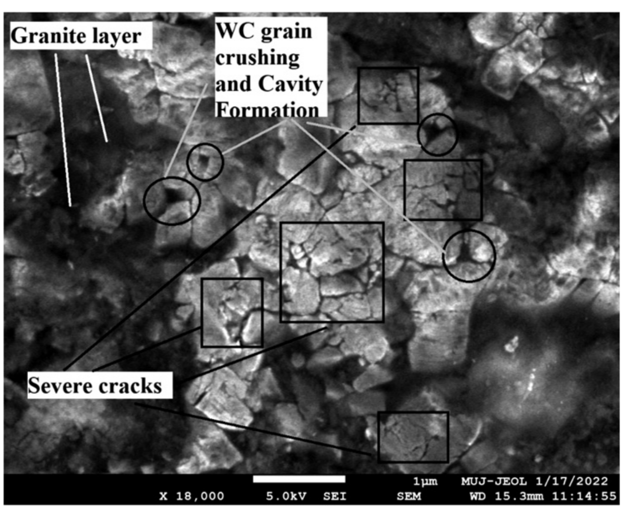

Figure 6: Severe cracks and cavity formation in WC grains; binder parts are surrounded by granite particles, forming a layer of rock

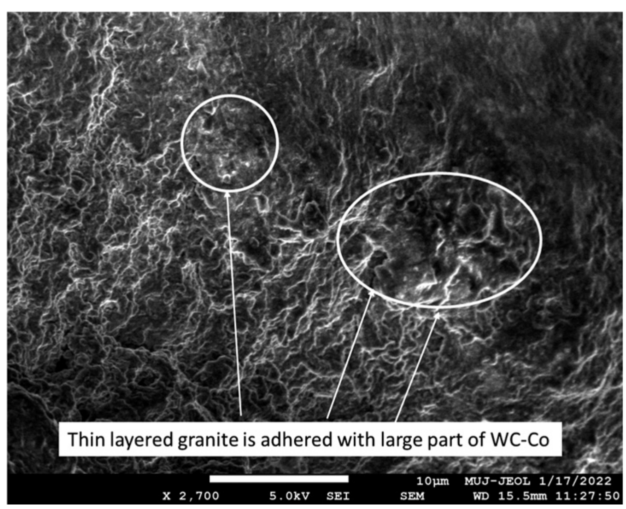

Figure 7: Granite-layer formation over the surface of WC-Co surface

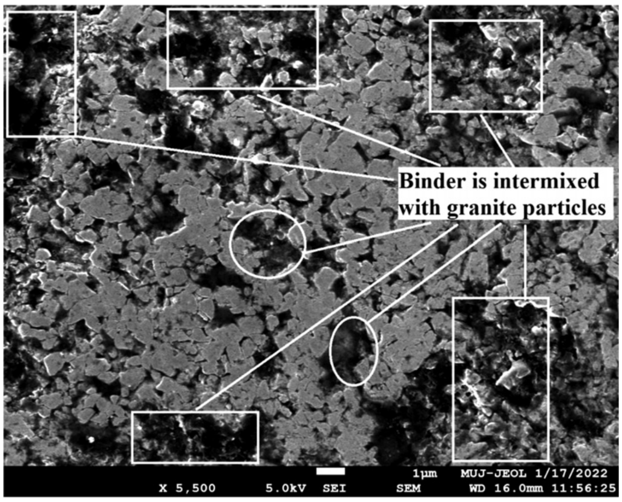

Figure 8: All rectangular and circular areas are showing Co-binder intermixed with granite particles

very hot. Another reason for the formation of the rock layer is the embedding of sharp and abrasive rock particles within the carbide surface under the strong thrust force applied during drilling. The granite layer is not so detrimental to the tool as it generally does not affect the basic alignment of WC-Co. **Figure 7** shows an area of the tool tip covered with granite where no grains are visible.

3.6 Co binder intermixing and degradation

The next stage of rock layer formation is the mixing of the rock and the breakdown of the binder. As mentioned earlier, this becomes an important stage for the binder metal when the hard and abrasive rock edges have settled on the tool surface. The binder used is Co, which has a lower hardness (almost half) than the WC grains. Therefore, under heavy abrasion and high load, some quartz particles can penetrate the area of the Co binder and mix with it. Mixing with the binder component sometimes deteriorates the binding properties of the Co and causes the WC grains to flake off. The rock mixed with the Co binder leads to a deterioration of the binder and rapid Co removal. Therefore, in previous research, it was found that the Co binder could not be increased beyond a certain level because its degradation can remove the WC grains more easily. The amount of binder mixed into the rock can be easily identified by its appearance. All rectangular areas in **Figure 8** show intermixed binder parts.

4 CONCLUSIONS

In this paper, an analysis of the wear phenomena in WC-Co-based drills was carried out. The drill was used to drill granite rock samples. This work is a small sample of the work in in-situ mining. The drilling tools are greatly affected by the quartz content of the rock. In this sense, this work includes a small experiment on rock drilling and a wear analysis of worn cemented carbide drills. The wear phenomena in cemented carbide tools were characterised using high-resolution electron microscopy.

The analysis revealed that there are five different types of wear phenomena in this case study, which are described in the article.

Smaller cracks are the beginning of the failure process, which is common with heavy loads and hard rock contact. Once smaller cracks are subjected to further loading, they transform into severe coarse cracks. These cracks are the result of the separation of the WC grain boundaries. After the severe cracks, crushing takes place, i.e., fragmentation of the WC grains under severe abrasion by heavy impacts. The fragmented WC grains are removed from their original places to create cavities in which the rock particles can easily embed. In addition, rock mixing and binder degradation are important wear processes that severely degrade the Co binder phase and hence Co-depletion. WC grain loss is the negative effect of Co depletion. A degraded Co-binder phase can no longer properly bind the grains for further cutting or drilling operations.

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