

ON THE CORRELATION OF CUTTING RESISTANCE AND PHYSICAL-MECHANICAL PROPERTIES OF LIGNITE AND OVERBURDEN ROCKS FROM OLTENIA COALFIELD

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1. THEORETICAL BACKGROUND

The performance of the excavation machines depends largely on the tool and overall machine characteristics, and on the other hand on physical mechanical characteristics of the excavated rock. There were more theories based on heuristic approach aiming to explain the main cutting parameters on the basis of basic physical mechanical properties of the excavated rock. The classical widespread parameters used by many researchers (mainly coming from rock mechanics community) are the unconfined compressive strength UCS, internal friction angle, cohesion, Brazilian test, hammer rebound, scratch test and point load indexes. In our opinion, all these parameters are intrinsic rock properties, ignoring the second element – cutting tool geometry, kinematics, shape, operating status a.s.o. so they are hard to characterize the main features related to excavation behavior of the given rock.

Despite this huge intellectual effort, spent to characterize intrinsic “cuttability” of rocks, the best results were obtained based on experimental data obtained on test rigs with as close as possible to real excavation conditions or in situ measurements performed on real working conditions. The argument that these measurements are more equipment and technology specific than excavated material specific remain a subject to debate.

Each manufacturer, for each particular coalfield has developed proper methodologies for data gathering and tricks for transferring these results towards excavating tool design and excavation process governing recommendations.

The most relevant source of information, i.e. the measurements performed in order to assess the forces acting on teeth of the bucket wheel excavator during the excavation process in real working conditions is difficult and expensive. The laboratory tests performed on the testing rig eliminates these disadvantages, even if they cannot reproduce all the conditions from the working place. Using full scale teeth for the laboratory tests is not possible, because that requires samples of large size impossible to be collected and manipulated. On the other hand, in order to satisfy the statistically reasonable number of samples, the amount of material used as samples would be very high and impossible to be collected.

By these reasons, both worldwide and in Romania the laboratory tests are performed using assay teeth at reduced scale, rationally selected, such as the results could be translated into reality.

An important problem is the transposition in reality of the measured forces in

laboratory using etalon teeth

In this respect, it is necessary to find out a few laws of dependence between the parameters of the cutting regime (specific energy consumption, specific cutting resistance) and the size of detached chips or particles.

One of the main parameters describing the excavation process is the specific cutting energy. According to Levent Ozdemir [2], based on more than 11000 cases of rock cutting using explosives and machines (roadheaders, TMB's, shearer loaders, drillers, etc.) drawn up a dependence of the specific energy consumption and the detached particle size. This dependence, of the specific energy consumption, E_s over the average dimension of detached material, d , are inside a band between two curves approaching an equilateral hyperbola energy, which is a metric of the excavation process energy-intensiveness.

In order to verify the similitude of the given curve and a hyperbola in the figure 1 we represented the function $E_s = f(d)$, transforming the units into SI ones, and using statistical data measured /collected relative to cutting machines using drag cutting principle. In the medallion is shown also the regressed equation describing the curve $E_s = f(d)$ such as:

$$E_s = 59,126 d^{-1,0718}, \text{ kWh/t} \quad (1)$$

As it can be seen the exponent is -1,0718, relative to -1, which characterize a quasi-equilateral hyperbola and so it results that the error of the curve is insignificant for any kind of rock detachment mode. On the other hand it results that the product of energy specific consumption and the size of particles (chips) resulted is a constant irrespective of the used procedure, i.e.:

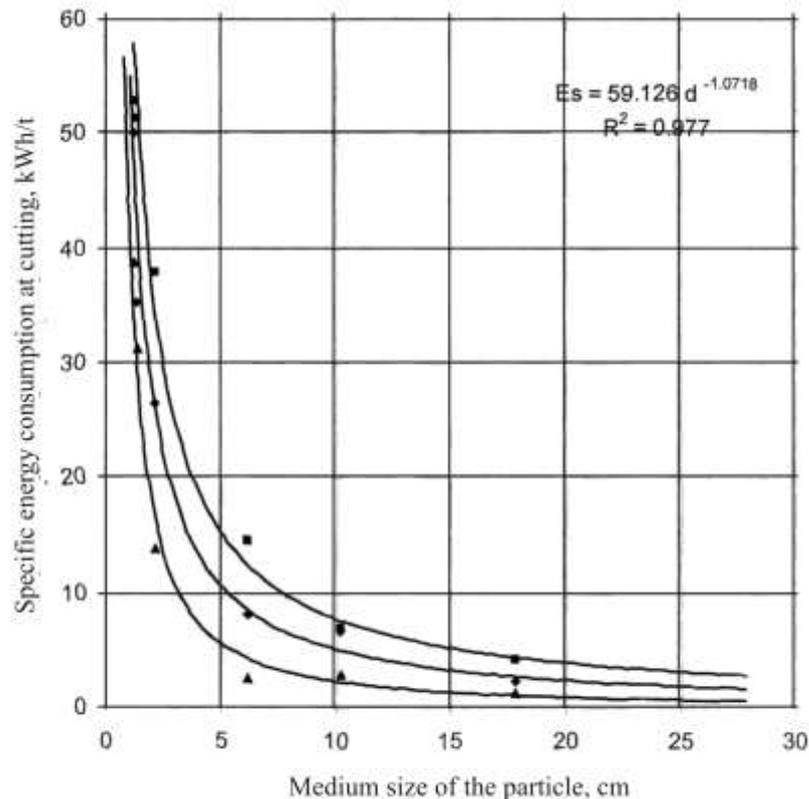


Fig. 1.
Specific energy consumption dependence by the medium size of the particle

$$E_s x d \cong \text{constant} \quad (2)$$

In the followings, we will demonstrate that for the transfer of the scale measurement data to real ones, an invariant parameter is needed, and we propose the so called specific cutting resistance.

As it is known, the specific energy consumption can be expressed as:

$$E_s = \frac{F_{xm}}{S_o}, \quad (3)$$

where $F_{xm} = Ah_o$ is the average cutting force, h_o the average depth of cut and S_o the cross section of the slice, which can be expressed:

$$S_o = k_f h_o^2 \quad (4)$$

or

$$S_o = k_f b h_o \quad (5)$$

where k_f is a shape coefficient of the slice and b is the width of the drag bit or drag tooth. .

On the other hand, the size of the rock chips resulted from the cutting process are :

$$d = k_{fr} \cdot h_i \quad (6)$$

where k_{fr} is a coefficient showing the capacity of self comminution of the rock (which can be related to the so called britleness).

Replacing (4) or (5) in (2) and considering (3) it results:

$$\frac{F_{xm}}{k_f h_o^2} \cdot k_{fr} h_o = \frac{F_{xm}}{h_o} \cdot \frac{k_{fr}}{k_f} = \text{ct.} \quad (7)$$

or

$$\frac{F_{xm}}{k_f b h_o} \cdot k_{fr} h_o = \frac{F_{xm}}{b} \cdot \frac{k_{fr}}{k_f} = \text{ct.} \quad (8)$$

We can notice that in the relation (6) the ratio $\frac{F_{xm}}{h_o} = A = \text{ct.}$, respectively from the relation (7) results $\frac{F_{xm}}{b} = A_1 = \text{ct.}$, which demonstrates that the specific cutting resistance (relative to the depth of cut or to the width of cutting edge) are constants which allow to calculate any value of force knowing the value of this invariant determined by experimental laboratory tests. That's for the experimental research has been focussed on the determination of these metrics.

2. LABORATORY TESTS



Figure 2
Experimental setup : a) testing rig; b) measuring device

At the laboratory of Mining Equipment of the University of Petrosani, fundamental research was performed for the determination of the cutting characteristics of coal and rocks at different mining fields of Romania

The experimental research were performed on a test rig presented in fig.2 a, and the data were recorded using a device, presented in fig. 2,b.

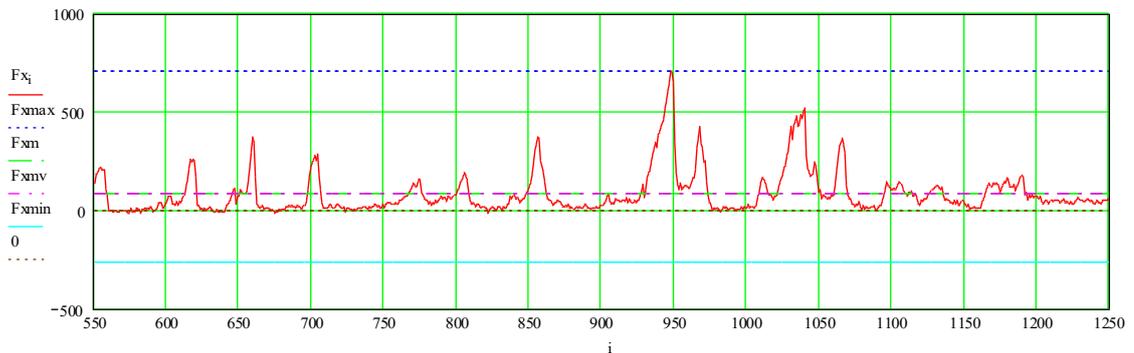


Fig. 3 Sample recorded diagram

Using this measuring device were recorded the diagrams of the variation in time of the cutting forces, F_x , penetration forces, F_y , and lateral forces, F_z , acting on the etalon teeth used during the experimental tests. A sample of recorded diagram for the force F_x is shown in fig. 3.

In the same time the volume of rock removed at each experiment was measured, in order to establish the chip slope angle ψ and the specific energy consumption.

Using the average values, the dependences between cutting force F_x and the depth of cut h_0 were plotted, as in fig. 4. With these values, for each location of collected samples and each type of assay tooth, the following characteristics can be determined:

- Specific cutting resistance of the lignite A relative to the depth of cut h_0 :

$$A = \frac{F_{xm}}{h_0}, \quad \text{N/cm} \quad (9)$$

- Specific cutting resistance of the lignite A_1 relative to the width of the cutting edge, b :

$$A_1 = \frac{F_{xm}}{b}, \quad \text{N/cm} \quad (10)$$

- Specific cutting resistance of the lignite K_e , relative to the cross section area of the slice, S_0 :

$$K_e = \frac{F_{xm}}{S_0}, \quad \text{N/cm}^2 \quad (11)$$

Tests were made on 20 lignite and 24 overburden rock samples (size 1mx1mx1m) collected among 8 open pit mines from Oltenia region, performing about 669 cut tests on lignite and 876 on overburden rock .

Three main categories of rock were identified regarding their behavior on cutting, i.e., lignite, clay, which is the „softest” overburden rock and sandstone, which is the most difficult to be excavated, in terms of hardness and abrasiveness.

The figures below depicts the comparison between these three kind of rocks, in terms of average cutting forces, F_{xm} , specific energy, E_s , and the chip section related specific cutting force, K_e .

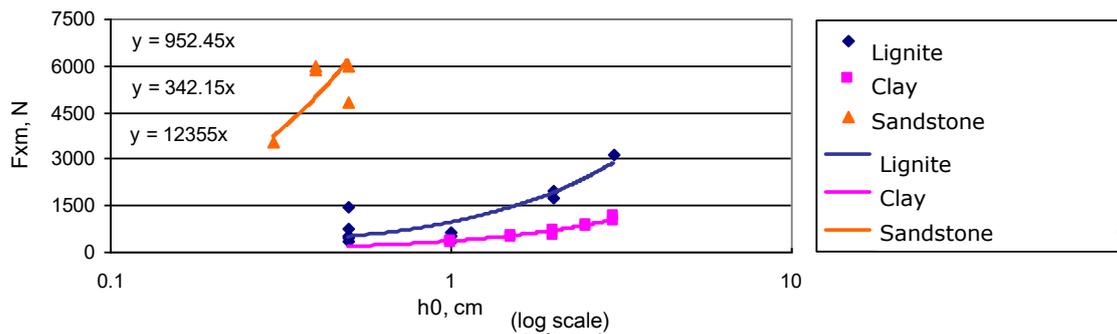


Fig. 4. Comparison upon F_{xm} as function of h_0 (x log scale)

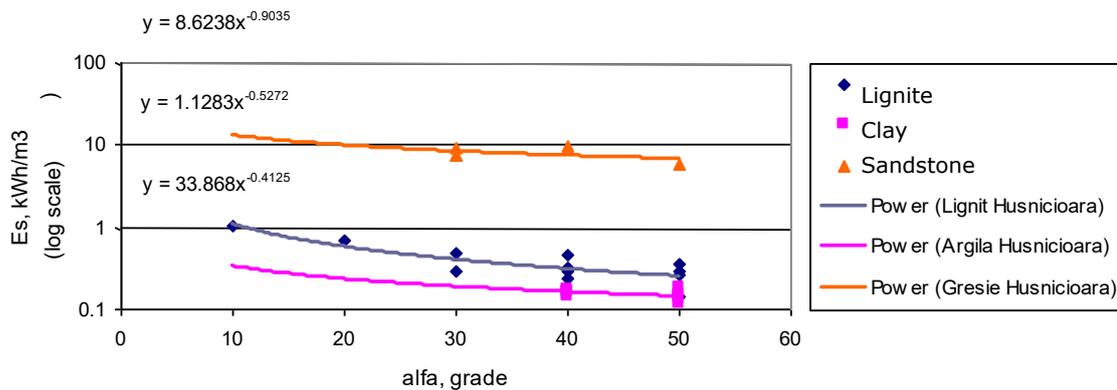


Fig. 5. Comparison upon E_s as function of α (v log scale)

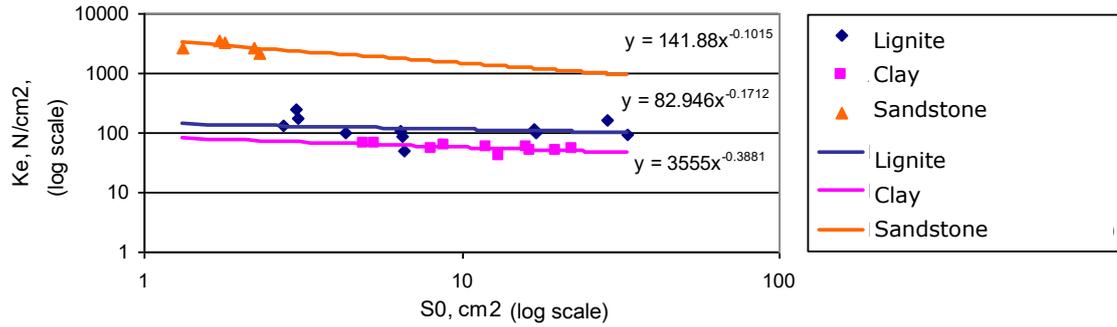


Fig.6 .
Comparison upon K_e as a function of S_0 (x , y log scales)

Considering that the differences between values are large, for an easier representation log scale was used on some axes.

In such way, the cutting force F_{xm} is 30 times larger in case of sandstone than in case of clay, and 15 times compared with the lignite.

The specific resistance K_e is 20 times larger in case of sandstone than the clay and 10 times compared with the lignite. The energy consumption , E_s it is 50 times larger compared with the clay and 25 times compared with the lignite.

It is useful to compare these results with those determined from the basic physical mechanical characteristics of the rocks using the classical theories of cutting .

In table 1, the average values for E_s , A and K_e , determined as before, are presented together with the basic physical mechanical properties, as coesion, C , internal friction angle, ϕ and unconfined compressive strength, σ_{rc} collected from literature, related to the same type of rocks.

Table 1 Main average data used for cuttability estimation

Rock type	σ_{rc} , MPa	C MPa	ϕ deg	A N/m	E_s MPa	K_e MPa
Clay	6	1	20	3.42	1.8	0.8
Lignite	12	2.5	30	9.52	3.6	1.6
Sandstone	27	4	10	120	50.4	7

Based on these values , using the least squares method, the following regression equations were derived :

$$E_s = 0.85830681 \sigma_{rc}^{2.162328} C^{-0.413209357} \phi^{-1.04675}$$

$$A = 3.72432675 \sigma_{rc}^{1.592777} C^{0.348245478} \phi^{-0.98134}$$

In the figure 7, the results obtained with above formulas and a simple regression curve are represented, showing the dependence of specific energy E_s with respect to σ_{rc} . The same for specific cutting resistance A is presented in fig . 8.

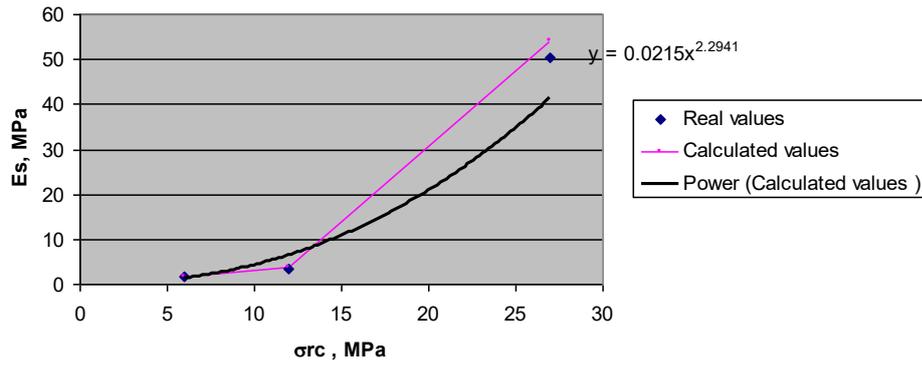


Fig. 7
Dependence of E_s with respect to σ_{rc}

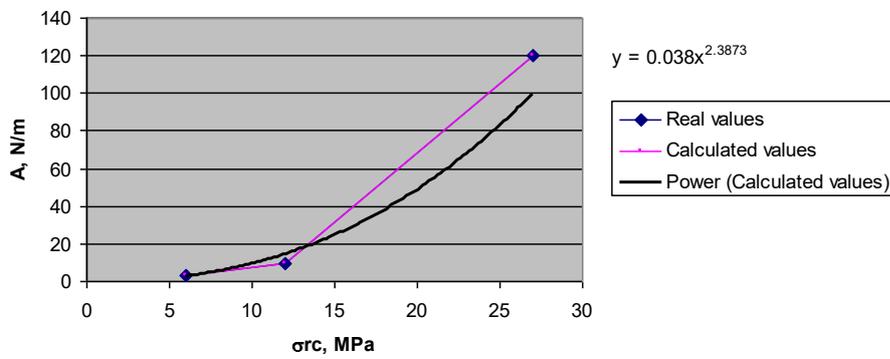


Fig. 8 Dependence of A with respect to σ_{rc}

The analogue dependences of E_s and A in respect to cohesion C are presented in figures 9 and 10.

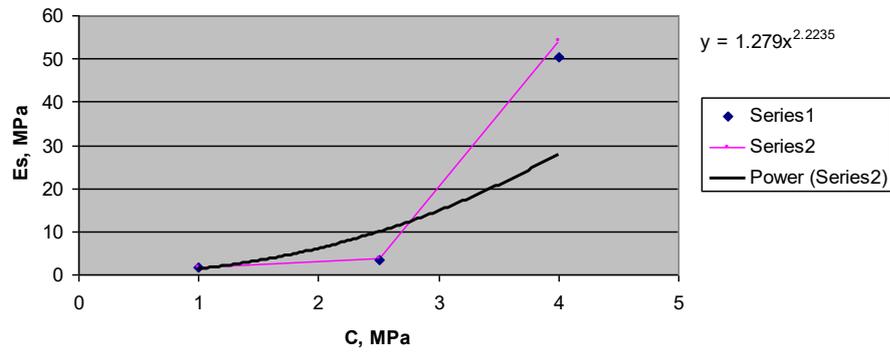


Fig. 9 Dependence of E_s with respect to C

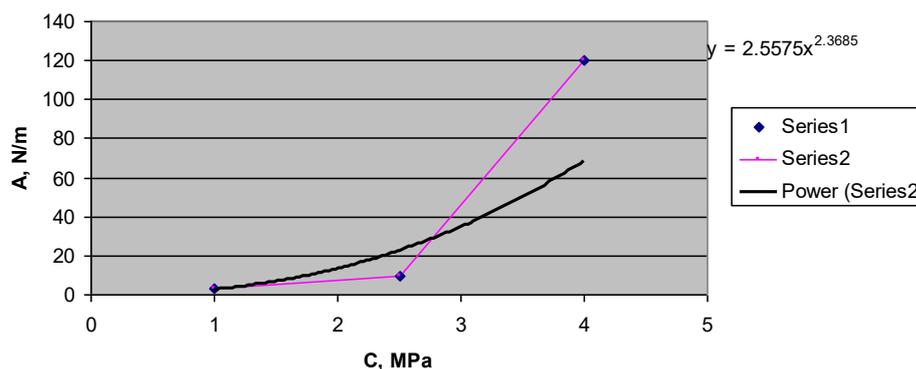


Fig. 10 Dependence of A with respect to C

Conclusion

In order to determine experimentally the cutting characteristic for sterile rocks and lignite, laboratory tests were conducted on a testing rig.

The possibility of the application with exactness of physical modeling and geometric similitude for the case of studying the cutting characteristics of rocks and lignite in quarries was demonstrated, in order to translate the laboratory results to real life by the use of regression relations.

Using this methodology, based on reliable laboratory data, it is possible to use correlation and regression formulas to predict the cuttability parameters of rock, as cutting specific resistance and specific energy consumption starting from basic physical-mechanical properties of rocks.

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