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Initial surface failure and wear of cemented carbides in sliding contact with different rock types

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ABSTRACT

The initial wear, deformation and degradation of cemented carbide in contact with different rock types are studied using a crossed cylinder sliding test. The sliding distance is limited to centimetres at a time, interrupted by successive SEM analysis. This allows for careful studies of the gradually changing microstructure of the cemented carbide during the test. Five different rock types are included; granite, metal sulphide ore, mica schist, quartzite and marble. All rock types are very different in microstructure, composition and properties. The cemented carbide grade used for the evaluation contains 6 wt% Co and fine (~ 1 µm) WC grains, a grade commonly used in rock drilling. The results show that the cemented carbide microstructure becomes altered already during the very first contact with rock. The initial wear rate and wear character is highly influenced by the rock type. The initial wear of the cemented carbide is highest against quartzite and lowest against marble.

1. Introduction

Cemented carbides are composite materials consisting of hard carbide particles in a more ductile binder phase. The most common combination is tungsten carbide (WC) particles in a cobalt (Co) binder. When used as drill bit buttons in rock drilling these composite materials generally show low wear. The combination of high hardness and toughness minimizes both plastic deformation and brittle fracture in contact with the rock.

The cemented carbide microstructure is usually well defined and manufactured following a powder metallurgy process route optimized to achieve the composition and properties sought for. On the other hand, the counter material in rock drilling, the rock, is a natural material generally showing large variations in both microscale, e.g. multimineral rocks, and macroscale, e.g. variation of rock type in a borehole, which will affect the drillability and penetration rate [1–3]. This wide group of rock types also differs quite a lot in both chemical, physical and mechanical properties. Just a few papers have looked into the properties of rock from the fundamental tribological perspective [4–6]. In [4] the friction between cemented carbide and a variety of rock types was measured in a pin-on-disc set up and the authors concluded that the differences in friction did not correlate to the commonly observed large differences in wear of the cemented carbide. In [5] the hardness distribution of different rocks was measured both in small scale (indentation depth 1 µm) and commonly used Vickers measurements with 500 g load. They concluded that hardness needs to be measured in small scale to be representative for the scale in which wear of cemented carbides occur in rock drilling, and to be able to identify hard inclusions/phases that are present also in minerals with relatively low hardness. The corresponding wear of a cemented carbide pin was evaluated in a scratch test set up in [6] and was found to correlate quite well to the measured small scale hardness in [5], but was also influenced by e.g. grain size of the rock, where smaller grains (i.e. cemented carbide pin passing more grain boundaries) were correlated to more wear.

A common strategy is to focus on the cemented carbide, which can be designed to achieve certain properties, and use a counter rock material to compare these against each other [7–9]. This approach could be used to optimize the cemented carbide grade used in a certain application. A recent study combines actual drilling and three different lab-scale tests of a set of cemented carbides. It includes both comparisons of wear ranking between the actual drilling and the lab tests and micro graphical studies of the worn drill buttons from the different tests [10]. Another strategy is to study the wear mechanisms of the cemented carbide against a certain rock material, to increase the knowledge about the wear in that application [8–17]. In [8,9,13–15] the focus is on detailed wear mechanisms against granite, references [11,12] deal with the occurrence of reptile skin in drilling of magnetite and also wear

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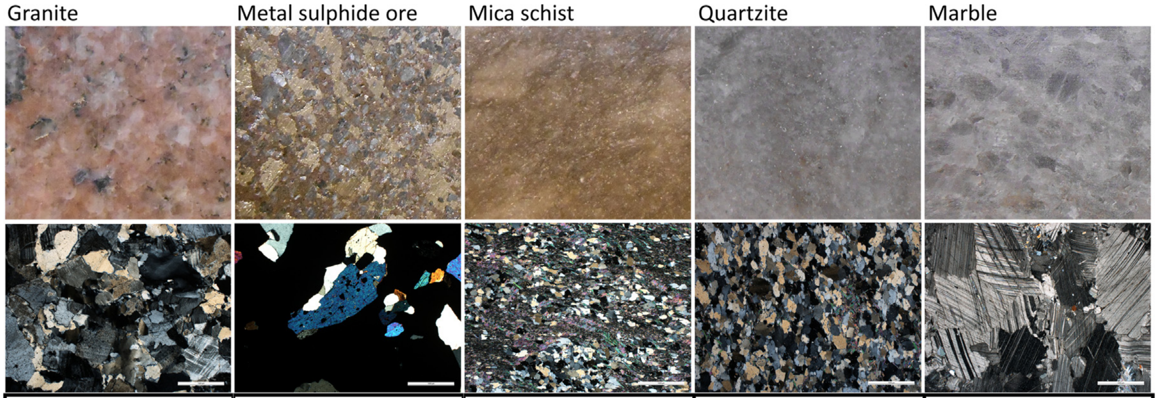

Granite	Metal sulphide ore	Mica schist	Quartzite	Marble
Quartz *white/gray*	Pyrite *gold*	Quartz *white/gray*	Quartz *white/gray*	Quartz *white/gray*
Feldspar *pink*	Amphibole *colorless*	Mica *brown*	Mica *brown*	Calcite *White*
Mica *black*	Quartz *white/gray*			
	Sphalerite *brown*			

Fig. 1. The appearance of the included rock types. Width of photograph (top row) 14 mm and light optical micrograph (second row, crossed-polarized light) 5 mm. Colour refers to the photographs and the birefringence of minerals in the micrographs are used to quantify the main minerals (> 1%) in each rock type.

Table 1
Quantity, grain size and nanohardness of the respective minerals (> 1%) in the included rock types.

Rock type	Mineral	Chemical formula	Quantity [%]	Grain size[a]	Hardness [GPa]
Granite	Quartz	SiO_2	25–40	Medium	12.8 ± 1.0
	Feldspar (alkali)	$KAlSi_3O_8$	40–50	Medium	10.5 ± 1.3
	Mica (Biotite)	$K(Mg,Fe)_3AlSi_3O_{10}(F,OH)_2$	15–20	Medium	3.4 ± 1.3
Metal sulphide ore	Pyrite	FeS_2	35–45	Medium	20.7 ± 1.1
	Amphibole (Cummingtonite)	$Fe_2Mg_5Si_8O_{22}(OH)_2$	5–10	Medium	12.2 ± 0.8
	Quartz	SiO_2	10–20	Medium	–[b]
	Sphalerite	$(Zn,Fe)S$	15–25	Medium	3.2 ± 0.3
	Others[c]	–	10–15	–	–
Mica schist	Quartz	SiO_2	50	Small	11.5 ± 0.7
	Mica (Muscovite)	$KAl_2AlSi_3O_{10}(F,OH)_2$	50	Small	2.8 ± 0.5
Quartzite	Quartz	SiO_2	95–97	Small	12.1 ± 0.8
	Mica (Muscovite)	$KAl_2AlSi_3O_{10}(F,OH)_2$	3–5	Small	4.4 ± 0.3
Marble	Quartz	SiO_2	1–2	Small	10.5 ± 0.9
	Calcite	$CaCO_3$	> 97	Large	2.2 ± 0.2

[a] Small refers to a mean grain size < 200 µm, medium 500–800 µm and large > 1.4 mm.

[b] No quartz was identified in the nanoindentation sample although significant amounts were found in the thin section.

[c] Other mafic minerals (e.g. pyroxenes, biotite mica) and feldspar. Less than 1% of each mineral.

against limestone [16] and sandstone [17] has been investigated.

In recent years some papers summarizing the wear mechanisms of cemented carbides in contact with different rocks has been published [11,18–21]. After studying the literature both [11,18] give suggestions for choosing the cemented carbide grade based on rock type and which problems that arise, respectively. In [22,23] buttons that have been drilling in quartzite, quartzitic granite, magnetite, chromite, manganese, coal/sandstone and gypsum are compared. Several similarities were observed; partial rock cover on the surface, formation of an intermixed layer with rock/Co/WC and penetration of rock deep into the cemented carbide button. Mechanisms of deterioration and removal of materials was suggested based on the different observations from the buttons [22]. Also differences, like formation of reptile skin for some of the rocks, and to which depth the rock infiltrated the microstructure, were pointed out [23]. However, although the observations from real drilling are very valuable, the cemented carbide grade, drilling depth and drilling parameters are not the same for all materials, since it has been optimized already for the application, i.e. the rock type, based on experience. Hence, the influence on wear from rock type has to our knowledge not yet been systematically investigated. Most of the field tests also include drilling for a long time, meaning that although several similarities are observed in steady state wear [23], differences in wear initiation might be hard to separate.

In the present work, the very initial deformation, degradation and wear of cemented carbide in contact with different rock types are studied using a crossed cylinder sliding test, previously shown to result in