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RESEARCH REGARDING THE LIGNITE AND ROCK EXCAVATION USING BUCKET WHEEL EXCAVATORS

***I.Kovacs*[1], *M.S. Nan*[2], *I. Andras*[3],**
[1,2,3]Professor Eng. PhD.,
University of Petrosani, Romania, Str.Universitatii, nr.20

***Abstract**: In this paper the results of experimental and theoretic research regarding the phenomena occurring in the rock and lignite cutting using bucket wheel excavator are presented. The invariant character of the specific cutting resistance is demonstrated, and the translation of laboratory test results at real scale is presented and exemplified on a concrete case.*

1. Theoretical background

The measurements preformed 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.

According to *Levent Ozdemir*[4], 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 .

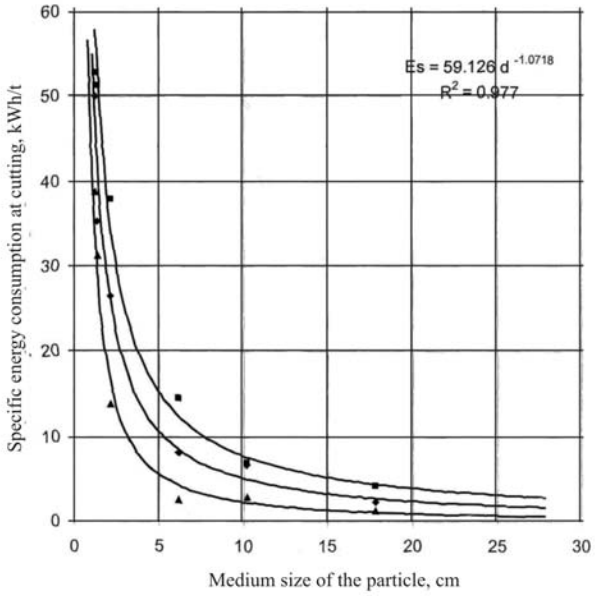

Fig. 1. Specific energy consumption dependence by the average size of the particle

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 anglo-saxon 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:

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

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 unsignificative 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.:

$$E_s x\ d \cong \text{constant} \tag{2}$$

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

$$E_s = \frac{F_{xm}}{S_o}, \tag{3}$$

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

$$S_o = k_f h_o^2 \tag{4}$$

or

$$S_o = k_f b h_o \tag{5}$$

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

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

$$d = k_{fr} \cdot h_i \tag{6}$$

where k_{fr} is a coefficient showing the capacity of self comminution of the rock.

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

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

or

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

We can notice that in the relation (6) the ratio $\frac{F_{xm}}{h_o} = A = \text{ct.}$, respectivelly from the relation (7) results $\frac{F_{xm}}{b} = A_1 = \text{ct.}$, which demonstartes that the speciffic cutting resistance (relative to the depht of cut or to the width of cutting edge) is constant which allow to calculate any value of force knowing the value of this invariant determined by experimental laboratory tests.

2.Laboratory tests

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.

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 disagram for the force Fx is shown in fig. 3.

a) b)

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

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 Fx and the depth of cut ho were plotted , as in fig. 4. With these values, for each location of colected samoples and each type of assay tooth, the following characteristics can be determined:

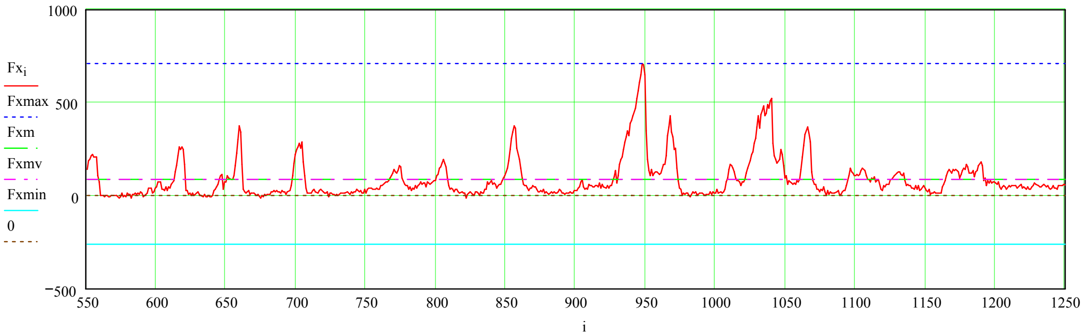

Fig. 3 Sample recorded diagram

- Speciffic cuting resistence of the lignite A relative to the depth of cut h_0 :

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

- Speciffic cuting resistence of the lignite A_1 relative to the width of the cutting edge, b:

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

- Speciffic cuting resistence of the lignite K_e , relative to the cross section area of the slice, S_o:

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

3. Translating experimantal results for real working conditions using analogy

In order to determine the value of the forces in real conditions, on the basis of dependences previously mentioned we can apply the laws of similitude. We note F'_{xm} the average real force for a tooth with a width b', relative to the value of the force F_{xm} established by laboratory test for an etalon tooth with width $b = 4$ cm and taking into account the relations defining the three variants of the specific resistance we can calculate the real forces as follows:

$$F'_{xm} = \frac{Ah'_0}{b} b' \quad , \qquad \text{N} \qquad (12)$$

$$F'_{xm} = A_1 b' \frac{h_0'}{h_0} \quad , \qquad \text{N} \qquad (13)$$

$$F'_{xm} = K_e S'_0 \qquad \text{N} \qquad (14)$$

where h'_0 and S'_0 represents the width respectively the cross section of the real slice in the studied case.

The mean values of the peaks F'_{xmv} and maximal forces F'_{xmax} , in the real case can be calculated with relations resulted from (8); (9) and (10), as follows:

$$F'_{xmv} = \frac{Ah'_0}{b} b' k_v , \qquad \text{N} \qquad (15)$$

$$F'_{xmv} = A_1 b' \frac{h'_0}{h_0} k_v \,, \qquad \text{N} \qquad (16)$$

$$F'_{xmv} = K_e S'_0 \, k_v \,, \qquad \text{N} \qquad (17)$$

respectively:

$$F'_{x\max} = \frac{Ah'_0}{b} b' k_d \,, \qquad \text{N} \qquad (18)$$

$$F'_{x\max} = A_1 b' \frac{h'_0}{h_0} k_d \,, \qquad \text{N} \qquad (19)$$

$$F'_{x\max} = k_e S'_0 \, k_d \,, \qquad \text{N} \qquad (20)$$

All the relations are referring to the calculus of forces for new tooth. In case of worn teeth, these values are corrected by a wear coefficient k_{uz} , $k_{uz} \geq 1$, according to the degree of wear. For new teeth $k_{uz} = 1$, for normally worn teeth $k_{uz} = 1{,}2\ldots1{,}5$, and for very worn teeth $k_{uz} \geq 1{,}5$. The exact values can be assessed by experimental testing.

For each of the values of the real forces we can write:

$$F''_{xm} = F'_{xm} \; k_{uz}, \qquad \text{N} \qquad (21)$$

$$F''_{xmv} = F'_{xm} \; k_{uz}, \qquad \text{N} \qquad (22)$$

$$F''_{xmax} = F'_{xmax} \, k_{uz} \quad , \qquad \text{N} \qquad (23)$$

where F'_{xm}, F''_{xmv}, F''_{xmax} represents the values of the cutting force for a certain degree of wear.

In order to exemplify the switching from laboratory testing results to the most probable values for a given real case, a tooth whit the attack angle $\alpha = 50^0$ was chosen, the etalon tooth having a width b = 4 cm, and the real teeth having a width b' = 12 cm.

Table 1.

Tooth type	F, kN / k_{uz}	În lab. conditions			In real working conditions					
		F_{xm}	F_{xmv}	F_{xmax}	F'_{xm}	F'_{xmv}	F'_{xmax}	F''_{xm}	F''_{xmv}	F''_{xmax}
New	1	2,3	2,2	17	35,3	33,9	26,5	-	-	-
Normally worn	1,2	2,7	2,6	20,5	-	-	-	42,4	40,7	31,8
	1,5	3,4	3,3	25,6	-	-	-	53	50,9	39,7
Heavily worn	2,0	4,5	4,4	34,1	-	-	-	70,7	67,9	53
	2,5	5,7	5,5	42,7	-	-	-	88,4	84,8	66,2

Choosing as real example the classic bucket wheel excavator, E_sR_c- 1400 $\frac{30}{7}$ 630, with teeth parameters as shown previously and the thickness of the slice dislocated by a bucket between 0,3…0,5 m we have the resulting real thickness of the chip cut by one tooth to have a medium value of h'_0 = 15 cm.

Based on the most probable tearing angle of the chips form the massif $\psi = 65^0$, results a surface of the transversal chip section of $S'_0 = 662{,}5$ cm^2.

Based on these data and applying the equations (8)…(19), the most probable values for the forces acting on a tooth of the bucket wheel excavator in the excavating process results, according to table 1.

The values of F_{xm} and F'_{xm} are the arithmetic media of the values obtained after A, A_1 şi K_e, respectively F_{xm}= 2370 N; 2360 N and 2090 N, and F'_{xm} = 35.550 N; 35.400 N, and 35.112 N.

Conclusion

The specific cutting resistance is the invariant factor which can connect the data obtained by laboratory tests on samples to the parameters of a real cutting equipment.

In case of bucket wheel excavators, the laboratory test can be performed only using scale reduced teeth taking into account the similarity laws.

Based on observation in a large number of experimental and field studies performed earlier, the invariant character of specific cutting resistance can be proved. This fact opens the way to use results of laboratory tests in real machine design.

In order tot determine experimentally the cutting characteristic for sterile rocks and lignite, laboratory test were chosen and conducted and the requirements imposed to the testing stand, tensometric dynamometer, measuring, amplification and recording equipment were defined

In order to conduct experimental researches the working methodology, sorting and valuation of experimental data was funded. The possibility of the application with exactness of physical modeling and geometrical similarity for the case of studying the cutting characteristics of rocks and lignite in quarries was demonstrated, in order translate the laboratory results to real life by the use of linear relations.

The example presented demonstrates the correctness of the assumption in using laboratory test data to calculate cutting parameters of bucket wheel excavators used in lignite open pits of Romanian lignite mining fields.

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