A Study to Investigate the Influence of Coal Properties on Bit Wear-ability of Roadheader

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Abstract

Coal is a naturally occurring mineral and one of the most important sources of energy all over the world. The physico-mechanical properties of the coal such as density, porosity, strength, hardness, abrasivity varies depending upon its type and location. Therefore, it requires the most appropriate techniques that can help to fulfil the required coal demand without disturbing the surrounding environment. The mechanical excavation technique is attractive for excavation of coal compare to conventional. But due to variation in coal properties and intrusion of foreign material the performance of machine and its tools changes. This study was conducted in the field and laboratory to assess the Roadheader bit performance. From the study it was found that coal properties (compressive strength, density, abrasivity) highly influences the bit wear ability rate that leads to reduction in instantaneous cutting rate of the Roadheader. Similarly the micro-structure study of the used and unused bit clearly indicates the changes in the bit chemical composition due to heating and abrasion leads to faster rusting.

Key words

Roadheader, Bit wear, Conical picks, Scanning electron microscopy.

1. Introduction

These days, use of coal is a prime source of energy. Besides the power industry, it is also the base of essential fuel for steel and cement plants as well as in many other industries. The Mechanical excavators, such as, continuous miner, roadheader, shearers are widely used for coal mining. The selection of these excavators and the related tools affect the production rate to a great extent. Tools may be of different shapes, such as, conical pick, radial pick, buttons shaped, etc. Conical pick is found to have advantages over the other tools. It has been found that when a conical pick is in use, the depth of cut increases while the need for specific energy decreases [1]. The shape of conical pick remains sharp due to symmetrical wearing process during cutting. Conical tool provides better efficiency as it requires the lowest specific energy for penetration. It also has a longer life than radial bits [2]. Different composition and properties of coal result in different types of wear mechanisms. Many researchers have investigated various wear mechanisms in the cemented carbide surface of the conical bits. However, they believe that there has to be further studies [3,4] for developing cemented carbide of different grades with high wear resistance properties and high efficiency in coal cutting.

Wear resistance property significantly increases, when the tool hardness becomes 80 % of the hardness of material being cut [5]. The conical picks have self-sharpening nature because of the remains sharp due to symmetrical wearing process during cutting [6]. Conical tool provides better efficiency as it requires the lowest specific energy for penetration [7]. It also has a longer life than radial bits [2]. As soon as the pick gets worn out, their performance reduces substantially.

The present paper deals with investigations of different coal properties and its effect on bit wear. Rock material, which may be little or huge in quantity, is always present in coal mine along with coals. These rock materials are the main cause for the deteriorating condition of the conical tool. The study was conducted at underground coal mines namely Moonidih mine of Bharat Coking Coal Limited where transverse type Roadheaders were deployed for cutting the coal. The coal characterization of cutting face were done with the help of L-type Schmidt hammer.

The objective of this study is to investigate the effect of coal properties on wear-ability of conical picks of Roadheader in coal development drive. The factors affecting the wear rate of picks are Density, Abrasivity and Strength of coal.

The Coal properties may be classified into four categories according to drill-ability, cuttability and machinability: that is textural, mechanical, structural and weathered characteristics.

The resistance of a tool wear when in contact with coal is the most common principle for measuring coal abrasivity. Cerchar abrasivity index (CAI) testing has been recommended by

International Society of Rock Mechanics as a rock mechanics testing method. Cerchar abrasivity index is usually defined for fine grained rocks with less than 1 mm grain size. However, for coarser rocks, the Cerchar abrasivity index can only be measured if more scratches are made [8]. The classification of abrasiveness [9 ,10], is: 0.3–0.5 not very abrasive; 0.5–1.0 slightly abrasive; 1.0–2.0 medium abrasiveness to abrasive; 2.0–4.0 very abrasive; 4.0–6.0 extremely abrasive.

The performance analysis of Roadheader is a very important task to improve the efficiency. Many researchers have given their model to analyze the performance based on their study. Some of them are;

Bilgin et al. [11] suggested that the machine advance rate of road header can be estimated using UCS & RQD. They recommended that the Rock Mass Cuttability Index (RMCI) can be defined as:

$$RQD = 115\text{-}3.3\ J_v \tag{1}$$

$$RMCI = \sigma_c \left\{ \frac{RQD^{2/3}}{100} \right\} \tag{2}$$

where, RQD = rock quality designation, (%) ; Jv = total number of discontinuities per cubic meter; RMCI = Rock Mass Cuttability Index, kg/cm2 ; σc = UCS, kg/cm2

Gehring [12] predicted the performance of a rock cutting machine such as a road header and suggested the following equation:

$$L = \frac{k}{\sigma c} N \tag{3}$$

where, L = cutting performance, b cm/h/; σc = UCS, MPa ; N = cutter head power, kW

K = a factor for consideration of relatively cuttability of a rock with certain UCS and for consideration of tuning effect between road header and rock.

To study the relationship between ICR and rock uniaxial compressive strength (UCS) for a milling type road header with 230kW cutter head power and an Alpine Miner AM 100 ripping type road header with 250kW cutter head power. He developed following equations:

$$ICR = 719/\ (UCS)^{0.78} \tag{4}$$ for ripping type road headers

$$ICR = 1739/\ (UCS)^{1.13} \tag{5}$$ for milling type road headers

where, ICR denotes as cutting performance (m³/hr); and UCS as the uniaxial compressive strength (MPa)

Bilgin[13] showed that main factors governing performance of roadheader were rock compressive strength & RQD. He suggested that the instantaneous cutting rate could be best predicted from rock mass cuttability index as:

$$RMCI= \sigma_c \left\{ \frac{RQD^{2/3}}{100} \right\} \tag{6}$$

where, RMCI = Rock Mass Cuttability Index(kg/cm2); RQD = rock quality designation(%);σc = UCS, kg/cm2

He also suggested to calculate the ICR using the RMCI values for roadheader having cutting power of 95 Hp

$$ICR= 0.28 \; P(0.974)^{RMCI} \tag{7}$$

where, P is the power of cutting head (hp); RMCI is the rock mass cuttability
Copur [14,15] stated that if the power and weight of roadheader were considered together, in addition to rock compressive strength, cutting rate prediction were more realistic.The predictive equa¬tions for transverse (ripping type) road headers are as follows:

$$ICR=27.511e^{0.0023(RPI)} \tag{9}$$

$$RPI=P*W/UCS \tag{10}$$

where, ICR= Instantaneous cutting rate (m3/hr or tonnes/ hr); RPI(road header penetration index); UCS(uniaxial compressive strength MPa); W(roadheader weight in tones); P(power of cutting head kW); and e (base of natural logarithm).

2. Field Study and Research Methodology

The study was conducted an underground coal mine to collect the actual cutting rate of the roadheader and collected the different cutting tools. The mine was designed by Polish consultants under a technical collaboration for horizon mining system to produce coking coal from coal seams at depth of 500 meters. The roadheader was deployed in a coal seam development. The

dimension of the drive was 2m high, 4.5m wide. The roadheader was deployed to cut the coal. The major specifications of the machine are; motor capacity of 100 kW (2 nos.), weight of the machine was 24tonnes, pics (96 nos.) was made of tungsten carbide (Fig.1).
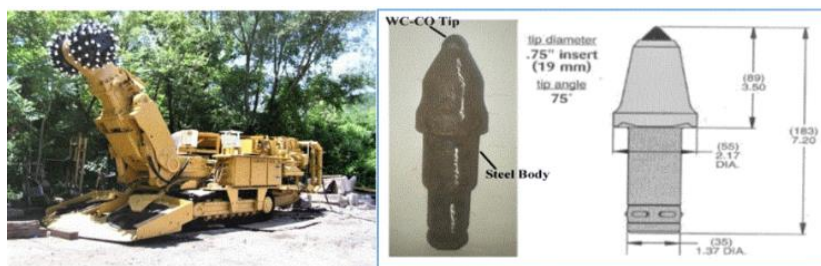

Fig 1. Conical pick of Alpine AM-50 RH

The Schmidt hammer was used to find the compressive strength of the coal at mines during recording the cutting rate of the roadheader. The Schmidt hammer rebound hardness test is a simple and non-destructive test originally developed in 1948 for a quick measurement of UCS and later was extended to estimate the hardness [16] and strength of rock the standard L- and N-type hammers, with respective impact energies of 0.735 and 2.207 Nm. The N-type hammer is less sensitive to surface irregularities, and should be preferred in field applications; while the L-type hammer has greater sensitivity in the lower range and gives better results when testing weak, porous rocks (Fig.2). The compressive strength of the rock was determined at interval of 2m in horizontal direction of both the side of the wall of the drive to get the rebound value after cutting the coal. Among the numbers obtained, the mean value was considered as the Schmidt number.

Fig 2. L- type Schmidt hammer

This procedure of performing Schmidt test was a compromise to the ISRM suggested method [17] where10 higher numbers were selected from 20 tests in the selected area. Schmidt hammer rebound number and respective converted uniaxial compressive strength values are

given in Table 1 and 2. In this study Copur and Gehring model were used for comparing the performance because of similarity in machine used and the field conditions.

The laboratory tests for determination of coal properties such as uniaxial compressive strength, tensile strength and cercher abrasibity index is shown in Fig.4 while Fig. 4 shows the determination of Roadheader conical picks cutting by electric discharge machining (EDM) and size of 6/10 mm picks for Scanning Electron Microscopy (SEM) analysis. Fig.5 shows the determination of Cercher hardness for the coal samples.

Fig.3. Laboratory testing for determination of UCS and tensile strength

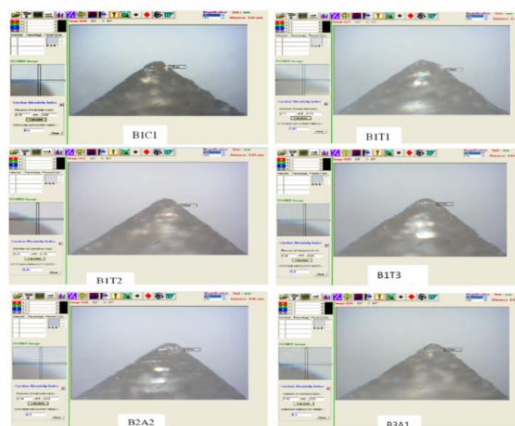Fig.4. Roadheader conical picks cutting by EDM machine and size of 6/10 mm picks for SEM analysis.

Fig.5. CAI values of different coal samples

3. Results and Discussions

The field observations of are tabulated in table-1 and laboratory results are in table- results are plotted graphically and are shown in the Fig. 6 to 9.

Table 1. Details of the field observations

Location		L-1	L-2	L-3	L-4	L-5	L-6	L-7	L-8	L-9	L-10
Cutting drive area (m^2)		9	9	9	9	9	9	9	9	9	9
Advancement (m/hr)		1.84	2.32	1.80	1.325	1.73	1.86	1.49	1.60	1.43	1.78
Avg. Schmidt Hammer rebound number		19	17	20	29	22	19	27	25	26	21
UCS (MPa)		17	13	18	31	21	16	27	24	28	20
Bit wear rate (mm/mM) x 10^{-3}		0.55	0.37	0.62	0.91	0.72	0.42	0.85	0.80	0.90	0.65
Power (kW)		100	100	100	100	100	100	100	100	100	100
ICR(m3/hr)		16.50	20.88	16.20	11.92	15.57	16.74	13.41	14.40	12.87	16.02
ICR (tonnes/hr)		22.35	28.18	21.87	16.09	21.02	22.60	18.10	19.44	17.40	21.63
Copur et al	ICR	38.064	42.06	37.38	32.87	35.78	38.84	33.75	34.62	33.50	36.25
	RPI	141.17	184.61	133.3	77.44	114.2	150	88.88	100	85.71	120
Gehring	ICR	78.88	97.24	75.44	49.37	66.89	82.70	54.98	60.30	53.45	69.50

Table 2. Abrasiveness values of different coal samples

Sl.no	Sample name	Pin wear (mm)	Cerchar abrasivity index (CAI)
1	B1T3	0.04	0.4
2	B3T3	0.06	0.6
3	B2C2	0.04-0.06	0.5
4	B3C1	0.05	0.5
5	B1T2	0.04-0.05	0.45
6	B1C1	0.05	0.5

Table 3. Density of different location sample of same drivage of mines

Sl no.	Coal sample	Length (mm)	Diameter (mm)	Volume (cm^3)	Mass (kg)	Density (kg/m3)
1	B1C2	67.68	44.52	105.3026	0.168	1594
2	B2C1	91.83	45.52	149.368	0.213	1426
3	B3C1	52.33	43.68	78.376	0.112	1431
4	B2C2	46.75	45.06	74.513	0.102	1368
5	B1T1	29.75	43.68	44.557	0.067	1503
6	B1T2	23.46	44.75	36.8793	0.055	1490
7	B1T3	32	44.34	49.405	0.064	1296
8	B3T3	35.22	43.86	53.206	0.071	1334
9	B4T1	35.22	43.86	53.206	0.074	1398
10	B4T2	29.75	43.68	44.557	0.069	1550

3.1 Relationship between uniaxial compressive strength (UCS) and bit wear rate

The relationship between uniaxial compressive strength (UCS) and) and bit wear rate (mm/m) of Roadheader is shown in Fig.6.
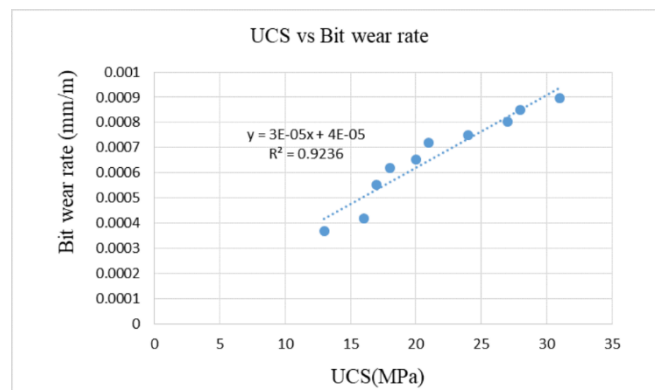

Fig.6. Graph between uniaxial compressive strength (UCS) and bit wear rate

From the above graphs it can be said that as UCS is increases the value of bit wear is increases. The reason behind this is that, as the uniaxial compressive strength increases the machine faces difficulties in cutting the rock at the same time bit wearing is also more during cutting rock process. The variability in UCS is mainly due to intercalation of shale, sandstone, carbonaceous shale. The reason behind this is that, the competent rocks, present in between coal

mass, made abrasive effect on tool leading to further plastic deformation. The variation in Bit wear is (0.00037 to 0.00091) 58% mm/m.

3.2 Relationship between coal density and bit wear rate

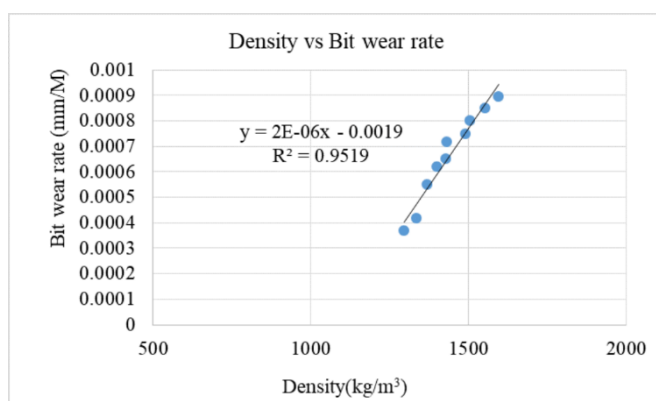The relationship between Density and bit wear rate of Roadheader is shown in Fig.7.

Fig.7. Graph between density and bit wear rate of Roadheader

From the above graphs it can be said that as density is increases the value of bit wear is increases. The variation in bit wear is (0.00037 to 0.00091) 58% mm/m while variation in density is (1594 to 1294 kg/m^3) 18%.

3.3 Relationship between abrasivity and bit wear rate

The relationship between Cerchar abrasivity index (CAI) and Bit wear rate of Roadheader is shown in Fig.8.
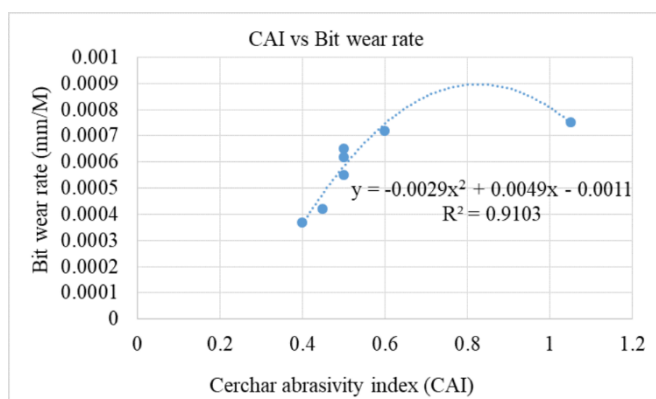

Fig.8. Graph between abrasivity and bit wear rate of Roadheader

From the above graphs it can be said that as abrasivity is increases the value of bit wear is increases. This may be due to the increase in presence of abrasive material in the coal. The variation in bit wear is 0.00037 to 0.00091 (58%) mm/m while variation in abrasivity of coal is 0.4 to 1.05 (61%).

3.4 Relationship between instantaneous cutting rate (ICR) and bit wear rate

The relationship between bit wear rate and Instantaneous cutting rate of Roadheader is shown in Fig.9.
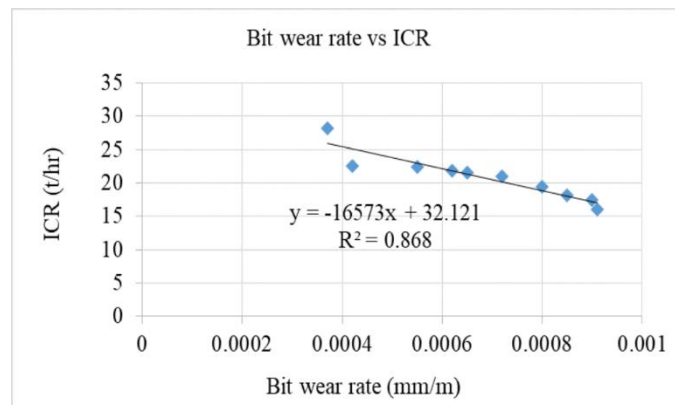

Fig.9. Graph between Bit wear rate and Instantaneous cutting rate (ICR)

From the above graphs (Fig.16) it can be said that as bit wear rate is increases the instantaneous cutting rate (ICR) reduces. This is due to the wearing of bit made it flattened and reduces the cutting performance of Roadheader. The variation in bit wear is 0.00037 to 0.00091 (58%) mm/m while variation in the ICR is 16.9 to 28.18 (40%), tonnes per hour.

3.5   Analysis of microstructure of worn-out roadheader bit

The microstructure study was conducted for unused and used bit to analyse its cracking, crushing and change in chemical composition.

Results of Scanning Electron Microscopy (SEM) through microstructure analysis are depicted in Fig. 10a-d. From the analysis wear phenomenon such as cracking and crushing was found with the different magnifications as show in Fig 10. The wear phenomenon crack formation is found at a magnification of Fig. 10. The enlarge cracks may be generated due to continuous impacts between the rock and Roadhearder bit. The tool faces experiences rapid action of friction followed by change in grain structure which result the cracks formation. Furthermore, due to continuous hitting between the rock particle and the tool maximum damaged

may come out from tool material due to sudden shocks which is observed at magnification of Fig.10. This damaged parts is showing the crushing. The crushing is also one of the wear phenomenon.

The chemical composition of the tool pick have been analyzed into weight % through energy dispersive X-ray analysis (EDX). From this analysis the composition of Spectrum 1 and Spectrum 2 are shown in figure. In Spectrum 1 is the chemical composition as shown the composition in the Table 4 of unused Roadheader bit whereas in Spectrum 2 is also chemical composition as shown in Table 5 of the worn-out Roadheader bit. These values are in form of weight % of carbon (C), Oxygen (O), Magnesium (Mn), Aluminum (Al) and Zinc (Zn) etc.
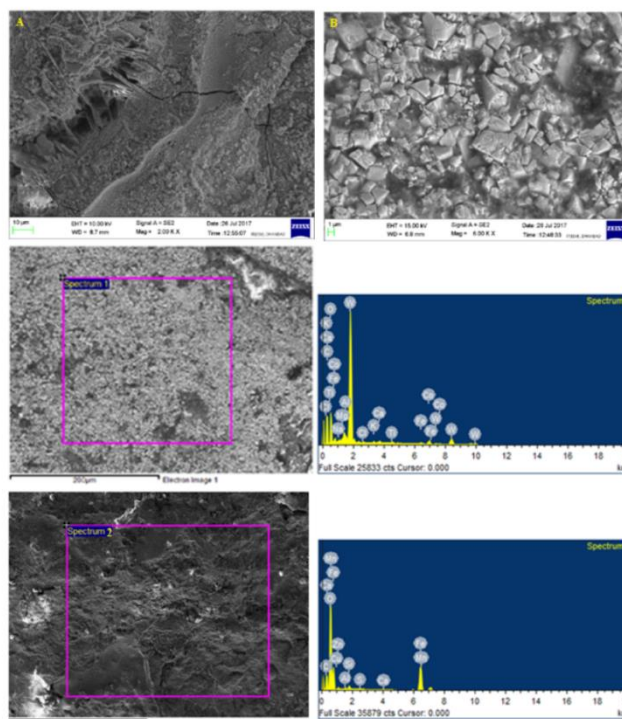

Fig.10. Results of SEM through microstructure analysis

Table 4. Composition of unused Roadheader bit

Element	C	O	Na	Mg	Al	Cl	K	Ca	Ti	Fe	Co	W	Total
Weight (%)	16.2	16.66	0.25	0.36	0.46	0.29	0.53	0.55	0.49	1.25	4.6	58.4	100

Table 5. Composition of used Roadheader bit

Element	C	O	Al	Si	S	Ca	Mn	Fe	Cu	Zn	Total
Weight (%)	11.67	39.72	0.38	0.80	0.18	0.16	0.53	43.49	1.44	1.64	100

The carbon content is varying from 16.20 % and 11.57 % by weight in spectrum 1 and 2, which is in higher side and may cause of reducing ductility and malleability of the material of the bit. Similarly, the oxygen content has also been increased from 16.66 % and 39.72 % by weight. The high changes of oxygen content leads to develop oxidization which signifies formation of rust. Generally in steel or Aluminium are used to protect the oxidation. But in the Spectrum 2 it is shown that the percentage of Aluminium is lower than the Spectrum 1. This change may lower strength of the steel. This analysis shows that composition of the material, and higher changes of weight % of the element leads to wear of the material.

4   Conclusions

The bit wear and cutting performance of the Roadheaders were analysed through Laboratory and field data and following conclusions were drawn.

1. The bit wear ability is increases as the UCS increases this is mainly due to intercalation of shale, sandstone, carbonaceous shale.

2. The bit wear is increases as the density of coal is increases. The variation in bit wear is (0.00037 to 0.00091) 58% mm/m while variation in density is (1594 to 1294 kg/m3) 18%.

3. The bit wear is increases as the coal abrasivity is increases. This is due to the increase in presence of abrasive material in the coal. The variation in bit wear is 0.00037 to 0.00091 (58%) mm/m while variation in abrasivity of coal is 0.4 to 1.05 (61%).

4. The instantaneous cutting rate (ICR) reduces as bit wear rate is increases. The variation in bit wear is 0.00037 to 0.00091 (58%) mm/m while variation in the ICR is 16.9 to 28.18 (40%), tonnes per hour.

5. Micro-structure analysis of the bit shows that the carbon content is reduced after use of the bit from 16.20 % and 11.57 % that causes reduced ductility and malleability of the material of bit. Similarly, the oxygen content has been increased from 16.66 % and 39.72 % by weight that leads to develop oxidization and signifies formation of rust.

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