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Wear assessment of the WC/Co cemented carbidetricone drillbits in an open pit mine

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Abstract. In rock drilling, the most important characteristic to clarify is the wear of the drill bits. The reason that the rock drill bits fail with time is wear. In dry sliding contact adhesive wear deteriorates the materials in contact, quickly, and is the result of shear fracture in the momentary contact joins between the surfaces. This paper aims at presenting an overview of the assessment of WC/Co cemented carbide (CC) tricone bit in rotary drilling. To study wear of these bits, two approaches have been used in this research. Firstly, the new bits were weighted before they mounted on the drill rigs and also after completion their useful life to obtain bit weight loss percentage. The characteristics of the rock types drilled by using such this bit were measured, simultaneously. Alternatively, to measure contact wear, namely, matrix wear a micrometer has been used with a resolution of 0.02 mm at different direction on the tricone bits. Equivalent quartz content (EQC), net quartz content (QC), muscovite content (Mu), coarseness index (CI) of drill cuttings and compressive strength of rocks (UCS) were obtained along with thin sections to investigate mineralogical properties in detail. The correlation between effective parameters and bit wear were obtained as result of this study. It was observed that UCS shows no significant correlation with bit wear. By increasing CI and cutting size of rocks wear of bit increases.

Keywords: bit wear; cemented carbide; tricone bit; rock properties

1. Introduction

Due to the increased demand for mechanical drilling and cutting of rock masses in mining, petroleum and civil engineering the drilling and cutting tools has turned out to be more dominant in various underground and surface operations. In large surface mining, rotary tricone bit which is a cemented carbide material (consists of tungsten carbide (WC) grains inserted or sintered into a steel cone and bonded together with a cobalt binder)is the most popular drilling tool for deep holes with large diameter. Their drilling rate has increased over the time due to higher powered drills and better control of the operational parameters, leading to increase in mining production and reduction in drilling costs. To decrease downtime related to drilling, it is inevitable to assess bit

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wear. Excessive wear and frequent breakage of the drilling bit is one of the major causes of downtime.

In drilling process, the most frequent types of tool wear are heel row wear (when bit lateral inserts erodes in contact with earth materials), gage row wear (in which cone binder matrix erodes in contact with earth materials) and WC insert breakage. Frequent wear types measured in this study are, radial and diametrical wears both regarded as heel row wear and matrix wear as gage row wear.

An example of a tricone drill bit for rotary drilling is shown in Fig. 1. In this drilling type, a large part of the torque energy is consumed in converting the rock into a fine powder. The arranging of the inserts is accordingly optimized to generate as large fragments as possible to improve the efficiency of the drilling (Beste and Jacobson 2008).

Description and assessment of the surface damage and wear mechanisms of WC rock drill bits require well monitored testing conditions given that the results achieved may soundly depend on the testing conditions, as well as type of rock material (Beste and Jacobson 2008, Larsen-Basse 1973, Perrot 1980, Angseryd *et al*. 2013, Olovsjo *et al*. 2013).

Wear mechanisms importantly include adhesive wear due to shear plane deformation, abrasive wear due to hard particles cutting, diffusion wear due to high temperature, fracture wear due to fatigue, and extrusion of WC inserts (Beste *et al*. 2006).

Okubo *et al*. (2011) used three methods, drilling test, Taber-abrasion test and turning-operation test to measure rock abrasivity in correlation with rock mechanical properties. They found that within the range of tests conducted, the turning-operation test turned out to be superior to the drilling test, albeit slightly, in terms of practicality. The results of those tests have been investigated and compared with the results of laboratory tests. There was a large degree of scatter in the data on gauge loss in button bits, which has obscured any correlations with laboratory data. Some correlations were found between height loss in button bits and laboratory findings.

Rostami *et al*. (2014) studied the influence of various parameters on Cerchar testing including

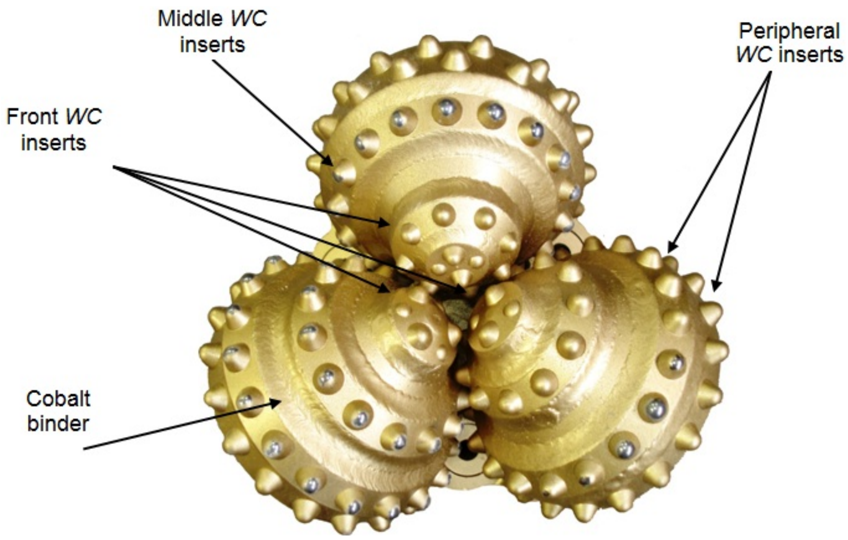


Fig. 1 A tricone bit equipped with 175 WC inserts designed for drilling in medium hard rock types such as weathered porphyritic dacite and andesite

pin hardness, surface condition of specimens, petro-graphical and geomechanical properties, test speed, applied load, and methods of measuring wear surface. Comparison of the CAI values and the physical properties of the rock indicated that CAI measured on rough specimens yields more consistent results and good correlation with UCS and EQC values. It was also concluded that there is a linear relationship between CAI values for different pin hardnesses, especially for rough specimens. The AVS test, originally developed by NTNU, has been used in numerous major international underground projects and the NTNU/SINTEF database does currently contain results from 1,590 tested samples (Dahl *et al*. 2012) However, the Cerchar test remains the most commonly used test for rock abrasion due to its simplicity and as such, the parameters influencing the measured results are the subject of the current study.

Plinninger *et al*. (2002) classified wear rate of button bits into six classes from very low to extremely high wear rate. It was based on the drilling length per number of consumed bits during drilling process. The drill bits with > 2000 m/bit and < 200 m/bit considered as very low and extremely high wear rate, respectively. Subsequently, they found correlation between rock abrasivity indices (Vickers Hardness Number of Rocks, VHNR; Cerchar Abrasivity Index, CAI; and Rock Abrasivity Index, RAI) and wear rate of drill bits. They concluded that RAI which takes into account a wide range of scale from rock mass to mineral properties could better estimate wear rate of button bits than other indices could.

ASTM B611 and ASTM G65 also suggested some standardized tests to evaluate wear of CC materials. Though, in these tests the effect of abrasive material was assessed and usually concluded that the harder the abrasive particle is the higher the wear rate of tools will be (ASTM 2000, 2010). Angseryd *et al*. (2013) developed a wear test for evaluation of WC/Co inserts introducing Al_2O_3 and SiO_2 particles under dry and wet conditions. They found that SiO_2 cannot affect the wear rate of WC grains. However, Al_2O_3 which is harder than WCs causes significant increase in the wear rate of WC/ Co inserts.

The relationship between abrasive particle size and wear of ductile materials such as metals is reported in the literature (Thakare *et al*. 2012). The wear rate for ductile materials increases rapidly with particle size within a size ranges from ~10 to 100 μm and reaches a limit with constant wear rate for larger particle sizes.

To date, many researchers have attempted to obtain the relationship between rock properties and penetration rate of rotary drill bits while few works were regarded to obtain the relationship between rock properties and its wear rate from mine. In addition, laboratory works for bit wear evaluation have been done in small scale. In this study it was tried to determine possible relationship between different rock properties and wear rate of rotary WC/Co cemented carbide bits that obtained directly at the field with two different ways i.e. calculation of bit weight loss using a digital balance and bit dimension loss using a micrometer.

2. Field measurements and procedures

2.1 Case study

The study was carried out on the tricone WC/Cocemented carbide bits at Sarcheshmeh copper mine located in southern Iran. Fig. 2(a) shows a tricone bit mounted on the drill rig during drilling a borehole. All tricone bits were API-RR321 standard type with diameter of $9\frac{7}{8}$ inches manufactured by Sandvik Co. They are mounted on a DMH Ingersoll–Rand drill rig to penetrate

Fig. 2 (a) Close up view of the drill bits during drilling the holes into the rocks; (b) a view of the Sarcheshmeh copper mine

rock masses. The system involves maximum 3000 psi feed pressure on the string, 400 psi air pressure to drag out rock and soil detritus, 200 RPM and 5000 psi rotation pressure. In Fig. 2(b) a view of the case study is shown.

The bits were investigated before drilling and after their useful life were completed. Worn bits were transferred to the warehouse. First step was to wash bits to remove penetrated dust and rock material from their surfaces. They were weighted before and after drilling the rock masses to obtain their weight loss. This represents eroded material because of contact with abrasive minerals of drilled rocks during the process.

2.2 Experimental works and field studies

Plinninger *et al*. (2002a) showed that "Abrasive wear" is the main wear process in most rock types. Abrasive wear leads to the removal of material from the tool surfaces while it is moving against the rock. It depends on the hardness difference between drill bit surface and drilling medium. It is caused by direct scratching of bit surface against hard particles of rocks. The most common abrasive mineral is known to be quartz, and quartz content is the significant parameter for hard rock description (Plinninger 2010). In this study, among the rock abrasivity indices, Equivalent Quartz Content (EQC), which uses Rosiwal grinding hardness, is used to assess the abrasiveness of the minerals in the rock samples. The reason for choosing this index is that, EQC takes into account hardness of all constituent minerals in the rock based on their contributions in rock fabric. The Rosiwal hardness and EQC are calculated based on Moh's hardness of the constituent minerals using Eq. (1)-(2) (Plinninger *et al*. 2002a)

$$RH = \exp((MH - 2.12)/1.05) \tag{1}$$

$$EQC = \sum_{i=1}^{n} RH_i . A_i \tag{2}$$

Where RH is the Rosiwal grinding hardness (%), MH is the Moh's hardness, EQC is the equivalent quartz content, Ai is the mineral percentage (%) and n is the number of minerals, which contributes in the rock texture.

In this study, samples from mine region have been collected and transferred to the laboratory. In Fig. 3, the geological map of Sarcheshmeh stock work including frequent rock types, intrusive dikes and sampling points are shown.

Moh's hardness for constituent minerals of the rock types was obtained based on the Moh's scale from 1 for talk to 10 for diamond (quartz' Moh's hardness is 7 in this scale). The Moh's

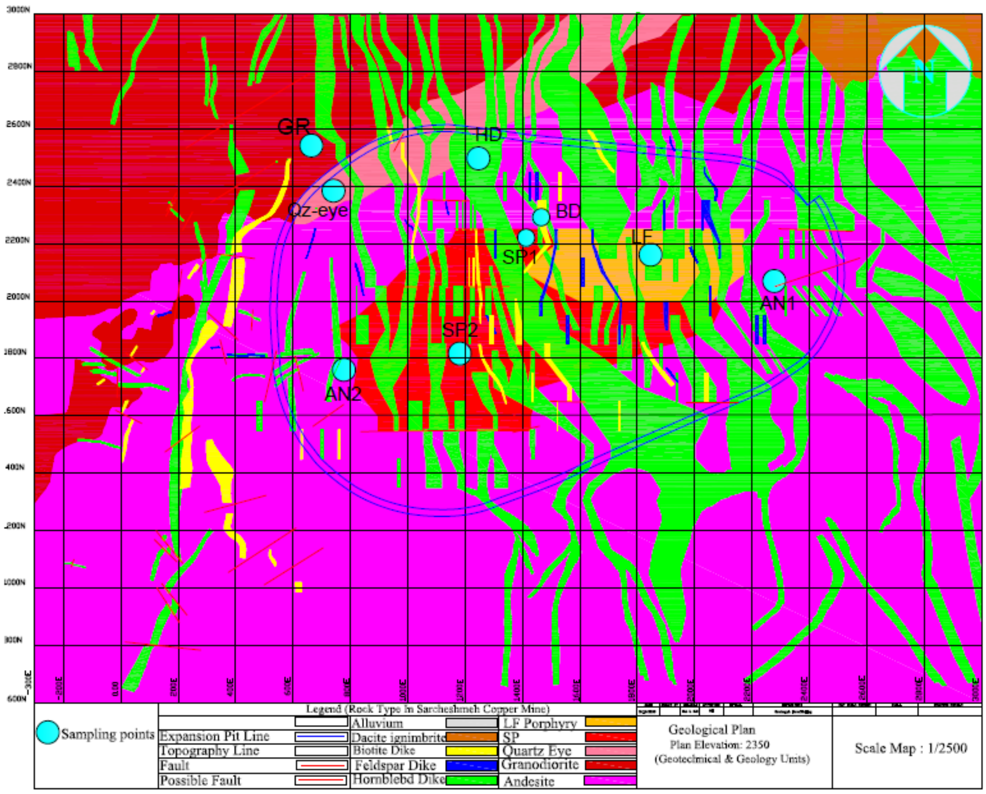


Fig. 3 Geological map of Sarcheshmeh copper mine and sampling points; map modified courtesy of (NICICO 2011)

scale for different minerals can be found in (Singh and Goel 2011). The percentage of each mineral, Ai was attained from X–Ray Diffractometry (XRD). For this purpose, samples of rock types from mine site have been collected, ground and pulverized to be prepared for testing. In an X–ray diffraction measurement, a mineral is mounted on a goniometer and gradually rotated while being bombarded with X–ray beams, producing a diffraction pattern of regularly spaced spots known as reflections. Subsequently, a graph is produced with degree (2θ) of X-ray diffracted beams in horizontal direction and intensity (count) of particular atomic systems in vertical direction. Finally, mineralographer matches the intensities with predetermined standard cards for each mineral. Percentage (weight) of each mineral is calculated from the area under mineral's peak. In Fig. 4 XRD results are shown for AN1 sample. It is seen that Clinochlore showed maximum intensity and maximum percentage and Pyrite showed minimum intensity and maximum percentage among mineral phases of AN1 sample. The same procedure repeated for other samples and their minerals have been determined.

The tests were conducted at XRD lab of the Sarcheshmeh research and development complex. The EQC of constituent minerals was calculated using Eqs. (1)-(2). In Table 1 the results of XRD analyses, percentage of constituent minerals and equivalent quartz content (EQC %) are shown. The sampling points definition showed in Fig. 3 is based on the petrologists' description which commonly used by them according to the geological history of Sarcheshmeh mine; GR: granodiorite, HD: hornblende dyke, BD: biotite dyke, Qz-eye: quartz eye, AN: andesite, SP: Sarcheshmeh porphyry, LF: late fine porphyry.

To obtain rock mechanical strength, 69 representative cubic samples of all the rock types with dimensions of 20 × 30 × 20 cm collected at the mine site and transported to the laboratory. Uniaxial compression tests were performed on truncated core samples, which had a diameter of NX size (54 mm) and L/D ~2-2.5. The stress rate was applied within the limits of 0.5-1.0 MPa/s. The tests were carried out according to (ISRM 2007).

To study the mineralogical properties, more in detail, thin sections of the rock types were prepared and investigated under polarizing microscope. The whole procedure for preparation and

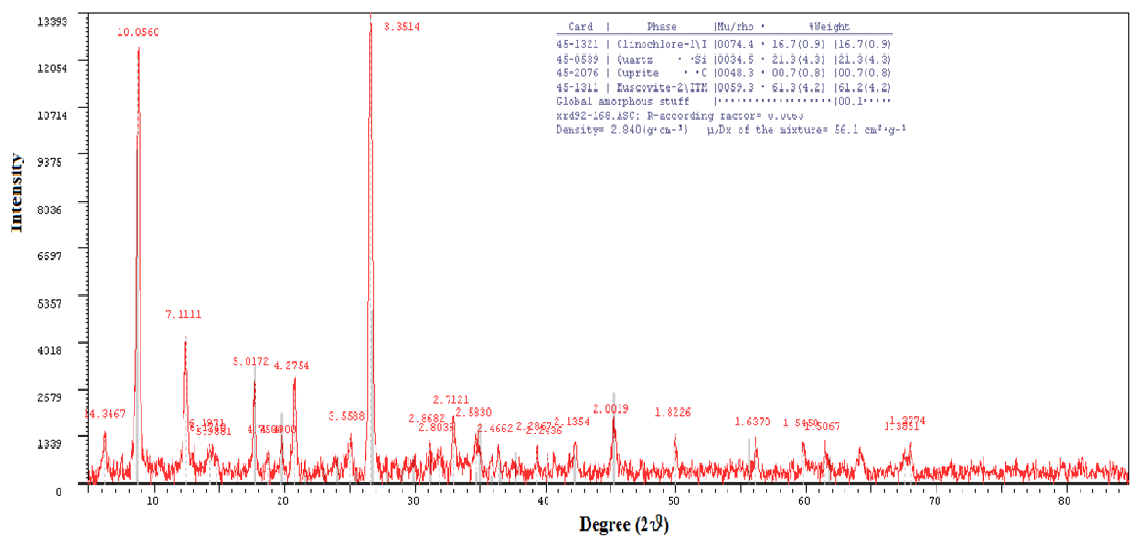


Fig. 4 XRD results obtained for AN1 sample

Table 1 Results of XRD analyses to determine mineralogical properties of the rocks

Sample No.	Minerals	Percentage (semi-quantitative)	Mohs hardness	EQC %
LF	Muscovite	53.3	2	47.47
	Quartz	44.9	7	
	Cuprite	1.8	4	
SP1	Quartz	43.7	7	46.16
	Muscovite	50.9	2	
	Clinochlore	5.3	2	
HD	Quartz	37.9	7	50.70
	Clinochlore	22.1	2	
	Albite	21	6	
	Illite	12.5	2	
	Cuprite	0.8	4	
	Anglesite	5.6	3	
GR	Muscovite	22.6	2	41.74
	Quartz	30.6	7	
	Clinochlore	20.1	2	
	Titanite	6.6	5	
	Albite	15.6	6	
	Bornite	4.4	3	
AN1	Clinochlore	16.7	2	23.04
	Quartz	21.3	7	
	Cuprite	0.7	4	
	Muscovite	61.2	2	
Qz-eye	Muscovite	66.6	2	32.21
	Quartz	30.2	7	
	Clinochlore	3.1	2	
SP2	Muscovite	30.5	2	62.18
	Quartz	59.2	7	
	Clinochlore	10.2	2	
AN2	Clinochlore	16.0	2	19.73
	Quartz	18.4	7	
	Illite	62.5	2	
	Cuprite	0.4	4	
	Pyrite	2.6		
BD	Albite	48.8	6	32.52
	Muscovite	26.3	2	
	Clinochlore	6.9	2	
	Quartz	6.9	7	
	Illite	11.1	2	

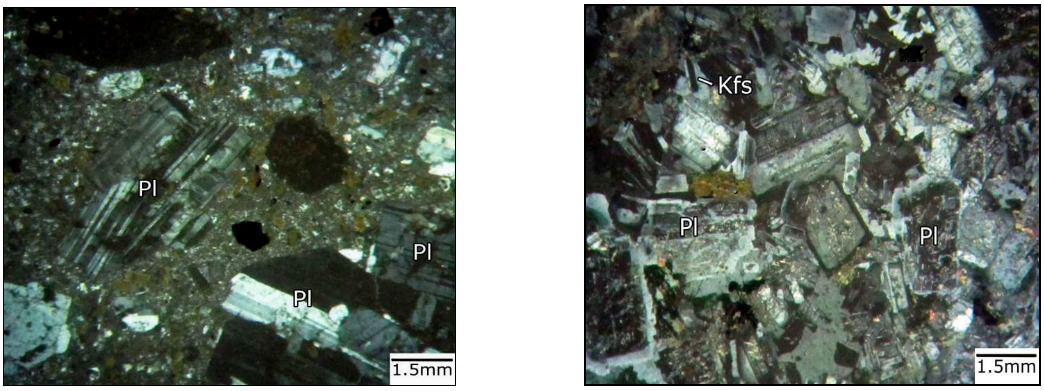
examination of thin section of rocks, including, trimming rock samples, sawing, grinding, finishing section's surface, mineral determination and modal analysis were explained in (ISRM 1978).

Andesite porphyry, dacite porphyry, microdiorite, quartz-eye and Sarcheshmeh porphyry were identified from the thin sections. Plagioclase feldspar with polysynthetic macles and ferromagnesian hornblende and biotite (> 75%) are the main minerals of andesite porphyry. The background consists of fine crystals where occurrence of phenocrysts made a porphyritic texture in the andesite sample. Feldspar minerals show low-grade substitution with ferroxide and sericite and also low–grade silicificaion in the fine minerals of the rock background. Opaque and zircon are secondary minerals where quartz, ferroxide, clay and sericite (< 14%) are altered minerals in the porphyritic andesite (Fig. 5(a)).

The main constituent minerals of microdioritic rocks are plagioclase feldspar with polysynthetic macles and ferromagnesian hornblende and biotite. Alkali feldspars were created in the margin and also space between plagioclase crystals. The rock has completely been crystallized and shows granular texture. Feldspars have undergone low-grade sericitic, chlorite and epidotic alterations. Opaque minerals, Titanite and quartz are secondary minerals in the sample (Fig. 5(b)). Porphyritic dacite has 18-45% quartz, 53-61% muscovite, 0.4-1.8% cuprite, 12-62% clayey minerals, 2.6% pyrite, 5.6% anglesite and 21% albite. In the background of biotites, needlelike rutile fine crystals and opaque minerals were created (Fig. 5(c)).

Plagioclase feldspars exposed to low to high grade sericitic alteration where ferromagnesian biotite and hornblende were extremely substituted with chlorite mineral (Fig. 5(d)). Plagioclase phenocrysts were intensely silicified and opaque minerals appear in 5-6% of the section (Fig. 5(e)). Quartz crystals formed marginal bay caused by fast grow or reaction with the background minerals (Figs. 5(d)-(e)).

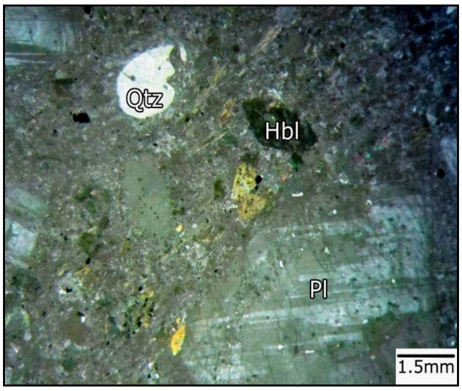
Among the geologist at the Sarcheshmeh copper mine, it is known to quartz-eye rock because of the occurrence of eye shape of coarse quartz crystals in a background of fine sericites (Fig. 5(f)). However, a highly silicified and sericitized rock can be seen under the polarizing microscope. It



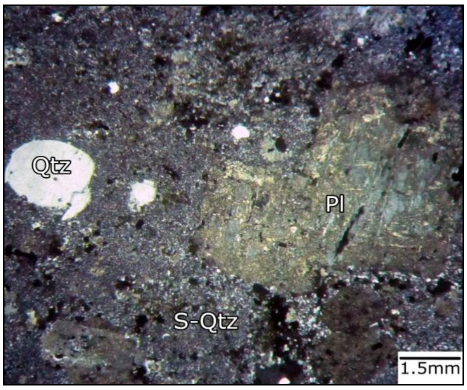
(a) (b)

Fig. 5 Petrographs of thin sections under polarized microscope: (a) Andesite porphyry, sample BD; (b) Granular microdiorite, sample GR; (c) Dacite porphyry, sample AN; (d) Dacite porphyry, sample HD; (e) Dacite porphyry, sample LF; (f) and (g) Quartz-eye, sample Qz-eye; (h) Sarcheshmeh porphyry, sample SP

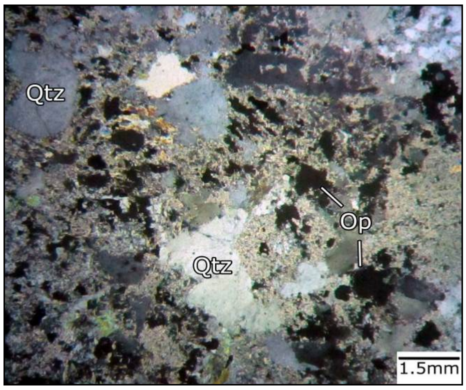
(c)



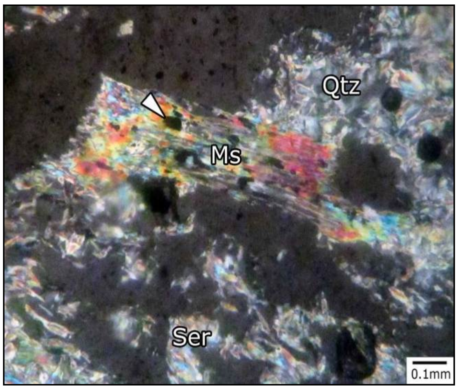
(d)



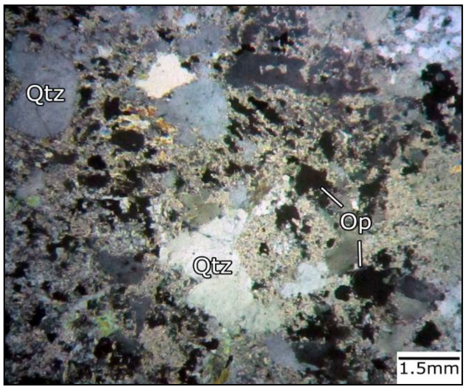
(e)



(f)



(g)



(h)

Fig. 5 Continued

seems that the base rock was an acidic igneous rock where altered quartz and sericite accumulated in the section. Opaque minerals form 6-7% of background. Coarse grained muscovite bearing opaque minerals in a fine base of sericites may probably substitute with a primary ferromagnesian mineral (Fig. 5(g)).

Sarcheshmeh porphyryis a highly silicified and sericitized frequent rock type at the Sarcheshmeh copper mine where most of the copper mineralization is located in this type of rock. Substitution was occurred by quartz and sericite where the primary minerals have been disappeared, wholly (Fig. 5(h)). Opaque minerals form 1-1.5% of the section.

An additional effective parameter, which influences the penetration rate and wear rate of drill bits is known to be the size range of drilling cuttings. Pfleider and Blake (1953) concluded that a rough correlation exists between penetration rate and size range of cuttings, i.e. the higher the penetration rate, the coarser the particle size. Ersoy and Waller (1997) showed that increasing the particle size of drilling cuttings increases wear rate of drill bits which is a function of bit penetration rate. Altindag (2003) determined a strong correlation between Coarseness Index (CI) of drilling cuttings and drilling rate, where it was observed that by increasing size range of drilling cuttings penetration rate of drill bit increases.

To determine size distribution of drilling cuttings, samples were taken from each hole (Fig. 6(a)) and sieved by a series of sieve sizes under wet condition according to British Standard (BS) procedure and method (Anon 1989). Sieve sizes of 3.5 (5,660 μm) to 100 (149 μm) were used (Table 2). Afterward, each sample was filtered and oven dried 100C° overnight, then the samples were weighted.

Coarseness index is a non-dimensional number and is calculated from sum of cumulative weight percentage of remains above particular sieve sizes. Weight, percentage weight, and cumulative weight percentage oversize of the particles (HD sample) is shown in Table 2. There have been many characteristic sizes extracted from the particle size distribution data in order to provide meaningful information from a broad range of particle sizes. There are many different ways of recording results and obtaining a mean size of particle distribution. The most commonly used graphical method is cumulative undersize (or oversize) against particle size on a logarithmic scale.

Table 2 The sieve analyses of a blast hole cuttings drilled in a hornblende dyke (HD)

Sample	Sieve size		Weight (g)	Weight (%)	Ccumulative %
	Micron (+)	Mesh (+)			
HD	5660	3.5	81.6	32.55	32.55
	4000	5	35.5	14.16	46.71
	2380	8	31	12.37	59.07
	2000	10	11.7	4.67	63.74
	1680	12	7.1	2.83	66.57
	1190	16	16	6.38	72.96
	841	20	5	1.99	74.95
	595	30	14.9	5.94	80.89
	420	40	5	1.99	82.89
	250	60	11.7	4.67	87.55
	210	70	4.2	1.68	89.23
	149	100	4.2	1.68	90.91
	-100		22.8	9.09	100.00
Σ			250.7	100.00%	*CI* = 948.03

(a)

(b)

Fig. 6 (a) Sampling from a drill hole cuttings for sieve analysis; (b) size distribution for drill cuttings (undersize) for HD rock type

An example of this graph for undersize material is shown in Fig. 6(b). The most important particle size characteristic agreed is "the median particle size (d_{50})", which is defined as that particle for which the quantity of particles (weight or number) equals 50% of the total of the cumulative distribution (Ersoy and Waller 1997). Also, another percentile which is common in sieve analysis and it needs to be determined is the diameter at which 80% of particle remains on sieve series, namely, d_{80}. Sieve analyses were carried out for all samples of drill holes cuttings to interpolate d_{80} and d_{50}, respectively.

2.3 Bit wear measurements

To obtain relations between bit wear and mineralogical properties of different rock type, several measurements were conducted on the newly unused bit as reference and then worn bits by a micrometer with a resolution of 0.02 mm. Around 200 measurements were carried out on each bit and their discrepancies with those of the new bit were regarded as an indicator of the drill bit wear (Fig. 7). The measurements were conducted at three directions, from each inserts tip to the bit heel row, red lines in Fig. 7 (bit radial wear), through each cone diameter, blue lines in Fig. 7 (bit diametrical wear) and insert protrusion also called bit matrix wear, green lines in Fig. 7. Alternatively, weight loss of bits was measured using a digital balance with resolution of 0.1gram. In fact, the wear data of used bits was normalized to the unused bits. Totally, fourteen bits were studied at the Sarcheshmeh copper mine. A good correlation also was found between weight loss of bit and dimension measurements. The correlation coefficients for radial, diametrical and matrix wear measurements with weight loss were calculated 0.66, 0.63 and 0.68, respectively. Therefore, either of two wear measurement methods can be taken into account in this study.

It should be noted that the operational parameters of the drill system including weight on bit (WOB), rotation speed (RPM) and air pressure (P), have not been changed significantly for the studied tricone bits during drilling process. At this case study, drill operators unwillingly and based on their experience have used constant parameter values i.e., WOB = 1500 – 1600 Psi, RPM = 100 – 150 rev/min, P = 55 – 60 Psi to reach an optimum drilling efficiency. Thus, our experimental and field works to attain possible relationships among rock properties and bit wear rate carried out independently from the effects of drill operation parameters.

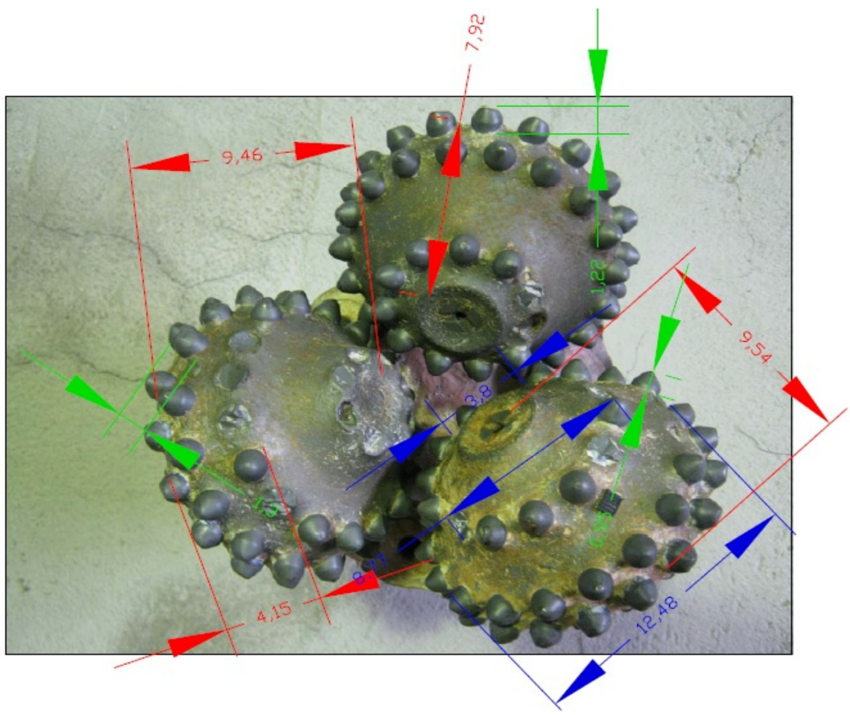


Fig. 7 The sketch of measurement points on the drill bit acquired using micrometer; red lines for radial measurements, blue lines for diametrical measurements and green lines for insert protrusions because of bit matrix wear

3. Results and discussions

All the rock properties obtained in this study along with wear measurements of the fourteen bits studied are presented in Table 3. The rock types drilled with each bit were different according to the in situ drill cutting observation after drilling process. Since the percentage of each rock type drilled by a particular bit cannot be determined, accurately, thus the rock properties for each bit number were averaged during calculations (Table 3).

Correlations between bit wear and rock properties were conducted to find possible relations which could be considered as reliable relationships for predicting rotary bit wear rate. In Fig. 8 the relationships are shown. Regression analyses were carried out between wear measurements and physico-mechanical parameters of rocks and results of pair wise correlation coefficients (R^2-

Table 3 The rock properties and bit wear database

Bit No.	Rock type	EQC%	QC%	Mu%	UCS (MPa)	CI	D_{80} (mm)	D_{50} (mm)	Normalized wear parameters			
									Weight loss (%)	Radial wear	Dia. wear	Matrix wear
1	HD + SP + AN	40	36.1	45.85	29.64	650	5.63	2.35	6.95	0.214	0.243	0.572
2	HD + SP	44.31	46.93	40.7	39.78	726.16	4.90	1.82	7.76	0.136	0.197	0.589
3	HD + SP + AN + BD	43	21.5	42.22	28.80	549.99	6.00	2.84	16.78	0.281	0.404	0.489
4	SP + HD	25	46.93	40.7	31.09	500	4.41	1.82	8.18	0.086	0.126	0.368
5	SP + HD + LF	31.73	47.33	47	24.51	513.95	4.99	2.31	7.97	0.103	0.093	0.323
6	SP + AN + HD + LF	46	33.61	54.1	23.35	700	5.15	2.39	5.00	0.120	0.132	0.689
7	LF + HD + SP + AN	47	33.61	54.1	24.70	700	5.13	2.39	9.56	0.148	0.230	0.661
8	HD + SP + BD	25.72	36.9	33.5	31.68	543.59	5.36	2.14	6.54	0.131	0.143	0.311
9	LF + HD + SP + AN	29.28	33.61	54.1	25.97	568.19	5.76	2.58	12.42	0.250	0.394	0.337
10	AN + HD + LF	25	30.63	57.25	24.01	548.24	5.86	2.78	9.48	0.240	0.193	0.438
11	HD + AN + SP + LF	27.1	33.61	48.97	27.69	556.25	5.76	2.58	15.02	0.227	0.529	0.385
12	LF + HD + SP	30.23	46.43	47	25.50	557.44	4.99	2.01	8.84	0.091	0.087	0.376
13	HD + SP + LF + BD	30.77	40.9	36.65	29.55	561.48	4.93	2.00	8.84	0.127	0.087	0.376
14	HD + LF + AN + SP	28.12	33.61	54.1	28.18	569.12	5.13	2.39	11.47	0.170	0.180	0.432

* QC: quartz content, Mu: muscovite content, CI: coarseness index, Dia.: diametrical wear

Table 4 The pair wise correlation coefficients (R^2-values) between wear measurements and physico-mechanical parameters of rocks

Wear measurements	Rock physico-mechanical parameters						
	EQC%	QC%	Mu%	UCS (MPa)	Coarseness Index	d_{50}(mm)	d_{80}(mm)
Weight loss (%)	0.012	0.08	0.023	0.006	0.11	0.36	0.33
Normalized radial wear	0.001	0.34	0.106	0.013	0.002	0.71	0.85
Normalized diametrical wear	0.003	0.079	0.052	0	0	0.4	0.52
Normalized matrix wear	0.77	0	0.1	0	0.8	0.007	0

values) are listed in Table 4.

It can be seen that there is a good relationship between equivalent quartz content (EQC) and matrix wear (wear of cobalt binder due to direct contact with abrasive mineral). By increasing EQC bit wear increases. Also, Thuro (1997) measured button bit life-time against EQC and he observed that by increasing EQC percentage bit life–time will decreases, significantly. No sensible

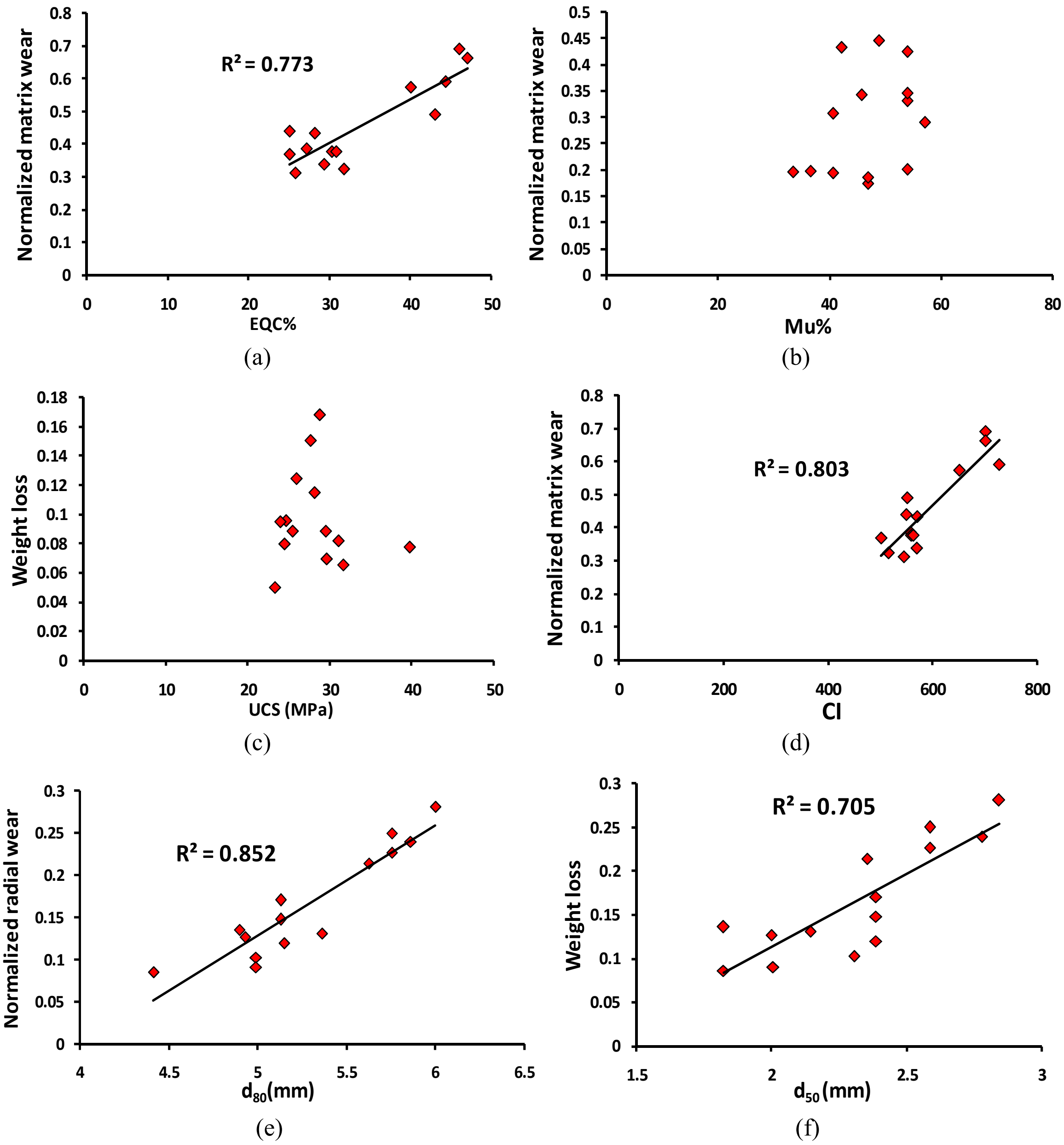


Fig. 8 The correlations between rock properties and different wear measurements, EQC: equivalent quartz content, QC: quartz content, Mu: muscovite content, CI: coarseness index

correlations were observed among net quartz content (QC), and muscovite content (Mu) with bit wear. It is due to that despite QC and Mu of rocks, the EQC takes into account the amount of hardness of all mineral content of the rocks.

No obvious relationship between wear rate of bit and UCS was observed. However, the UCS of rocks is one of dominant parameters on bit penetration rate. Generally, it is expected that high UCS gives high wear rate. The same result also was obtained by Ersoy and Waller (1995) on the wear of PDC pin, hybrid and impregnated core drilling bits. They found that diorite with higher UCS and Moh's hardness shows lower wear rate in relation to granite. On the other hand, they concluded that quartz content, grain size and grain shape factor, which were higher for granite in relation to diorite, are more significant than UCS in evaluation of bit wear (Ersoy and Waller 1995).

The coarseness index (CI) showed good correlation with the bit matrix wear where by increasing coarseness of the rocks it increases. Also, d_{80} and d_{50} of sieve analyses of rocks showed good correlations with bit radial wear and bit weight loss, respectively. It can be seen by increasing the diameters of 80% and 50% of undersize rock cuttings under particular sieves, bit wear increases. Ersoy and Waller (1995) revealed that wear rate of bits as a function of penetration rate will increase when coarseness of drill cuttings increases. Also, they studied wear of PDC bits and they found that one of the main factors causing wear of the bit matrix is the erosion of bit surface from drilling cuttings.

4. Conclusions

Wear of WC/Co cemented carbide (CC) tricone bits were assessed using effective rock physico-mechanical properties at a surface mine in south Iran. Wear measurements calculated by measuring bit weight loss in relation to unused bit using a digital balance with resolution of 0.1 gram and bit matrix, radial and diametrical wear using a micrometer with resolution of 0.02 mm. Fourteen rotary tricone with WC grains were studied. Drilling records were obtained at different rock types at field and correspondingly rock block and drilling cuttings samples were collected and transferred to the laboratory. Since drill system operational parameters as WOB, RPM and air line pressure were almost constant during drilling process then our studies on the wear of those bits could not be affected by those parameters.

XRD analyses, thin sections, sieve analyses and mechanical tests were conducted on the drilling cuttings and core samples, respectively. Equivalent quartz content (EQC), net quartz content (QC), muscovite content (Mu), uniaxial compressive strength (UCS), coarseness index (CI), d_{80} and d_{50} were the rock properties that obtained.

The finding showed that EQC demonstrates good correlation with bit matrix wear that by increasing EQC, it increases. However, QC, Mu and UCS showed no significant relationship with bit wear. It seems rock's particle size and hardness could be more effective properties rather than mechanical properties. Furthermore, EQC engages hardness of all constituent minerals of a rock type based on the Moh's harness that could show good correlation with wear of drill bits.

It was observed that by increasing CI, d_{80} and d_{50} of rock types bit matrix wear, bit radial wear and weight loss will increase, linearly. It can be concluded that particle size of a drill cuttings is the effective factor on the drilling rate and bit wear. By increasing particle size of a drill cuttings due to increase in their abrasivity, wear of bits will increase, obviously.

The results of this study are only applicable at this case study and further studies in many cases are needed to find reliable relations.

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