Annual of the University of Mining and Geology "St. Ivan Rilski"
vol.45, part I, Geology, Sofia, 2002, pp. 83-88

ROCK ABRASIVITY IN OPEN-PIT COAL MINES

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ABSTRACT
A methodology has been developed for determining the abrasivity of different lithological varieties from the Pliocene complex of open-pit coal mines in the East Maritsa Coal Basin (Bulgaria). The relationships between the individual parameters are presented and described by their mathematical equations. Close relationships have been established between abrasivity and the moisture content, quartz and feldspar quantities which serve as qualitative parameters in selecting the material for manufacturing the bucket teeth, in predicting the rate of the bucket wheel motion and the conveyor belt service time. The results obtained can be used in other operations related to the geological and mining cycle on sites under similar conditions.

INTRODUCTION

Hard inclusions (sandy limestones, compact limestones, quartz sandstones, etc.), clays and sands of high abrasivity are encountered during the operation of bucket-wheel excavators in the Pliocene overburden complex of open-pit mines in the East Maritsa Coal Basin. As a result of that abrasivity, the cutting devices of the excavators (bucket teeth) and the conveyor belts wear out fast. Their replacement is very expensive thus raising the coal production costs. On the other hand, the negative effect on the overburden stripping rate is taken into account as well.

The different mineral composition of the overburden lithological varieties affects the abrasivity through the quantitative content of the individual constituents. The latter have been used as a basis for creating a methodology for analytical determination of the abrasivity coefficient.

INVESTIGATION METHODOLOGY

The abrasivity of hard inclusions was tested under lab conditions by the Baron-Kuznetsov method (1961). A steel cylindrical indenter (a pin of grooved silver steel) was introduced by dry friction on the non-polished surface of the hard inclusion. The abrasivity (A) is determined by the expression:

$$A = \frac{a}{N} \text{, mg/km,} \qquad (1)$$

where:
a - abrasivity index, mg;
N - correction coefficient for abrasivity determination, km.

Three values are used for the coefficient N – N=0,01 km; N=0,005 km and N=0,002 km. Coefficient N=0,002 km (Table 1) is accepted for theoretical and experimental reasons.

Table 1

Lithological description	Abrasivity index a, mg	Abrasivity, mg/km		
		0,01	0,005	0,002
Calcareous clay	19,40	1940	3880	9700
Varigrained sand with clayey-calcareous welding	63,30	6330	12660	31650
Coarse-grained sand with calcareous welding	44,90	4490	8980	22450
Fine-grained sand with carbonate welding	11,60	1160	2320	5800

For clays and sands the abrasivity is determined following the formula proposed by Kuntysh et al (1980) and improved by Stoeva, Zaneva-Dobranova et al (1992):

$$A = \frac{V d \sigma_{on}}{100} \text{, mg/km,} \qquad (2)$$

where:
V - reduced volume content of a highly abrasive constituent (for this case quartz or feldspar), %;
d – grain size (diameter of prevalent sand or feldspar fraction), m;
σ_{on} – tensile strength, 10^5 Pa.

For the sand fraction (quartz) it is assumed that:
- fine-grained sand d=0,01 mm;
- small-grained sand d=0,25 mm;
- medium-grained sand d=1,00 mm (Table 2).

For the feldspar it is assumed that d=0,01 mm (Table 2).

Table 2

Lithological description	σ_{on}, 10^5 Pa	Quartz, %	Abrasivity, mg/km for			Feldspar, %	Abrasivity, mg/km for d=0,07 mm
			d=0,25	d=1,00	d=0,01		
Greyish-black clay	1,09	4	109	436	4,36	4	4,36
Greyish-black clay with coal inclusions	1,09	3	81,75	327	3,27	2	2,18
Bluish-green clay with dust-like carbonate substances	1,09	12	327	1308	13,08	9	9,81
Coarse-grained sand with clay welding	0,33	27	222,75	891	8,91	32	10,56
sandy rust-coloured clay	1,56	43	1677	6708	67,08	12	18,72

The abrasivity was determined for d=1,00 mm, a diameter proved to be most reliable.

RESULTS

Greyish-black clays with and without coal inclusions, bluish-green clays with dust-like carbonate substances and rust-coloured sandy clays were tested (Table 2). The hard inclusions were presented by: varigrained sand with carbonate welding, sandy or dolomitized limestone, calcareous clays (argillites), etc. (Table 1).

The tests proved that the abrasivity determination depends mostly on the terrigenous grain size, natural moisture content, etc.

The relationship between abrasivity (A) and natural moisture content (W_n) of the different clay varieties from the overburden horizons of the East Maritsa Basin mines is very indicative and permits future prediction assessments concerning the wear-and-tear of the bucket teeth and conveyor belts.

The greyish-black organic clays having up to 20% maximum content of organic substance are characterised by 1500 mg/km maximum abrasivity. In those clays, the abrasivity decreases considerably (up to 200 mg/km for W_n=60%) with increasing the natural moisture content (Fig.1, curve A). The limit value for W_n is approx. 60%. The rising branch of curve A shows an increase in abrasivity of up to 1300 mg/km with increasing the moisture content (W_n values above the limit ones). This can usually be observed in black clays with coal inclusions. The relationship between abrasivity and W_n is described by a hyperbola of the type:

$$A = 57674{,}2 - 2847{,}37W_n + 46{,}0849W_n^2 - 0{,}241466W_n^3 \text{, mg/km,} \qquad (3)$$

or a correlation coefficient r=0,72.

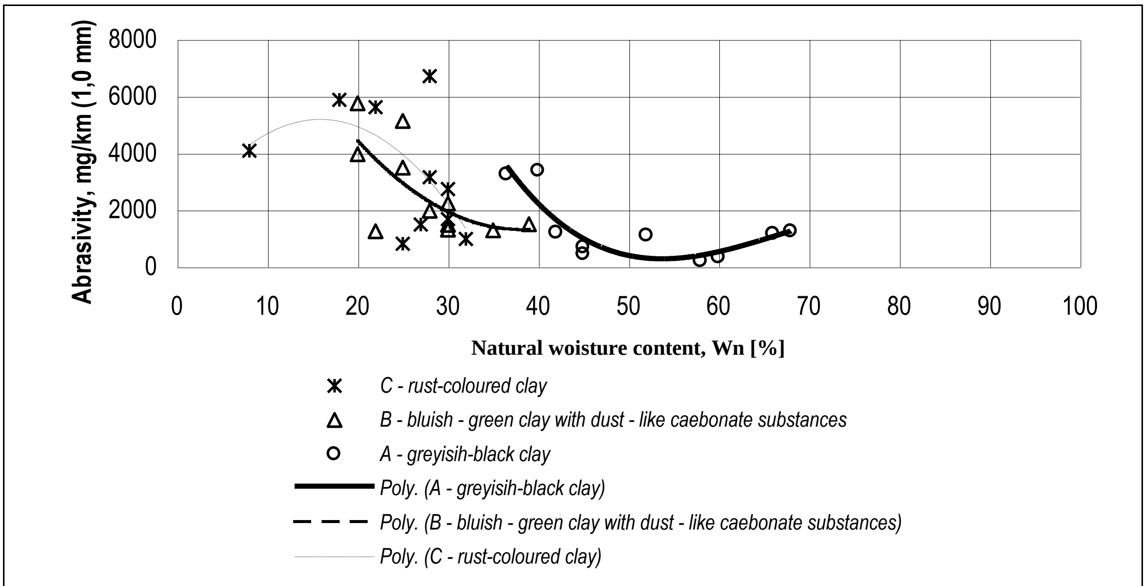


Figure 1.

The bluish-green clays are characterised by a very wide range of abrasivity variation determined not only by the quartz content but also by the different state of the calcareous constituent. Abrasivity values of up to 1200-1300 mg/km (Fig. 1, curve B) are related to the calcareous content in the form of dust-like carbonate substances. In lithological varieties containing up to 25% quartz and calcareous substance in the form of concretions, the abrasivity values increase up to 5200-

5700 mg/km. The relationship between abrasivity and natural moisture content for the bluish-green clays with dust-like carbonate substances is described by a parabola equation and has the following form:

$A = 15190{,}3 - 729{,}199 W_n + 9{,}57678 W_n^2$, mg/km, (r=0,47) (4)

The rust-coloured sandy clays are characterised by high data scattering (Fig. 1, curve C). The high abrasivity of up to 7000 mg/km is determined by the large-sized, uneven, sandy grains of the weakly welded sands which are insignificantly affected by the moisture content. Those results are typical of the East Maritsa Basin mines. Even in small-grained varieties the high abrasivity is not influenced by the moisture content. A proof of that is the low correlation coefficient (r=0,30) corresponding to the parabola equation:

$A = 1478{,}82 + 467{,}692 W_n - 14{,}7564 W_n^2$, mg/km, (r=0,30) (5)

The tests show that in hard inclusions the natural moisture content (W_n up to 5,6%) has an insignificant effect on the abrasivity. For instance, the low moisture content is due to the specific properties of the inclusions presented mainly by lumps of lithified varieties.

The reason for the wide range of abrasivity variation (from 1150 to 108100 mg/km) for the same lithological types can be accounted for by the broad variety of inclusions as regards their mineral composition, cementation structure and various strength characteristics.

The general trend of the relationship A=f(W_n) is described by a hyperbola of the form (Fig. 2):

$A = 62084{,}7 - 34092 W_n + 6109{,}42 W_n^2 - 245{,}523 W_n^3$, mg/km (r=0,48) (6)

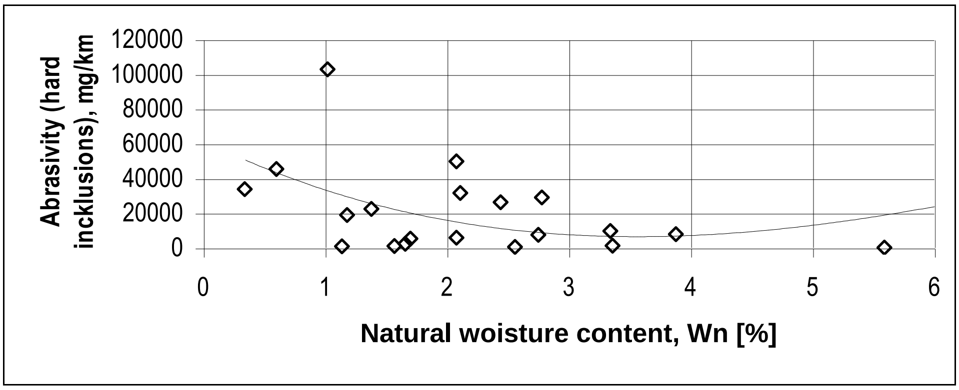


Figure 2.

The study on the effect of the proportional content of quartz on the abrasivity is of particular significance since it is the most abrasive constituent in the Pliocene overburden clays.

For the greyish-black clays having up to 18% quartz content, which form the first group of those clays, the abrasivity values are in the order of 50-1400 mg/km. For the second group of such clays, having coal inclusions and over 18% quartz content, the abrasivity values rise up to 3600 mg/km.

The relationship between abrasivity and quartz [A=f(SiO_2)] is described by the parabola equation (Fig. 3, curve A):

$A = 142{,}59 + 85{,}477 SiO_2 + 1{,}488 SiO_2^2$, mg/km (r=0,97) (7)

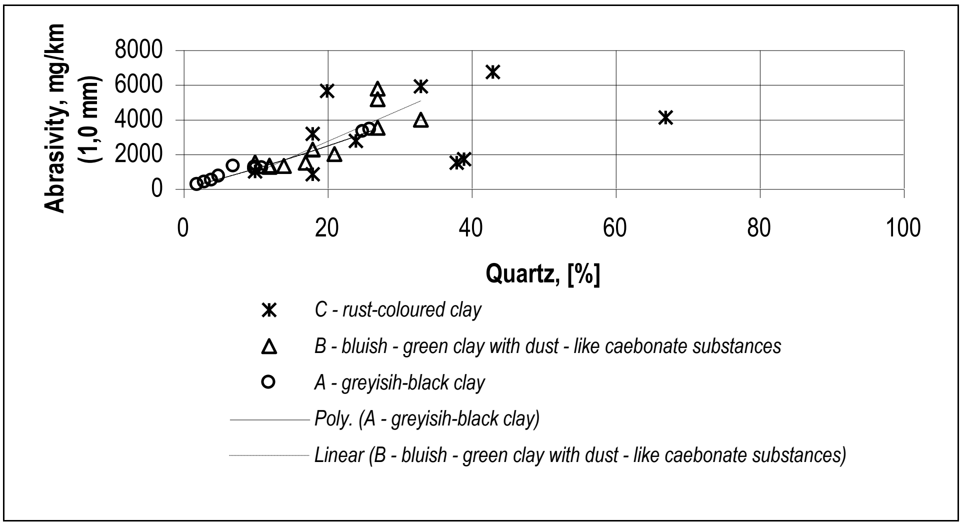


Figure 3.

The tendency towards changing the abrasivity depending on the quartz content in the bluish-green clays with dust-like carbonate substances is similar to that in the greyish-black clays (Fig. 2, curve B). For a quartz content of up to 10-15%, the abrasivity is 1300-1500 mg/km. Considerably higher values (5200-5800 mg/km) can be observed with increasing the quartz content over 15%. This is due to the presence of calcareous substance in the form of concretions.

The relationship between abrasivity and quartz for the bluish-green clays containing dust-like carbonate substances is described by a straight-line equation:

$A = -913{,}977 + 180{,}742 SiO$, mg/km, (r=0,71) (8)

Due to the small amount of data on the abrasivity of the rust-coloured sandy clays, the correlation coefficient is r=0,168. This makes it impossible to describe and analyse the relationship A=f(SiO_2) by using mathematical tools. The distribution obtained is shown in Fig. 3.

The relationship between the feldspar constituent and abrasivity has the same tendency (Fig. 4, curves A, B, C) for all three lithological varieties. When assessing the degree of wear of the bucket teeth and conveyor belts, it is necessary to take into account the maximum abrasivity values, namely:

- for the greyish-black clays - up to 2000 mg/km for 16% feldspar content;
- for the bluish-green clays containing dust-like carbonate substances - up to 4500 mg/km for 26% feldspar content;
- for the rust-coloured sandy clays - up to 5600 mg/km for 15% feldspar content.

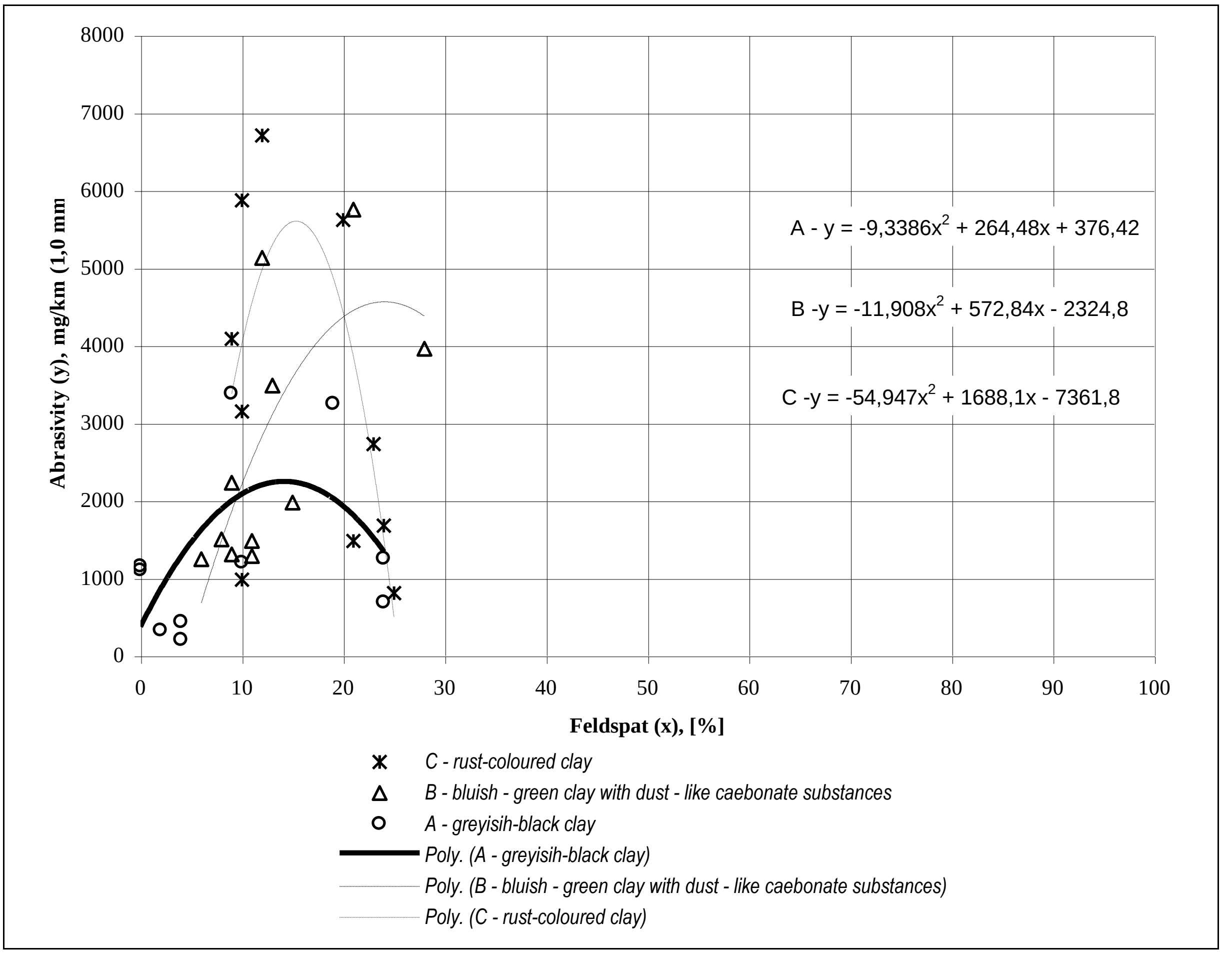
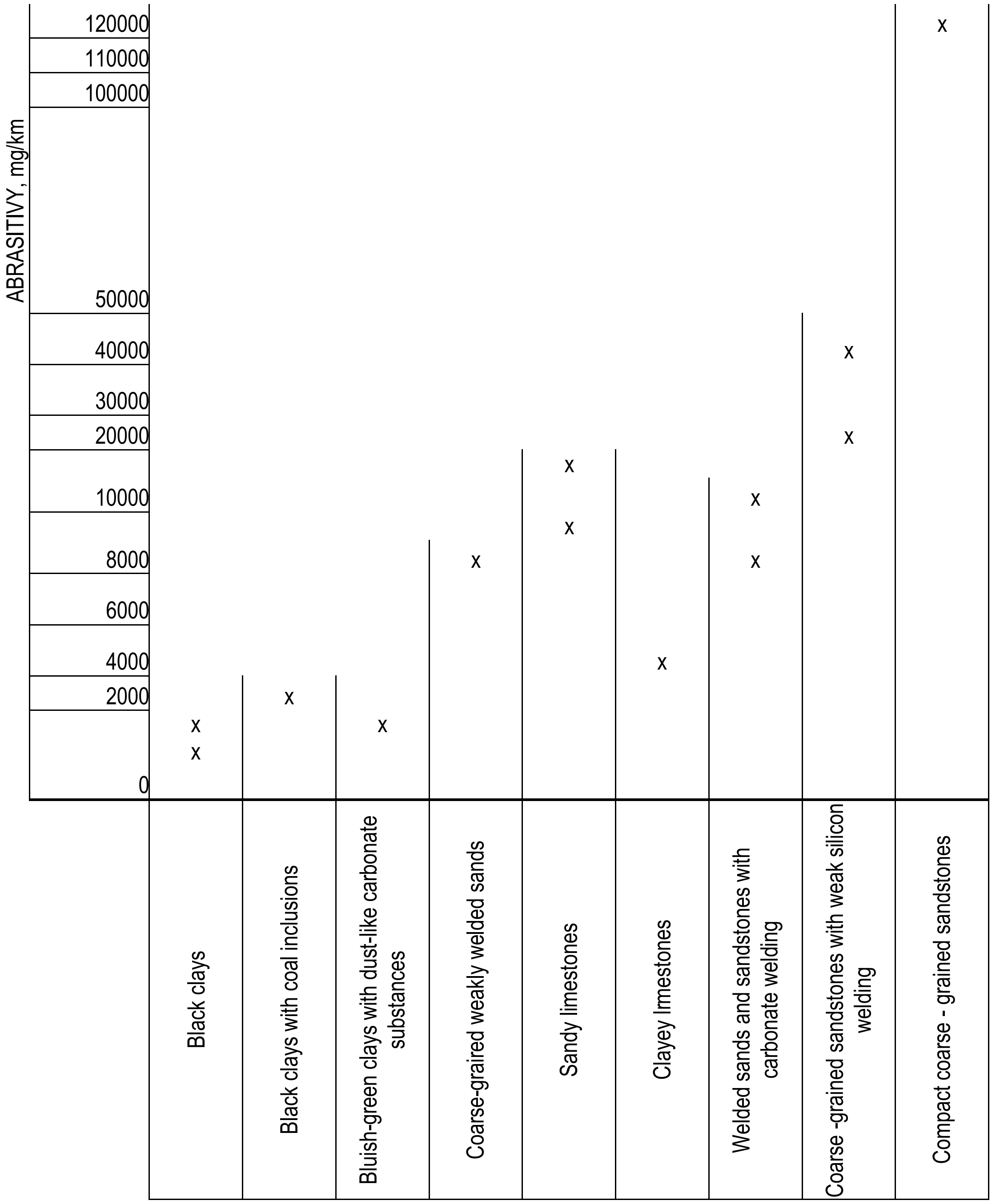


Figure 4.

The results of the tests carried out to determine the abrasivity of the different lithological varieties are summarised in Table 3. It can serve as a basis for a preliminary qualitative parameter in selecting the material for manufacturing bucket teeth and estimating their resistance capacities. Closely related to the latter is the rate of the bucket wheel motion (the excavator output, respectively) when cutting each coal web of the respective lithological variety.

Table 3



4. CONCLUSION

The relationships obtained between abrasivity and the natural moisture content, quartz and feldspar quantities in clays, sands and hard inclusions are of particular interest. They provide characteristics which can serve as criteria for the wear-and-tear of the BWE teeth and conveyor belts and can influence the technological process. The results presented have certain practical applications in:

- borehole explorations related to the annual planning of mining operations;

- predicting the overburden volumes for each subsequent year;

- geophysical exploration in zones of hard inclusion concentrations.

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