LABORATORY METHOD USED FOR DETERMINING OF THE CHARACTERISTICS OF THE CUTTING SOFT ROCK

SORIN MIHĂILESCU[1], GABRIEL PRAPORGESCU[2]

Abstract: Laboratory methods have the advantage of high precision measurement, and for determining a number of parameters. In addition, it can make a sufficiently high number of attempts to provide an acceptable accuracy in the determination of the parameters with a random variation, such as rock cutting.

Keywords: rock cutting, laboratory method

1. INTRODUCTION

Research regarding the mechanical cutting of rocks and coal, as non-homogenous and non-isotropic materials, can be split in three categories:

- Research on the cutting phenomenon;
- Research on determining the cutting specific resistance and the forces which influence the cutting instrument;
- Research on the geometry of the cutting instruments.
- This research can be done as follows:
- Theoretically;
- Experimentally, in lab conditions;
- Experimentally, on site conditions.

The clean theoretical study of the cutting phenomenon for rocks does not allow the exact determination of the parameters that characterize the cutting and their interdependence, sometimes leading to wrong results, [1], [3], [5], [6]. Therefore, it is necessary for these studies to be combined with experimental research methods.

Regarding the experimental research in lab conditions, since in practice the simplified hypothesis from rock mechanics aren't accepted and thus there isn't an analytical study methodology accurate enough for determining the cutting

[1] *Assoc. Prof., PhD, Eng., University of Petroşani, , mihailescus@gmail.com*
[2] *Assoc. Prof., PhD, Eng., University of Petroşani, gpraporgescu@gmail.com*

characteristics of rocks and coal, their precise determination is done only through experiments. These tests can be effectuated in lab conditions on deposit samples or through direct experiments on work site conditions, [7], [8].

Experimental tests effectuated on work site conditions have the advantage of being performed directly on the deposit, but, due to the difficult conditions from the work front, they cannot be precise enough and they only allow the determination of a limited number of parameters. The use of experimental methods on work site conditions is costly, as it requires expensive equipment and qualified staff, and sometimes it requires the work to be stopped, [2], [4].

Establishing the characteristics on mechanical cutting of the rocks, as it takes place in case of excavators, combines, cutting machines, etc., is an important problem that can be used to understand the rock dislocation phenomenon, the interdependence regularities between the geometric and technologic parameters of the cutting installations, the cut splinter parameters and the cutting process parameters.

Their experimental determination in lab conditions mainly refers to measuring, direct or indirect registration of the following values:

- Cutting force F_x;
- Penetration force F_y;
- Lateral (rotation) force F_z;
- Cutting specific resistance K_e;
- Splinter breaking angle ψ;
- Specific energy consumption E_S;
- Cutting power needed P;
- Energy consumption for a given period E, etc.

The knowledge of these parameters and their interdependence allows the modernization of the cutting part of rotor excavators based on a scientific approach, eliminating the relative and costly empiricism.

2. ABOUT SAMPLING, PRESERVATION AND PREPARATION OF SAMPLES

The sampling for lab experiments has raised issues related to the sampling place to obtain a relevant specimen, to the sampling method of various rocks from the massif, the preparation of the extracted blocks for obtaining the experiment samples, the specimen manipulation, preservation and fixing in special designed boxes.

Every unit established the sampling place based on the documentation elaborated together with the management and the geological service.

The sample preparation will be extracting relatively large blocks (4-5 times the specimen volume), from which the specimens were obtained by manual modeling in order to avoid additional cracking. The block will be extracted, either manually, either by using single bucket excavators.

To exemplify, figures 1, 2, 3 and 4 present the four phases for sampling-preservation and attachment of specimens as follows: block extraction, specimen modeling, preservation by waxing and the specimen fixed in the box.

Fig. 1. Extracted block for specimen modeling

Fig. 2. Specimen modeling

Fig. 3. Specimen preservation by waxing

Fig. 4. Specimen preserved and fixed in the box

3. SAMPLE STAND FINISHING AND PREPARATION

The stand for mechanical cutting experiments for non-homogenous materials was done based on a project of the Mining Machines and Installations Lab from the University of Petroşani. Thus, figure 5 presents the stand overview where we observe: the experiment machine, the sample fixing device on the machine table, the rock sample fixed in a wooden box and the strain dynamometer attached to the data measurement and registration installation.

In a different room inside the protection screen, there are the electrical energy general supply boards and the data recording installation, needed to record and process the data obtained during the experiments. Figure 6 presents this installation, based on a strain bridge, the analogue-digital conversion board, the computer and its monitor.

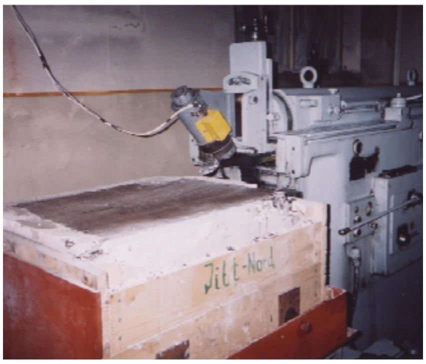

Fig. 5. Test stand

Fig. 6. Data recording and processing installation

4. LAB EXPERIMENTS DEVELOPMENT

On the sample stand presented above there can take place experiments on sampled specimens for determining the rock cutting characteristics.

Each rock that will be object to the experiment must be placed on the experimental installation board through the fixing device. Figure 5 presents a specimen fixed in the device right before the experiment. We notice that opposite to the strain dynamometer the sample is front supported by a metal slab that is changed as the height of the sample decreases due to surface cuts.

Initially, the upper surface of the sample is leveled by cutting, removing the gypsum, paraffin and the upper lignite layer. Figure 5 presents a sample after these operations.

For performing a cutting experiment, the strain dynamometer is provided with the needed standard tooth, its edge being positioned next to the sample margin (or adjacent cut) at the depth of the experiment. Figure 7 presents in fact the cutting experiment, done after the data measurement, recording and processing installation is activated and verified.

The experiments are performed with 5 standard teeth at cutting depths of 1...5 cm in order to have enough information on the cutting behavior of the rocks. Figure 7 presents an experiment performed at cutting depth h_0 = 2 cm.

The deployed mass is removed after cutting from the sample surface, the volume of the deployed mass being determined using the plasticine mold method (figure 8). The volume of every mold is determined by observing a beaker filled with water where the mold is sank. After the possible number of cuts on the sample surface is performed, this needs to be leveled again, and the procedure presented above is repeated. On the same leveled surface there are performed adjacent experiments with the same cutting depth in order to use less samples.

Every experiment is encoded in order to ease the computer data processing. The experiment code mentions: the open pit name, the rock layer, the standard tooth type, the cutting depth and the experiment number.

Fig. 7. Performing an experiment

Fig. 8. Plasticine mold cutting

5. EXPERIMENTAL DETERMINATION OF F_x CUTTING FORCE, F_y PENETRATION FORCE, F_z LATERAL FORCE AND OF THE SPLINTER BREAKING ANGLE ψ

The F_x cutting force is tangential to trajectory of the tooth from the excavator bucket, has random variation, takes only positive values, meaning it opposes the movement of the tooth in the massif and has the highest absolute values among the components of the resultant force influencing a tooth in a certain relative position to the rock massif.

The measurement installation registers in time, during the installation, the variation of this force together with the other two components.

Figure 9 presents a principle diagram with the variation in time of the cutting force F_x. On the diagram there are noted: maximum value F_{xmax} of the peak forces, corresponding to the maximum height h_{max}, in mm, average value F_{xmv} of the peaks, corresponding to the height h_{mv}, in mm, and the real average value F_{xm}, corresponding to the average height h_m, in mm. The moment of cutting start t_1, in s, corresponding to the diagram length l_1, in mm and the moment of cutting determination t_2, in s, corresponding to the diagram length l_2, in mm, are noted on x-axis while Ω_x, in mm^2, represents the value of the area between the variation curve of F_x and the time section in the interval $t_1...t_2$.

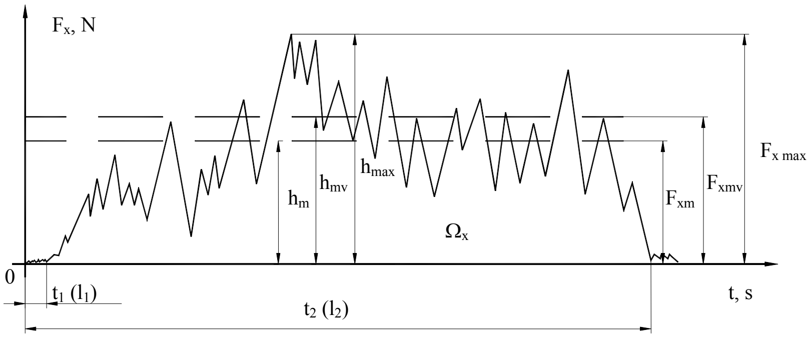

Fig. 9. F_x variation diagram

The penetration force F_y acts normal to the trajectory of the tooth from excavator bucket, has random variation, takes positive values (as it opposes to the penetration of the tooth in the massif) and negative values (as it helps the penetration of the tooth in the massif when pushing the splinter to the clearance surface of the tooth).

Figure 10 presents a principle diagram of the variation in time of the penetration force F_y, being noted the moments t_1 and t_2, respectively the lengths l_1 and l_2, the value of the forces F_{ymax} and F_{ymin}, corresponding to the diagram height h_{max} and h_{min} and Ω_y – the surface of the diagram $F_y = f(t)$.

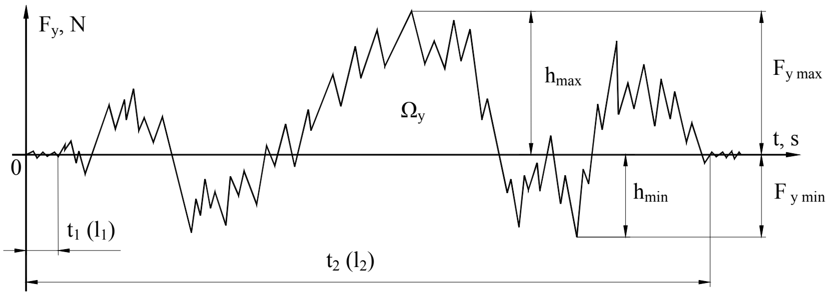

Fig. 10. F_y variation diagram

In practice the ratio, k_y is used to explain easier the penetration forces F_y, whom variation is directly related to the variation of the forces F_x. The k_y is defined by the relation:

$$k_y = Med\left(\frac{F_y}{F_x}\right). \tag{1}$$

Knowing the ratio k_y and the variation of the forces F_x we can estimate the variation of the forces F_y, diminishing the data volume needed to characterize the mechanical rock cutting phenomenon using the forces F_y.

The lateral force F_z acts binormal to the trajectory presented by the tooth top from the excavator bucket, have random variation, is opposite to the rotor pivoting speed v_p, working either from left to right (positive conventional direction) or from right to left (negative conventional direction).

Figure 11 presents a principle diagram for the time variation of the lateral force F_z, being noted the moments t_1 and t_2, respectively the lengths l_1 and l_2, the value of the forces F_{zmax} and F_{zmin}, corresponding to the diagram height h_{max} and h_{min} and and Ω_z – the surface of the diagram $F_z = f(t)$.

Lab experiments are needed to highlight the variation of lateral forces, due to the pivoting movement of the rotor, when the sample is moved laterally with the speed v_p, together with the movement of the standard tooth with the cutting speed v_t. The chart of the cutting experiments with two movements is presented in figure 12, where are noted: tooth cutting speed v_t, sample lateral movement speed v_p, cutting base width b, cutting length L, lateral force F_z and the leaning angle of the trajectory φ by the speed direction v_t.

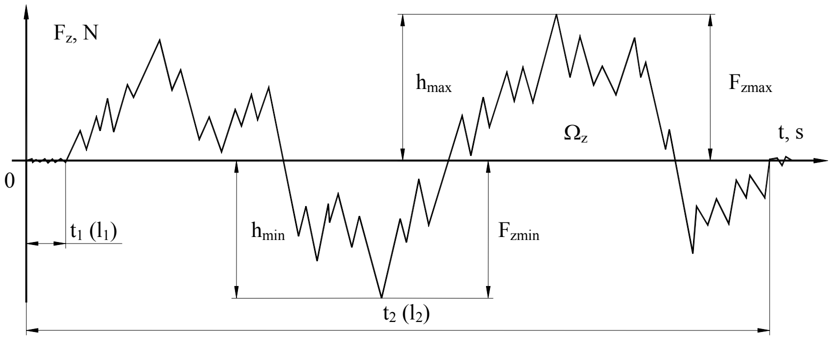

Fig. 11. F_z variation diagram

The ratio v_t/v_p from lab experiments needs to be close to the true value for the most used excavators, in order to ensure the similarity with the front dislocation of rocks.

In practice, the ratio k_z is used to explain easier the lateral forces F_z, whom variation is directly related to the variation of the forces F_x. The ratio k_z is defined by the formula:

$$k_z = Med\left(\frac{F_z}{F_x}\right). \qquad (2)$$

Non-homogeneous materials are detached from the massif by a certain breaking angle and not by the cutting instrument profile. Noting ψ this breaking angle, as it shows in figure 12, the value ψ = 20...80° for different materials and work conditions.

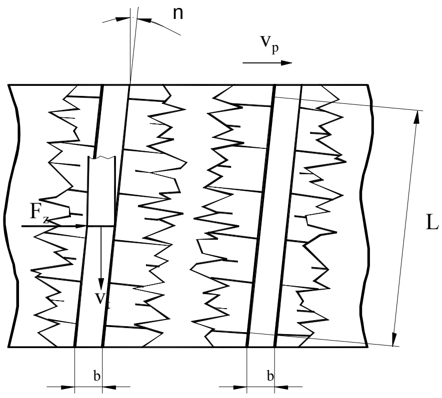

Fig. 12. Chart of the cutting experiment with two movements v_t and v_p

It is important to determine the most probable value of the angle ψ as it influences the value of the transversal surface of the splinter, the volume of material detached from the massif and, consequently, the cutting specific energy consumption. Moreover, it virtually defines the distance and the placement position of the teeth on the excavator bucket.

The splinter breaking angle ψ has also a random variation, like the other values characteristic to rock cutting. This is why the experiments reveal the average value with the most probability to appear in use.

Therefore, it is determined the transversal section surface of the detached splinters (of the cut) with the relation:

$$S_0 = \frac{V}{L}, \text{cm}^2 \tag{3}$$

where V is the volume, in cm^3, and L the length of the considered cut, in cm (Fig. 13), practically determined with the plasticine mold method.

Having the S_0 values, the splinter breaking angle ψ is calculated with the formula:

$$\psi = arctg\left[\frac{S_0}{h_0^2} - \frac{b}{h_0}\right] \tag{4}$$

where the significance of the values is the same as in figure 13.

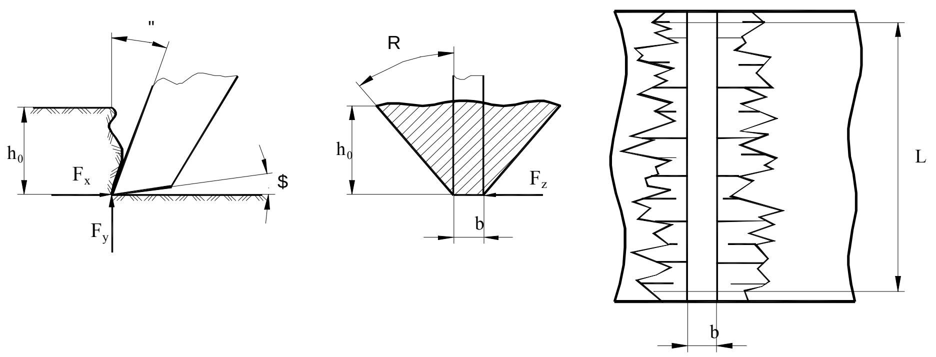

Fig. 13. ψ breaking angle determination

6. EXPERIMENTAL DATA PROCESSING

Data resulted from measurements were recorded in text files, three for each measurement, corresponding to the three measured components, F_x, F_y, F_z. The file names were coded with a letter representing the open-pit, a number representing the number of the measurement and the letter x, y, z corresponding to the determined component.

An application in MATHCAD was developed for basic data processing, with the following features:

- File data reading and assigning to the three variables, F_x, F_y, F_z;
- Value displaying, in natural values (mV where they were recorded);
- Correction (to the value zero), considering that the reference value is not zero;
- Data visualization, on three windows, for the entire measurement scale (2000 values, with intervals of 1,5 ms);
- Scale value correction, to get daN values (using the scale values from dynamometer calibration);
- Manual selection of the interval limits for the relevant values of the measurements and their assignment to „left” and „right” values
- Determination of the minimum, maximum and average values of the three components;
- Determination of the peak number and values;
- Determination of the peaks average, F_{mv}, of the average, minimum and maximum values of the three components on the relevant area of measurement and their visualization;
- For the components *y* and *z* which can take positive and negative values, the average value and the peaks average value were determined both for the negative and positive values and for the global values (positive or negative);
- Calculation and display of the empirical histograms for the values of the three measured components;
- Recording a coded name file with the values resulted from the determinations, together with the identification data of the measurements for further data processing using the Excel program.

The variation regularities of the cutting forces depending on the cutting depth and on the teeth clearance angle resulted from the experiments on samples using the experimental data processing methodology (fig. 14).

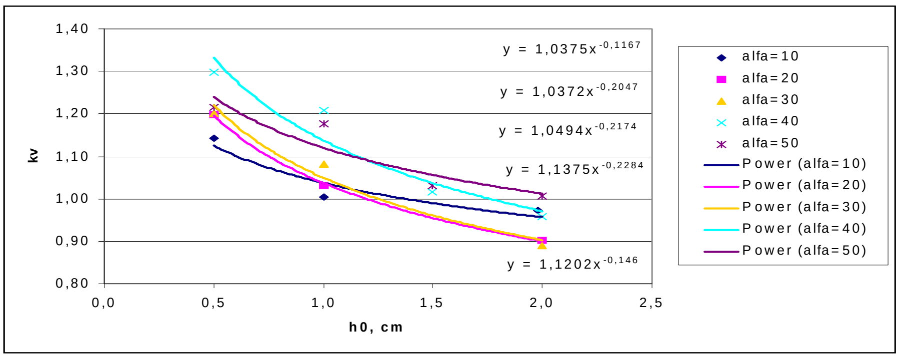

Fig. 14. The variation coefficient dependency of the average k_v, on the cutting depth h_0, for different α values

7. CONCLUSIONS

From the above presented, the following conclusions are drawn:

- The parameters which characterize the rock cutting process have a random variation in time and their interdependence regularities can only be determined experimentally, not theoretical;
- The determination of rock cutting characteristics can be done by lab experiments on samples from the rock massif;
- Sampling and sample preservation requires a strict working methodology and techniques for this process;
- Experiments in lab conditions requires an experimental stand with installations for data measurement, recording and processing;
- The test stand and the installation for data measurement, recording and processing needs to be prepared carefully, calibrated and verified correctly, and these procedures have to be repeated periodically during the experiments in order to ensure the attainment of precise and correct data;
- Experimental tests in the laboratory are not limited possibility of repetition, are accurate, cost effective and are recommended especially for comparative studies.

REFERENCES

[1]. **Beron, A.J., Kazanski, A.S., Leibov, B.M., Pozin, E.Z.,** *Rezanie uglia Gasudarstvennoe Naucino-Tehniceskoe Izdatelstvo Literaturâ pa gornomu delu.* Moscova, 1962.

[2]. **Durst, W., Vogt, W.**, Schaufelrad Bagger Trans Tech Publications, 1986.

[3]. **Evans, I.,** *Line spacing of picks for effective cutting*. Int. J.Rock Mech. Mining Sci.Vol.9.pp.355-361. Pergamon Press 1972.

[4]. **Kovacs, I., Zoller, C.L., Ridzi, M.C., Nan, M.S., Mihăilescu, S.,** *An installation for in situ measuring and recording of forces that act upon the cutting device teeth of the rocks detachment machine* (in romanian), BI nr. 123483/30.12.2012,

[5]. **Lebrun, M.,** *Étude théorique et experimentale de l'abattage mecanique. Application á la conception de machines d'abattage et de creusement (these de doctorat)*, École National Supérieeur des Mines de Paris, 1978.

[6]. **Nishimatsu,Y.,** *The mechanics of rock cutting*. Int. J. Rock Mech.Min.Sci. Vol.9-pp.261-270. Pergamon Press 1972.

[7]. ***, Contract no. 6/2002, *Study on the waste rock mechanical cutting behavior from overburden layers of coal and lignite open pits of CNL "Oltenia" in order to increase technical and economic performance of extraction with rotor excavators* (in romanian), settled between the University of Petroşani and CNL "Oltenia" Târgu Jiu.

[8]. ***, Contract no. 1/2006, *Theoretical and experimental research on increasing the degree of excavation machines usage in lignite open pits of S.C. Energy Complex Turceni S.A.* (in romanian), settled between University of Petroşani and S.C. Energy Complex Turceni S.A.