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Mehanizem obrabe kotalnega dleta

Roller cone wear mechanism

Povzetek

Kotalna dleta se množično uporabljajo pri izdelavi hidroloških, naftnih, plinskih in drugih vrtin, za katere pridobivanje jedra ni bistvenega pomena. Odpoved delovanja dleta med vrtanjem ima za posledico zmanjšanje napredka vrtanja, zaradi česar je potrebno poškodovano ali izrabljeno kotalno dleto odstraniti iz vrtine. Zaradi tega dejstva se znanstveniki in inženirji v čedalje večji meri posvečajo raziskavam, katerih rezultati bi pripeljali k podaljšanju efektivnega časa delovanja dleta in k povečanju napredka v efektivnem času delovanja dleta.

V delu so bile izvedene „in situ“ spremljave vrtalnih parametrov med izvajanjem vrtalnih del s kotalnim dletom Smith SB117PS premera 215.9 mm, ki je namenjeno za vrtanje v mehkejših hribinah. Po izvedenem vrtanju je bilo dleto temeljito preiskano za ugotovitev poškodb in obrabe, ki je nastala med vrtanjem.

Pri preiskavah smo uporabili naslednje sodobne in standardizirane preiskovalne metode: analizo mikro in makrostrukture hribine in materialov kotalnih dlet, ki je bila izvedena z optično in elektronsko mikroskopijo, simultano termično analizo materialov kotalnih dlet, analizo kemijske sestave hribine in materialov kotalnih dlet ter določitev geomehanskih parametrov hribine. Nastalo obrabo, lokalne porušitve in razpoke smo kvantitativno in kvalitativno opredelili in povezali z režimom vrtanja in mineraloško sestavo hribine.

Na podlagi metalografskega pregleda kotalnih dlet in geofizikalnih lastnosti kamnin so se ugotovile strukturne spremembe materiala kotalnih dlet ter način in potek njihove obrabe.

Ključne besede: vrtanje, kotalno dleto, mehanizem obrabe, karbidni oplast, HV trdota, visoka temperatura

Summary

Roller cone drill bits are widely used for drilling the hydro geological, oil, gas and other wells, for which the acquisition of the core is not essential. The breakdown of the drill bit or rapidly decreasing of rate of penetration during the drilling process results in a reduction in the progress of the drilling, which makes it necessary to remove the damaged or worn roller cone bit from the well. Due to this fact, scientists and engineers are increasingly focusing on research, the results of which would lead to an extension of the effective time of the drill bit and to increase the rate of penetration.

In our work, was monitored “in situ” drilling parameters during the drilling process with the Smith SB117PS

215.9 mm diameter roller cone drill bit, intended for drilling in soft rock materials. After drilling, the bit was thoroughly examined to determine the damage and wear that occurred during drilling.

The following modern and standardized investigative methods were used: analysis of the micro and macrostructure of rock materials and materials of roller cone bits carried out by optical and electronic microscopy, simultaneous thermal analysis of materials of drill bits, analysis of the chemical composition of rock materials and materials of drill bits, and determination of geomechanical parameters of rock materials. The resulting wear, local bursts and cracks were quantitatively and qualitatively defined and linked to the drilling regime and the mineralogical composition of the rock material.

Based on the metallographic examination of materials of drill bits and geophysical properties of rocks, the structural changes in the material of the drill bits and the manner and course of their wear have been identified.

Keywords: drilling, roller cone bit, mechanism of drill bit wear, carbide coating, HV hardness, high temperature

1 Uvod

Rotacijsko vrtanje je najbolj priljubljena metoda vrtanja vrtin. Za rotacijsko vrtanje se uporabljajo vrtalni sestavi, ki so sestavljeni iz več kosov posameznih cevi. Na koncu vrtalne cevi je na težek stabilizator ali vrtalni venec pritrjeno kotalno dleto. Dodatna teža in večji zunanji premer stabilizatorja tik nad kotalnim dletom pripomoreta k zagotavljanju ravne vrtine. Vrtalni sestav je votel, po njem pa kroži vrtalna tekočina, bodisi blato bodisi zrak, in se skozi šobe v kotalnem dletu pretaka navzgor po zunanji strani vrtalnega sestava. Kotalno dleto z vrtenjem razbije material, vrtalna tekočina pa odrezke prenese na površje, kjer se usedajo v rezervoarju za blato. Z vrtalnimi stroji je mogoče uporabiti več vrst dlet. Najpogosteje se uporablja vrtalno dleto. Vrsta in število rezalnih zob na kotalih dlet se razlikujeta glede na vrsto formacij, ki jih je treba prebiti. Pri vrtanju z blatom se uporablja vrtalna tekočina iz bentonitne gline in vode. Blato ima več namenov: iz vrtine odstranjuje odrezke, preprečuje sesedanje vrtine in zmanjšuje izgubo vode v formacije, saj na steni vrtine tvori filtrsko pogačo, zadržuje odrezke ob ustavitvi vrtanja, hladi in čisti vrtalni sestav in dleto

1 Introduction

Rotary drilling is the most popular well drilling method. The principle of rotary drilling is based upon a rotating drill stem made of lengths of drill pipe. A bit is attached to a heavy stabilizer or drill collar at the end of the column of drill pipe. The extra weight and larger outside diameter of the stabilizer just above the bit helps to maintain a straight drill hole. The drill stem is hollow and has a drilling fluid of either mud or air circulating down the drill stem out through the nozzles in the bit and up along the outside of the drill stem. The rotating action of the bit breaks up the material and the drilling fluid carries the cuttings to the surface where they settle out in a mud tank. Several types of bits are available to the rotary driller. The bit most generally used is the tricone roller bit. The type and number of cutting teeth on the bit cones vary depending upon the type of formations to be penetrated. Mud rotary utilizes a drilling fluid of bentonite clay and water. The mud serves several purposes: remove cuttings from the well, prevent collapse of the well and reduce water loss to the formations by forming a filter cake on the borehole wall, suspend cuttings when drilling is stopped, cool and clean the drill ter maže ležaje dleta in dele črpalke za blato.

Življenjska doba kotalnega dleta oz. čas učinkovitega vrtanja sta odvisna od lastnosti materialov, iz katerih so izdelani sestavni deli kotalnega dleta. Kotalno dleto se obrablja zaradi kamnine, skozi katero se vrta, in režima vrtanja.

Učinkovito delovanje dleta je odvisno od njegove odpornosti na dejavnike, ki se pojavljajo med njegovim delovanjem. Med dejavnike, ki zmanjšujejo čas učinkovitega delovanja kotalnega dleta, lahko uvrstimo: material, iz katerega so izdelana kotala in zobje svedra, režim vrtanja, ki obsega obremenitev dleta med vrtanjem, število vrtljajev dleta in količino vrtalnega blata glede na geomehanske lastnosti kamnine, skozi katero vrtamo.

Sika 1. Kotalno dleto Smith ST117

Figure 1. Roller cone drill bit Smith ST117

stem and bit, and lubricate bit bearings and mud pump parts.

The lifetime of the roller cone bit or the time of effective drilling operations depends on the properties of the materials from which the components of the roller cone bit are made. The rolling cone bit becomes worn due to the effects of the rock material through which is drilled and the drilling regime.

The effective operation of the bit depends on its resistance to the factors that occur during its operation. Among the factors that shorten the time of the effective operation of the roller cone bit, we can include: the material from which the rollers and the teeth of the bit are made, the drilling regime, which includes the load on the bit during drilling, the number of bit rotations and the amount of the drilling mud in relation to the geomechanical properties of the rock material, through which we drill.

We analysed the mechanical properties of the steel material of the roller cone bit Smith ST117, diameter 215.9 mm (8 ½”), which was drilled through 610.70 m of sandstone.

In the investigation of the properties of the steel material of the roller cone drill bit, we inspected the materials of the bit body, rollers and teeth. We examined the method of wear and determined the critical points of erosion effect on the steel material of roller cone bits. For this purpose, we analysed the rock material that the examined roller cone bit drilled through.

The results of our analysis present the mechanisms that result in the wear of the roller cone bit material under the given conditions of the rock material and the drilling regime.

Analizirali smo mehanske lastnosti jeklenega materiala kotalnega dleta Smith ST117 s premerom 215,9 mm (8 ½ palca), ki je prevrtalo skozi 610,70 m peščenjaka.

Pri preiskavi lastnosti jeklenega materiala kotalnega dleta smo pregledali materiale držaja dleta, kotal in zob. Proučili smo mehanizem obrabe in določili kritične točke učinka erozije na jekleni material kotalnih dlet. V ta namen smo analizirali kamnino, skozi katero je vrtalo pregledano kotalno dleto.

Rezultati naše analize prikazujejo mehanizme, ki povzročajo obrabo materiala kotalnega dleta v danih kamninskih pogojih in ob danem režimu vrtanja.

2 Materiali in metode

V toku preiskav za izvedbo karakterizacijo obrabe kotalnega dleta, smo izvedli detajlne preiskave materialov skozi katere je bilo vrtano in preiskave materialov iz katerih je sestavljeno dleto. V ta namen smo v prvi fazi izvedli pregled dleta, ki je zajemal optični pregled stanja dleta po izvedenem vrtanju skozi hribinski masiv po metodologiji IADC (International Association of Drilling Contractors).

Na pridobljenem vzorcu hribinskega materiala, skozi katerega je bilo vrtano, smo izvedli laboratorijske analize za ugotovitev njegovih mehanskih in mineraloških lastnosti.

Na vzorcu hribinskega materiala so bile izvedene naslednje preiskave:

- pregled karakterističnega vzorca hribine skozi katero je bilo vrtano,
- pregled geokemične in mineraloške sestave vzorca hribine skozi katero je bilo vrtano z metodo XRF (X-ray fluorescence), z uporabo Thermo NITON XL3t XRF analizatorja,
- pregled trdnostno deformacijskih

2 Materials and Methods

In the course of the investigations to characterize the wear of the roller cone bit, detailed investigations were carried out on the materials through which it was drilled, drilling parameters and the materials from which the roller cone bit was made. To this end, in the first phase, we carried out a review of the roller cone bit, which included an overview of the condition of the bit after drilling through the rock formation, according to IADC (International Association of Drilling Contractors) methodology.

From the obtained sample of rock material, we carried out laboratory analyses to determine the mechanical and mineralogical properties of the rock through which it was drilled with the considered drill bit.

The following investigations were carried out on a sample of rock material:

- a visual overview of rock material,
- an overview of the geochemical and mineralogical composition of the sample of the rock material through which it was drilled using the XRF (X-ray fluorescence) method, using a Thermo NITON XL3t XRF analyser
- an overview of the strength-deformation properties of the rock material was carried out according to ASTM standard D7012-10

While drilling through the known rock material, drilling parameters were also monitored as follows:

- the load on the drill bit,
- the number of rotations of bit,
- the quantity of the pumped drill mud,
- the pressure of the pumped drill mud,
- the penetration rate,
- the length of the drilling interval.

After a visual inspection of the bit, we cut it apart to perform tests to discover the metallurgical properties of the steel from lastnosti hribine skozi katero je bilo vrtano po standardu ASTM D7012-10.

V toku izvedbe vrtanja skozi poznani material smo spremljali tudi vrtalne parametre in sicer naslednje:

- obremenitev na dleto,
- število obratov vrtalnega drogovja,
- količino črpanega izplačnega materiala,
- tlak izpiranja,
- hitrost napredka,
- dolžino izvrtanega intervala.

Po izvedenem vizualnem pregledu kotalnega dleta, se je le to razstavilo za namen ugotavljanja lastnosti jeklenih materialov iz katerih je kotalno dleto sestavljeno in pridobitev kvalitetnih vzorcev za preiskavo poškodb materialov, ki so nastale v toku vrtanja.

V nadaljevanju smo izvedli kompletno analizo jeklenih materialov kotalnega dleta, ki je zajemala naslednje preiskave:

- kemična analiza jekla telesa kotalnega dleta z ARL MA-310 optičnim emisijskim spektrometrom,
- sestavo karbidne obloge zob z XRF (X-Ray flurescence spektrometry) metodo z uporabo Thermo NITON XL3t XRF analizatorjem,
- pregled prereza zobov z elektronskim mikroskopom Jeol JSM 5610 po metodi EDS/SEM (energy dispersive spectroscopy / scanning electron microscope),
- termalna analiza DSC (differential scanning calometry) jekla kotala, telesa dleta in karbidne obloge zob dleta z Netzsch Jupiter STA449C
- dilatometrična analiza jekla zob in karbidne obloge z Bähr DIL 801 nizkotemperaturnim dilatometrom,
- meritev trdote jekla po Vickersu z 100 g obremenitvijo z Shimadzu type M mikro trdotnem testerjem.

which the roller cone drill bit was made and to produce test samples for the investigation of material damage that occurred during the drilling work.

In the following paper, we carried out a complete analysis of the steel materials of the roller cone bit, which covered the following examinations:

- the chemical composition of roller body steel with an ARL MA-310 optical emission spectrometer,
- the composition of the carbide coating of bit teeth with the XRF (X-ray fluorescence) method using a Thermo NITON XL3t XRF analyser,
- a cross-sectional view of the bit teeth with a Jeol JSM 5610 electron microscope using the EDS/SEM analysis (energy dispersive spectroscopy / scanning electron microscope),
- DSC (differential scanning calorimetry) of roller steel and tooth carbide coating with the Netzsch Jupiter STA449C
- a dilatometric analysis of the roller steel and the tooth carbide coating with a Bähr DIL 801 low temperature dilatometer,
- Vickers hardness tests on the roller steel with a 100 g load with a Shimadzu type M microhardness tester.

3 Results

3.1 Rock material

A geological investigation was performed on the rock material. Geologically, the rock material is fine-grained sandstone with a carbonate binder, poorly bonded with grains of mica, hornblende and quartz.

Tabela 1. Rezultati geomehanskih lastnosti hribinskega materiala

Table 1. Results of the geomechanical properties of rock material

Gostota / Density	Kohezija / Cohesion	Strižni kot / Angle of internal friction	Modul elastičnosti / Elastic module	Enoosna tlačna trdnost iz točkovnega indeksa / Compressive strength from spot strength index test	Točkovni trdnostni indeks / Spot strength index
ρ	c	φ	E	σ_c	I_{s50}
[Mg/m³]	[MPa]	[°]	[MPa]	[MPa]	[kPa]
2.007	0.361	51.2	3098	1.219	81.3

Tabela 2. Mineraloška sestava hribinskega materiala – geokemična

Table 2. Mineralogical composition of the sample rock material - geochemical

SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	K_2O	TiO_2
%	%	%	%	%	%	%
47.49	10.57	3.30	4.63	9.82	2.24	0.54

3 Rezultati

3.1 Hribinski material

Geološko je material, skozi katerega je bilo vrtano, peščenjak s karbonatnim vezivom, slabo vezan, fino zrnat z vsebnostjo zrn sljude, rogovače in kremena.

3.2 Kotalno dleto

Po izvedenem vrtanju je bilo kotalno dleto makroskopsko pregledano po IADC metodologiji, kjer se je ovrednotilo stanje kotal in zob kotalnega dleta. Ugotovljeno je bilo, da so zobje enakomerno obrabljeni

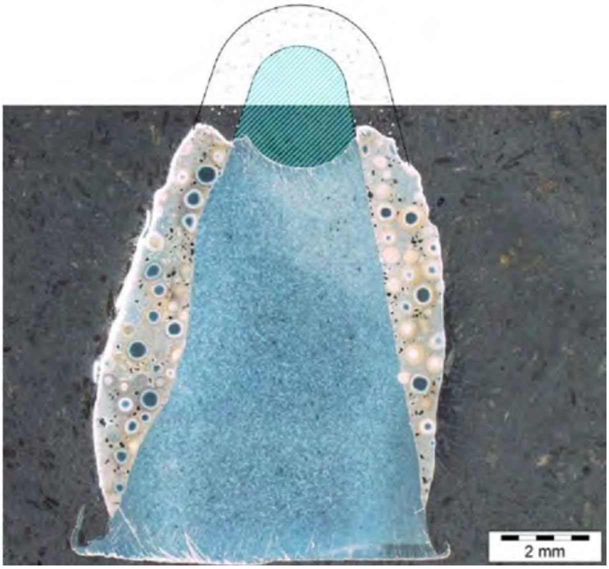
3.2 Roller Cone Bit

After drilling, the drill bit was macroscopically examined using IADC methodology, where we evaluated the condition of the rolls and the teeth of the drill bit. We found that the teeth of the bit were evenly worn and the formation of erosion channels at the top of the teeth was quite evident. The teeth of the external line were eroded on the side that was not protected by the carbide coating, in contrast to its initial state. On all of the drill bit's teeth, erosion channels were clearly visible. The results of dull inspection of the drill bit can be seen in Table 3.

Tabela 3. Rezultati pregleda obrabe kotalnega dleta skladno z IADC standardom

Table 3. Results of dull inspection of drill bit according to IADC dull grading system

Rezalna struktura / Cutting structure				Ležaji / tesnila / Bearings / seals	Premer / Gauge	Druge obrabe / Other dull char.	Vzrok izvleka dleta / Reason pulled
Notranja vrsta zob / Inner rows	Zunanja vrsta zob / Outer rows	Karakterističa obraba / Dull char.	Lokacija / Location				
T1	T2	SS	A	E	I	ER	TD



Slika 2. Makroskopski prerez zoba kotalnega dleta z rekonstrukcijo prvotne geometrije

Figure 2. Macroscopic cross-sectional view through the teeth of the drill bit, with the reconstruction of the original geometry

ter da je evidenten nastanek erozijskih kanalov na vrhovih zob. Zobje zunanje vrste so bili obrabljeni na straneh, ki niso bile zaščitene s karbidno oblogo. Na vseh zobeh kotalnega dleta je bilo opaziti erozijske kanale. Rezultati pregleda dleta so prikazani v tabeli 3.

3.3 Jeklo kotala

Pregledali smo sestavo jeklenega materiala tako telesa kotalnega dleta z zobmi kot karbidne obloge zob.

Preiskava kemične sestave jekla kotal in telesa zob je bila izvedena z optičnim emisijskim spektrometrom. Rezultati kemične sestave so prikazani v tabeli 4.
Glede na rezultate kemične analize (tabela 4) smo ugotovili, da je v tem primeru, jekleni material iz katerega so izdelana kotala in telesa zob, tako imenovano orodno jeklo z delo v hladnem s povečano žilavostjo.

Pri izvedbi metalografskih preiskav z elektronskim mikroskopom smo analizirali prerez zob, kjer smo pregledali osnovni material, ki sestavlja telo zob, spoj s

3.3 Roller steel material

We examined the roller material for both the steel body with teeth and the carbide coating of the tooth.

An examination of the chemical composition of the roller steel was carried out on an optical emission spectrometer. The results of the chemical composition of the investigated steel can be seen in Table 4.

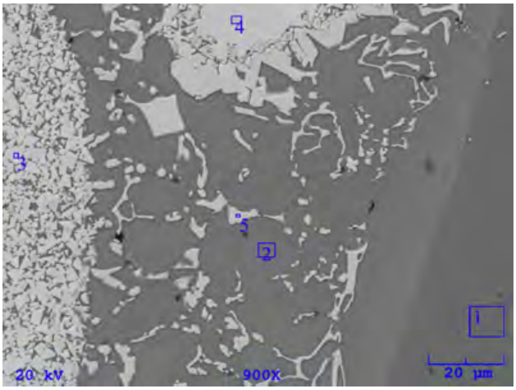
Based on the results of the chemical analysis (Table 4), we have found that, in this case, the steel material of the tooth base is the so-called cold work tool steel with increased toughness.

In the execution of the metallographic investigations by scanning electron microscopy, we analysed the tooth section where we examined the basic tooth material – cold work tool steel, the joint with the carbide coating and the carbide coating itself. EDS analyses were also performed, which showed the chemical composition of the involved phases. Figure 3 shows the SEM image of the sample in the area of the

Tabela 4. Rezultati kemične analize jekla kotal in telesa zob

Table 4. Chemical analysis of the investigated roller steel – tooth body

Element / Element	Enota / Unit	Rezultat / Result
C	mass.%	0.145
Si	mass.%	0.25
Mn	mass.%	0.59
P	mass.%	0.007
S	mass.%	0.002
Cr	mass.%	0.11
Ni	mass.%	3.50
Cu	mass.%	0.18
Mo	mass.%	0.201
V	mass.%	0.01
Ti	mass.%	0.005
Nb	mass.%	0.005
Al	mass.%	0.053
N	mass.%	< 0.003



Slika 3. SEM prikaz zoba, od karbidne obloge, cone mešanja do jekla telesa zoba (od levo proti desni): 1 – telo zoba, 2 – matrica karbidne obloge, 3 – karbidni material, 4 – karbidni material, 5 – karbidni material

Figure 3. SEM image of bit tooth, from carbide coating, mixing zone till steel tooth base (from left to right): 1 – tooth body, 2 – carbide coating matrices, 3 – carbide material, 4 – carbide material, 5 – carbide material

carbide coating, the mixed zone and the steel of the tooth.

Tabela 5. Elementarna sestava telesa zoba (1-slika 3)

Table 5. The elemental composition of tooth body material (1-fig. 3)

Element / Element	Concentration / Koncentracija	
	at. %	wt. %
Si	0.497	0.250
Mn	0.347	0.342
Fe	95.876	95.958
Ni	3.279	3.450

Tabela 6. Elementarna sestava matrice karbidne obloge (2-slika 3)

Table 6. The elemental composition of carbide coating - matrix (2-fig. 3)

Element / Element	Concentration / Koncentracija	
	at. %	wt. %
Mn	2.445	2.244
Fe	90.158	84.128
Co	3.397	3.345
Ni	0.958	0.940
W	3.014	9.343

Table 7. The elemental composition of carbide coating (3-fig. 3)

Tabela 7. Elementarna sestava karbidne obloge (3-slika 3)

Element / Element	Concentration / Koncentracija	
	at. %	wt. %
Fe	2.913	0.903
W	97.087	99.097

Tabela 8. Elementarna sestava karbidne obloge (4-slika 3)

Table 8. The elemental composition of carbide coating (4-fig. 3)

Element / Element	Concentration / Koncentracija	
	at. %	wt. %
W	100.000	100.000

karbidno oblogo (cona mešanja) in karbidno oblogo. Opravljene so bile tudi analize EDS, ki so pokazale kemijsko sestavo vključenih faz. Slika 3 prikazuje SEM sliko vzorca na območju karbidne obloge, cone mešanja in jekla telesa zoba.

Rezultati simultane termične analize (STA) (slika 4) jekla vzorčenega iz telesa kotala, da se pri temperaturi 695.2°C začne evtektoidna transformacija v trdnem stanju, ki jo zaznamuje endotermni pik. Ko je le ta zaključena (738°C) kovinska osnova dobi kristalno strukturo avstenita. Pri temperaturi 1352.1°C se v preiskovanem jeklu začnejo taliti nizkotemperaturni evtektiki, nato pa pri 1483.5°C primarni zmesni kristali avstenita. Taljenje je zaključeno pri temperaturi 1524.5°C.

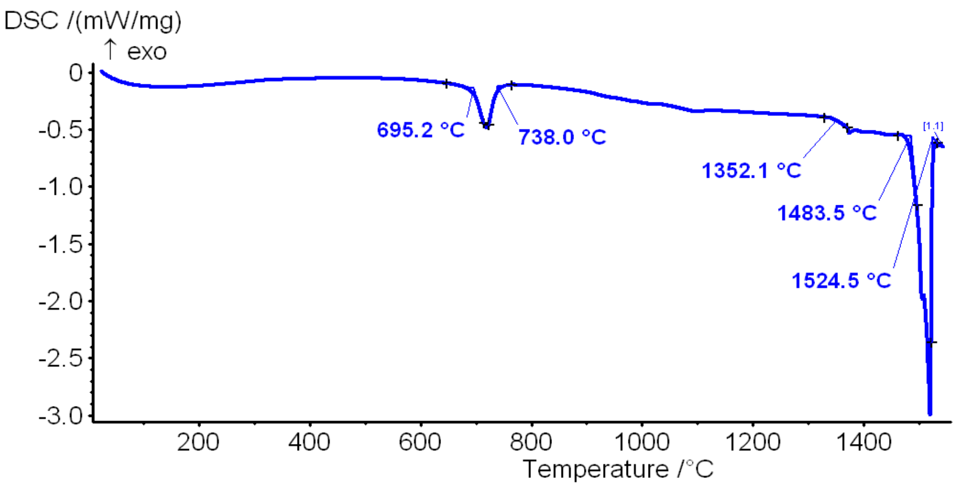
Na sliki 5 je predstavljena ogrevalna krivulja preiskovanega vzorca obloge iz karbidne trdine, ki na površini še vsebuje cono mešanja med jeklom telesa zoba in karbidno oblogo. Pri temperaturi 725.7°C se začne evtektoidna transformacija ki je nedvomno v zvezi z delom cone mešanja med jeklom in karbidno oblogo. Sicer le ta ni

Tabela 9. Elementarna sestava karbidne obloge (5 - slika 3)

Table 9. The elemental composition of carbide coating (5 - figure 3)

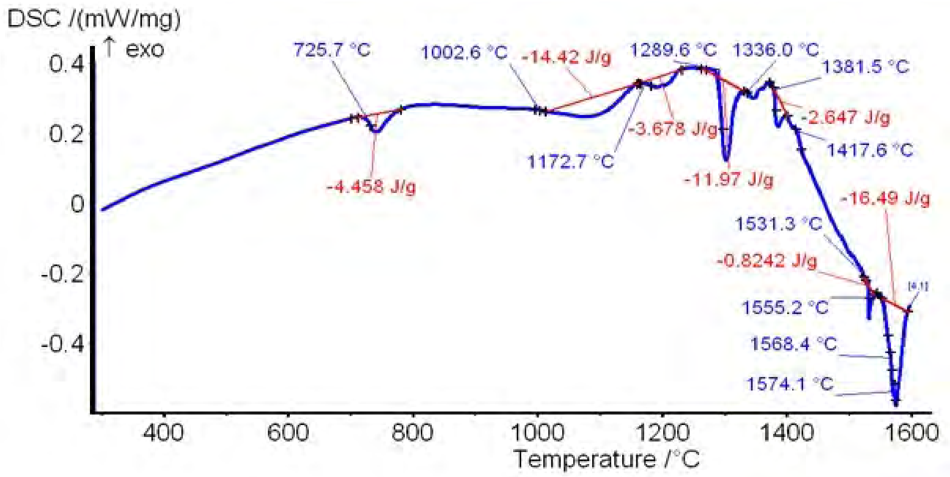
Element / Element	Concentration / Koncentracija	
	at. %	wt. %
Mn	2.503	1.284
Fe	55.166	28.772
Co	2.345	1.291
W	39.986	68.653

The results of simultaneous thermal analysis (STA) (Figure 4) of the steel sample from the body of the roller show that an eutectoid transformation in solid state starts at a temperature of 695.2 °C, which is characterized by an endothermic peak. When this was completed (738°C), the metal base was transformed into an austenite structure. At a temperature of 1352.1 °C, the low temperature eutectics began to melt into the investigated steel and then, at 1483.5 °C, into the primary



Slika 4. Segrevalna DSC krivulja jekla kotala in telesa zoba

Figure. 4. DSC heating curve of the steel of the roller and body of the bit tooth



Slika 5. Segrevalna DSC krivulja jekla karbidne obloge zoba

Figure 5. DSC heating curve of carbide coating of the bit tooth

značilna za karbidno oblogo. Pri 1002.6°C se začne raztapljanje elementov iz cone mešanja v kobaltovi osnovi karbidne trdine. Prvo taljenje je registrirano pri 1289.6°C, zaključi pa se pri temperaturi, ki je višja od 1600°C.

Dilatometrijska ogrevna krivulja jekla iz katerega je kotalo in dilatometrijska analiza karbidne obloge je prikazana na sliki 6. Iz meritev je razvidno, da se jeklo pri segrevanju linearno širi do temperatur evtektoidne premene. Naklon krivulje ustreza temperaturno razteznostnemu koeficientu orodnega jekla za delo v hladnem. Nasprotno temu pa krivulja preiskovanega vzorca karbidne trdine, ki vsebuje tanek sloj cone mešanja kaže relativno položnejšo krivuljo. Torej temperaturni razteznostni koeficient karbidne obloge je bistveno manjši. Če pogledamo razliko v področju delovnih temperatur, ki lahko lokalno dosežejo tudi 500°C, kljub intenzivnemu hlajenju z izplako, je razlika, ki znaša absolutno 0.15 %. Razlika je pomembna, saj ima za posledico močno povečanje notranjih

austenite crystals. The melting process was completed at a temperature of 1524.5 °C.

Figure 5 shows the heating curve of the investigated carbide coating sample, which, on the surface, still contained a mixing zone between the steel of the tooth body and the carbide coating. At a temperature of 725.7 °C, an eutectoid transformation began, which is undoubtedly related to the part of the demisting zone between the steel and the carbide coating. Otherwise, this is not typical for carbide coatings. At 1002.6 °C, the dissolution of the elements from the mixing zone began in the cobalt matrices of the carbide coating. The first melting was registered at 1289.6 °C and was terminated at a temperature of more than 1600 °C.

The dilatometric heating curve of the roller steel and the dilatometric heating curve of the carbide coating is shown in Figure 6. From the measurements, it can be seen that the steel extends linearly to the temperatures of eutectoid transformation during heating. The inclination of the curve corresponds to the linear thermal expansion coefficient of the steel for cold napetosti predvsem v coni mešanja, ki predstavlja preferentno mesto za iniciacijo in propagacijo razpok. Dilatometrijska krivulja karbidne obloge kaže v področju evtektoidne transformacije tudi odklon, ki je v zvezi z evtektoidno transformacijo tanke plasti na karbidni oblogi, le da so referenčne temperature nekoliko višje. Vzrok za višje temperature je spremenjena kemijska sestava cone mešanja.

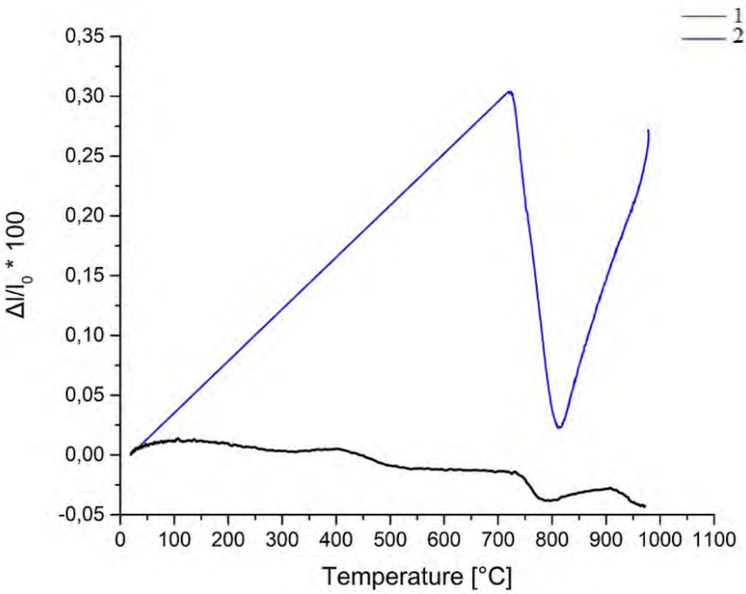
Bile so izvedene tudi meritve mikrotrdot po Vickesu. Iz tabele 10 je razvidno, da ima kotalo nekoliko višje trdote kot zobje, kjer so trdote v povprečju 380.3775 HV in 327.5854 HV. Trdote v karbidni prevleki so pričakovano veliko višje in dosežejo trdoto celo do 2200 HV.

4 Diskusija

Pri izvedbi režima vrtanja lahko ugotovimo, da je bilo kotalno dleto obremenjeno skladno priporočilom proizvajalca kotalnega dleta.

work tool steel. On the contrary, the curve of the investigated sample of carbide coating, which contains a thin layer of the mixing zone, shows a relatively flat curve. Therefore, the temperature expansion coefficient of the carbide coating is considerably lower. If we look at the difference in the zone of working temperatures that can reach a local temperature even at 500°C, despite intense cooling, the absolute difference is 0.15 %. This is important because it results in a strong increase in internal stresses, particularly in the mixing zone, which is the preferred site for the initiation and propagation of cracks. The dilatometric curve of the carbide coating shows a deviation in the field of eutectoid transformation, which is related to the eutectoid transformation of the thin layer of the mixing zone on the carbide coating, except that the reference temperatures are slightly higher. The cause of higher temperatures is the chemical composition of the mixing zone.

We also performed micro hardness tests according to Vickers. In Table 10, it can



Slika 6. Dilatometrijska analiza jekla kotala (telesa zoba) in karbidne prevleke 1 – karbidna obloga, 2 – jeklo telesa zoba

Figure 6. Dilatometric analysis of the steel of the roller and carbide coatings 1 – carbide coating, 2 – tooth steel material

Tabela 10. Rezultati meritev trdote po Vickersu

Table 10. Vickers hardness test results

d1	d2	HV0,1	
21.97	22.85	369.2692	Kotalo / Roller
21.93	21.89	386.3155	
21.92	22.3	379.3581	
22.26	22.21	375.1048	
21.92	21.59	391.8399	
		380.3775	Povprečje / Average
23.74	23.42	333.5333	Telo zoba / Tooth core
23.74	23.95	326.1611	
23.93	23.62	328.0846	
23.8	23.87	326.4349	
24	23.87	323.7129	
		327.5854	Povprečje / Average
17.65	17.94	585.6402	Karbidna obloga / Carbide coating
9.46	9.41	2083.258	
9.11	9.23	2205.404	
13.24	12.56	1114.416	
16.55	14.98	746.1719	
12.51	11.72	1263.514	
		1482.553	Povprečje / Average

Ko je upadel napredek vrtanja, se je kotalno dleto odstranilo iz vrtine. Izvedel se je vizualni pregled poškodb, ki so privedle do slabšega delovanja dleta. Ugotovilo se je, da so na dletu nastale poškodbe v obliki izrabe materiala zob dleta povsod tam kjer

be seen that the roller has a slightly higher level of hardness than the teeth, where the hardnesses are, on average, 380.3775 HV and 327.5854 HV respectively. The hardness in the carbide coatings were expected to be much higher and reach up to 2200 HV.

4 Discussion

In the implementation of the drilling regime, it can be determined that the drill bit was loaded and rotated in accordance with the recommendations of the manufacturer of the bit.

When the penetration rate started to rapidly decrease, the drill bit was extracted from the well. A visual inspection of the fatigue of the bit, which led to the poorer operation of the bit, was carried out. It was found that the wear on the bit occurred in the form of the loss of tooth materials in places where the teeth were not protected by a carbide coating. Such characteristic wear of the bit is shown in Figure 7.

Figure 7 illustrates the loss of steel material due to the erosion action of the mud, which contained a large proportion of silicate particles (Table 2). The wear was reflected in the reduction of the dimensions of the body of the tooth and the formation of erosion channels at the tip of the tooth. The formation of erosion channels at the top of the tooth can be attributed to the decay of the carbide coating during the drilling process, which allowed the flushing of mud with silicate particles (Table 2) to erode into the newly opened surfaces, as shown in Figure 8.

Due to the considerable differences in the strength and thermal expansion properties between the carbide materials that represents the coating (protection) of the tooth body and the steel material

Slika 7. Karakteristične poškodbe kotalnega dleta

Figure 7. Characteristic wear of roller drill bit

Slika 8. Poenostavljena slika strujenja izplake preko kotal dleta

Figure 8. Simplified sketch of mud flow through the roller of drill bit

dleto ni bilo zaščiteno s karbidnim ovojem. Karakteristične poškodbe dleta v obliki izrabe materiala so prikazane na sliki 7.

Na sliki 7 lahko opazimo izrabo materiala zaradi erozijskega delovanja navrtanine, ki je vsebovala velik delež silikatnih delcev (tabela 2). Poškodbe se odražajo v zmanjšanju gabaritov telesa zob in v tvorbi erozijskih kanalov na vrhu zob. Tvorbo erozijskih kanalov na vrhu zob lahko pripišemo razpadu karbidne obloge v toku vrtanja, ki je omogočila, da je lahko izplaka z vsebnostjo silikatnih (tabela 2) delcev erozijsko delovala na novo odkrite površine, kot je prikazano na sliki 8.

Zaradi precejšnje razlike v trdnostnih in toplotno razteznostnih lastnostih med karbidnim materialom, ki predstavlja oblogo (zaščito) telesa zoba in jeklenim materialom telesa zoba, je tokom izvajanja vrtalnih del, zaradi različnih razteznih oziroma elastičnih materialnih karakteristik, prišlo do tvorjenja razpok med materialoma, kot prikazuje slika

of the tooth body and also due to various expansions or elastic material characteristics, cracks formed between the materials as shown at the Figure 9. A consequence of this is the split of the carbide coating from the tooth body. The result of this split between materials was the formation of a new steel surface through which mud containing a large amount of silicate abrasive components flowed. The abrasive components, which eroded the newly opened surfaces at the tips of the teeth, were caused by the formation of erosion channels and consequently the loss of the steel tooth material. The display of the formation of micro cracks resulting from the different elastic properties of the materials is shown in Figure 9. The picture shows the edge of the erosion channel at the top of the tooth. On the left side of the image, we can see a lining of carbide coating and, on the right side, the steel material of the tooth and the formation of a micro crack can be

9, in posledično do odstopanja karbidne obloge. Posledica odstopanja karbidne obloge je bila odprta nova ploskev (erozijski kanal), preko katere je potekalo strujanje izplačnega medija, ki je vseboval veliko količino silikatnih abrazivnih komponent. Abrazivne komponente so erodirale novo odprte ploskve na vrhovih zob in povzročile erozijske kanale in s tem posledično izgubo jeklenega materiala zoba. Prikaz tvorjenja mikro razpok, ki so posledica različnih elastičnih lastnosti materialov je prikazan na sliki 9. Na sliki je prikazan rob erozijskega kanala na vrhu zoba. Na levi strani slike je vidna obloga iz karbidnega materiala, na desni strani slike pa je viden material telesa zoba dleta ter tvorjenje mikro razpok. Ob vrhu zoba so vidni mikro erozijski kanali. Karbidna obloga na vrhu zoba, ki je odpornejša proti obrabi ampak krhka, postopoma razpada pod vplivom obremenitev na dleto v toku vrtanja, ter strižnih sil v kombinaciji z segrevanjem in ohlajanjem zob v toku vrtanja. Ta proces je viden na zgornji levi strani slike 9.

V našem primeru nam ni uspelo nedvomno določiti temperature jekla med vrtanjem. Prepričani smo lahko le, da je bila temperatura na vrhu zob med vrtanjem nižja od temperature prekristalizacije jekla dleta. Prekristalizacijo lahko določimo s testom trdote po Vickersu skupaj z opazovanjem kristalne strukture jekla z elektronskim mikroskopom. Pri pregledu nismo našli znakov prekristalizacije jeklenega materiala. Temperatura prekristalizacije jeklenega materiala našega kotalnega dleta je 695.2 °C. To smo ugotovili s toplotno analizo. Zaradi tega lahko z dilatometričnim testom ugotovimo vpliv temperature. S tem poskusom smo ugotovili, da se razlika med materialnimi lastnostmi jekla telesa zob in karbidne obloge izraža pri temperaturi, ki je višja od 100 ° C, kot je prikazano na sliki 6. Te temperature so prisotne v

seen. At the top of the tooth, micro erosion channels are visible. The carbide coating at the top of the tooth, which is more resistant to erosion, but fragile, gradually disintegrates due to the effects of pressure (weight on bit) and shear conditions combined with heating and cooling during the drilling process. This process can be seen in the top left side of Figure 9.

In our case, we did not manage to determine the temperature of the steel during the drilling beyond doubt. We can only be sure that the temperature on the top of the teeth, during drilling, was lower than the temperature of the recrystallization of drill bit steel. That recrystallization could be measured by the Vickers hardness test, along with an observation of the crystalline structure of the steel with an electronic microscope. We did not find any signs of recrystallization of steel material. The temperature of the recrystallization of steel material of our drill bit is 695.2 °C. This was determined by simultaneous thermal analysis. Because of this, we could determine the temperature influence by dilatometric test. During this test, we find out that the difference between the material properties of the tooth steel and carbide coating are expressed at a temperature higher than 100 °C as shown in Figure 6. These temperatures are present during the phase when the teeth are in contact with the rock material. During the journey of the tooth around the cone axis, the temperature of tooth steel decreases because of the influence of the mud. If this warming and cooling time is short enough, there is no immediate deviation in the carbide coating, but only in the formation of micro cracks at the contact of the carbide coating and tooth steel. These micro cracks are extended (during this time period) along the contact between the materials, which leads to a deviation of the carbide coating.

fazi, ko so zobje dleta v stiku s hribinskim materialom. Med potovanjem zoba okoli osi kotala se temperatura jekla zob zniža zaradi vpliva izplačnega medija. V kolikor je ta čas segrevanja in ohlajanja dovolj kratek, ne pride do takojšnjega odstopanja karbidne obloge, temveč le do nastanka mikro razpok na stiku karbidne obloge in jekla telesa zob. Te mikro razpoke se v tem časovnem obdobju podaljšajo vzdolž stika med materiali, kar vodi do odstopanja karbidne obloge. Ta pojav je bil zaznan le na vrhu zoba, medtem ko na straneh zob na preiskanem kotalnemu dletu ni bilo zaznanega nastanka mikro razpok v karbidni oblogi.

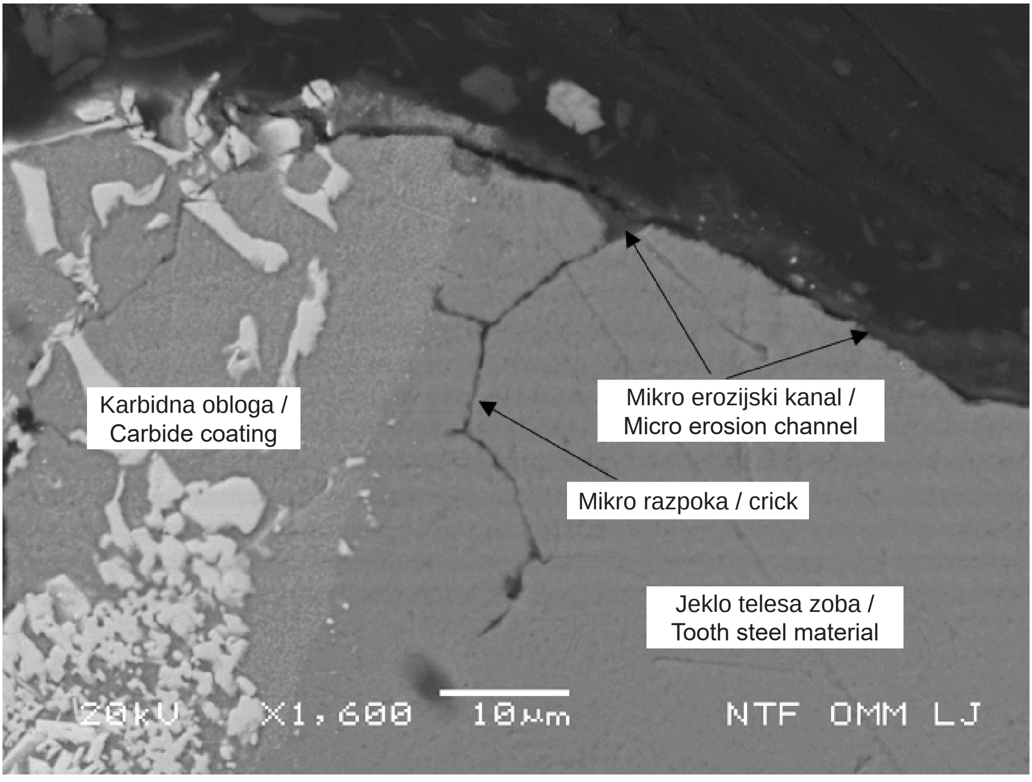
Podobne pojave lahko opazujemo tudi na samem telesu zoba, ki ni v območju

This phenomenon was only observed at the top of the tooth, while on the side of tooth, the formation of micro cracks in the carbide coating was not detected on the investigated drill bit.

Similar phenomena can also be observed on the tooth body itself, which is not in the area of the carbide coating. Figure 10 shows the formation of micro cracks and erosion channels along the edge of the tooth.

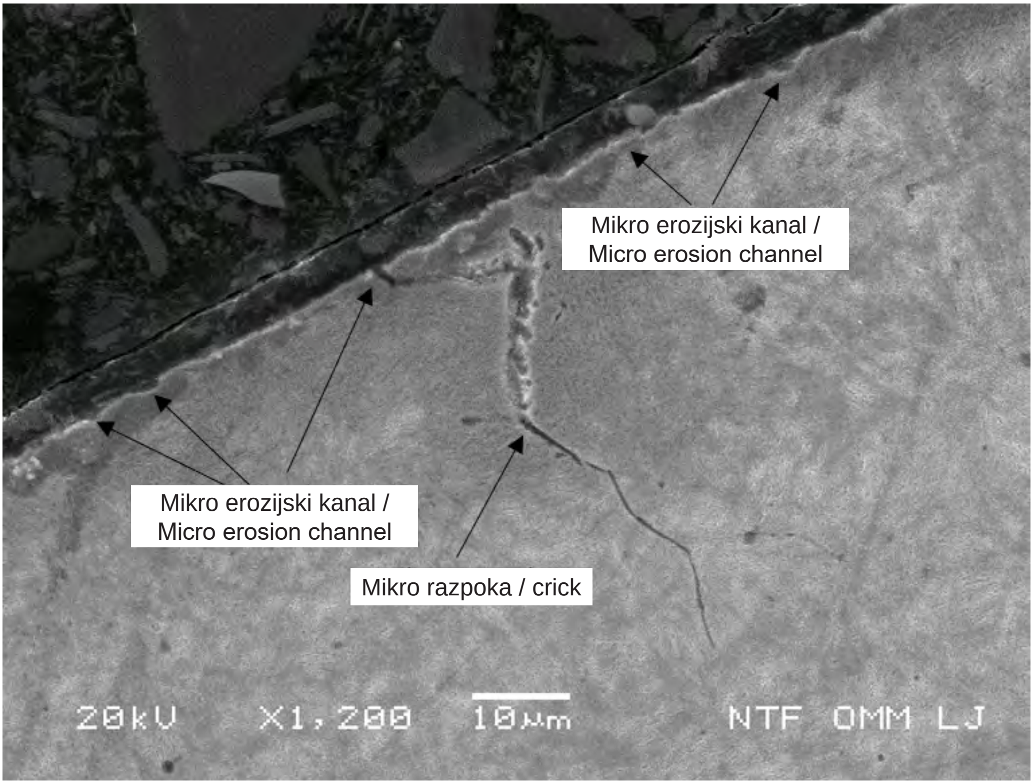
5 Conclusion

The results of our research, which included investigations of rock and steel material, represent the wear investigated in the



Slika 9. Tvorba mikro razpok kot posledica različnih elastičnih lastnosti materialov

Figure 9. The formation of micro cracks as a result of various elastic properties of materials



Slika 10. Mikro razpoka in erozijski kanali

Figure 10. Micro cracks and erosion channels on the tooth body

karbidne obloge. Na sliki 10 lahko opazimo tvorjenje mikro razpok in erozijskih kanalov na robu zoba.

5 Zaključek

Rezultati naših raziskav, ki so vključevale preiskave kamnin in jeklenih materialov, predstavljajo ugotovljeno obrabo kotalnega dleta v peščenjaku. Z opisanimi preiskovalnimi metodami smo odkrili mehanizem obrabe jeklene osnove kot tudi karbidne obloge zob glede na vpliv vrtanja skozi peščenjak, ki vsebuje veliko vsebnost abrazivnih delcev.

roller cone drill bit in sandstone. With the described investigation methods, we discovered the mechanism of wear of the teeth steel basis as well as in the carbide coating according to influence of sandstone which contains a large content of abrasive particles.

The characterization of the wear of the roller drill bit, which is described in our work, is a complex analysis of several factors. On the one hand, the interaction between the rock material and the drill bit is closely connected to the drilling regime. In this case, we dealt with the action of the steel material of the drill bit on the rock material - sandstone. During the drilling process, the drill bit was heated while in contact with the

Karakterizacija obrabe kotalnega dleta, ki je opisana v našem delu, je kompleksna analiza več dejavnikov. Na eni strani nastopa interakcija med hribinskim materialom in dletom, ki je tesno povezana z režimom vrtanja. V tem primeru imamo opravka z stikom materiala dleta na hribinski material. V toku vrtanja se zobovje dleta segreva na stiku s hribinskim materialom in nato ohlaja zaradi vpliva izplačnega medija. V tej fazi prihaja do izraženja deformabilnostnih lastnosti jekla iz katerega je narejeno kotalo dleta in zobovje ter na drugi strani deformabilnostnih lastnosti karbidne obloge. V tem primeru zaradi različnih temperaturnih razteznostnih koeficijentov pojavlja tvorba mikro razpok na jeklenem materialu zoba, ki omogoča prodiranje izplačnega medija, ki vsebuje erozijske mikrodelce, v novo tvorjene razpoke. Karbidna obloga zoba je erozijsko odpornejša vendar krhka, zaradi česar v toku vrtanja, zaradi vplivov tlačnih in strižnih razmer, postopoma odpada.

Med raziskavo smo odkrili, da je obraba jekla zob bolj progresivna kot obraba karbidne obloge. Površine zob, ki niso prekrite s karbidno oblogo, so bolj izpostavljene vplivu erozije. Erozijski učinek predstavlja nastajanje erozijskih kanalov, v katere vteka izplačni medij, ki vsebuje velik odstotek agresivnih delcev. Razpad karbidne prevleke, ki poteka počasneje od obrabe jekla telesa zob, je posledica obremenitev dleta med vrtanjem in temperaturnih razlik, ki se pojavijo med vrtenjem kotal. Zaradi različne stopnje obrabe obeh materialov se spremeni geometrija zob in s tem učinkovitost kotalnega dleta.

Izboljšave odpornosti jekla zoba, ki je v osnovi obravnavanega vzorca, precej žilavo, se ponujajo v površinski obdelavi le tega. Površinska obdelava jekla zoba, v smislu povečanja erozijske odpornosti, se lahko izvede z metalurškimi postopki ali kasnejšo obdelavo površine celotnega zoba pred nanašanjem karbidne obloge.

rock material and then cooled due to the influence of the drilling mud. At this stage, the differences between the deformability properties of the steel material of the rollers and the teeth, and, on the other hand, the deformability properties of the carbide coating become evident. In this case, due to the different temperature expansion coefficients, the formation of micro cracks on the steel material of the tooth causes the penetration of a dispersed medium containing erosion microparticles in the newly created cracks. The carbide coating of the tooth is more resistant to erosion, but fragile, which causes it to gradually disintegrate during the drilling process due to the effects of pressure and shear conditions combined with the heating and cooling.

During our research, we discovered that the wear on the tooth steel is more progressive than the wear on the carbide coating. The surfaces of the teeth, which are not covered with a carbide coating, are more exposed to the influence of erosion. The erosion effect is represented by the formation of erosion channels into which the mud, which contains a large percentage of aggressive particles, flows in. The disintegration of the carbide coating, which is a slower process than the steel wear, is a consequence of the bit load during drilling and the temperature differences, which occur during the roller rotation. Because of the different rate of wear of both materials, the geometry of the teeth changes and, thus, the effectiveness of the drill bit.

The improvement of the resistance of tooth steel, which is rather tough, is offered in the surface treatment of this. The surface treatment of tooth steel, in terms of increased erosion resistance, can be carried out by means of metallurgical processes or the subsequent treatment of the surface of the entire tooth prior to the application of the carbide coating.

V zadnjem času pa se za zaščito pred erozijsko odpornostjo pričenja z eksperimentiranjem z nano materiali, ki že kažejo morebiten novi trend v razvoju erozijske odpornosti materiala kotalnih dlet.

As such, the protection against erosion resistance begins with experiments in nano materials, which already show a potential new trend in the development of erosion resistance in the rollers and tooth material of roller cone drill bits.

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