THE INFLUENCE OF ROCK PROPERTIES ON THE WEAR OF MINING TOOLS FOR ROTATING DRILLING

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ABSTRACT

Taking into account the advantages of the rotating drilling versus the percussive one, it is necessary to manufacture removable drilling bits for rotating drilling in hard rocks. The actual level of the knowledge regarding the rock cutting does not allow an adequate mathematical description of the interaction between the tool and the rock in case of rotating drilling. In conclusion the experimental tests represent the main means used for the assessment of the possibilities to perform constructive modifications of the tools or appropriate drill hammer design. In the paper the results of the tests performed on a testing rig regarding the rotating drilling are presented.

KEYWORDS: rotating drilling bit, wear of drilling tools.

1. GENERALITIES

Blast hole drilling is performed using drill hammers by means of three methods: rotating, percussive and rotating-percussive. These methods are different one which other by the mode of acting of the tool and the rock’s detachment. The tools used for drilling are the drill rods. They consist in the drill bit, the rod and the end. The drill bits can be mono-blocks, or detachable ones. The last one type is the more used in practice.

The rotating drilling of blast holes is performed using carbide plate armored detachable drill bits. Generally were realized several types of such tools both for drilling in coal and in sterile rocks, with hardness until average. In Romania is standardized and is produced in large scale only one type of detachable drill bit, i.e. the bit CR (STAS 7476-90), devoted exclusively to the drilling in coal or soft rocks.

Taking into account the advantages of the rotating drilling versus the percussive one, the advance rate 3-4 times greater, possibility to use the electric, pneumatic or hydraulic actuation, more reduced dust generation, perspectives of increasing the advance rate, it is necessary to begin the manufacturing detachable bits for drilling in harder rocks.

The application field of the rotating drilling is limited to the range from soft to medium hardness rocks, corresponding to compression strength less than 80MPa. The power consumption to rotate the rod when we drill medium and hard rocks can be obtained by electric or electro hydraulic actuation of the drill hammers. Regarding the advance force, it can be developed easily by using the recently developed drilling jumbos. However, some technical problems regarding the wear of the tools in hard rocks were not solved in a satisfactory manner.

The reduction of the wear of drilling tools can be realized by using better materials to manufacture the bits, the improvement of the geometry of cutting edges, improvement of wedge sharpening, or adequate selection of the drilling regime parameter’s for different rocks.

The actual level of knowledge regarding the rock detachment by splintering does not allow a complete mathematical description of the rock-tool interaction at rotating drilling. By consequence the experimental research is the main way to assess the possibilities to apply some constructive modifications of the drilling tools or for dimensioning the drill hammers.

2. TOOLS FOR ROTATING DRILLING

The tools for rotating drilling of blast holes are the drill rods for coal, drill rods for coal and soft rock, drill rods for hard rock. In Romania only one kind of detachable drill bit with carbide plates devoted to the rotating drilling of blast holes in coal for diameters of 35 and 45 mm. are standardized. In the figure 1 such a drilling bit is presented.

Taking into account the advantages of rotating drilling related to the percussive one, such as 3-4 times higher advance rate, possibility of use different kind of energy for actuating the driller, reduction of the amount of dust, better perspectives of increasing the advance rate, the improvement of the domestic drilling tools is needed in such a manner, that they cover the whole range of holes to be drilled in many kind of rocks, from soft to medium hard rocks.
The drilling bit (fig. 2) consist in the body a, the end, b and two wings, c on which the carbide plates are pasted, each wing being a separate cutting tool.

The active part of the tool consist in the rake face 1 on which the rock chips are sliding during the drilling and the main setting face 2, oriented always towards the cutting face C-D, the secondary setting face 3, oriented towards the core of rock and the lateral setting face 4, which has a small conical shape for the exhaust of detritus. The mentioned faces generates the main wedge 5 and the secondary wedge 6, and the intersect of the two wedges, the peak of the tool 7. The lateral wedge is not participating to cutting; its role is only to push out the formed chips.

In the constructive-functional reference system (fig. 2) we have: \( \alpha \) – main clearance angle; \( \beta \) – main wedge angle; \( \gamma \) – main rake angle \((\alpha + \beta + \gamma = 90^\circ)\); \( \alpha_1 \) – secondary clearance angle; \( \beta_1 \) – secondary wedge angle; \( \gamma_1 \) – secondary rake angle \((\alpha_1 + \beta_1 + \gamma_1 = 90^\circ)\); \( \alpha_2 \) – lateral clearance angle; \( \varepsilon \) – plate peak angle; \( 2\kappa \) – bit’s peak angle; \( \varphi \) – the opening angle between the secondary setting facets.
The removable bits regardless the field of application consist in an active part, body and jointing part. The active part come in contact directly with the rock and participates directly to the chip’s removal and exhaust, even to the guiding of the rod. For the realization of these functions the main components of the active part must be oriented in a certain way in the space which is established by the geometry and the profile of the bit. The determination of the geometry and shape of the active part represents fundamental problems in the design, manufacturing, exploitation and sharpening of these bits.

The active part of the bit consists in two wings armored with carbide plates, each wing being a distinct cutting tool.

The rock cutting is performed by the wedges located in a conical shape towards the surface of the blast hole and the uncutted rock core, which will be removed by self crushing. For this reason, the bit powered by a driller bi the mean of a rod performs apart from the main rotating movement a secondary advance one in axial direction.

The angles of the active part of the bit are reported to a constructive and a functional reference system.

The bits performs the rock removal by the main blades disposed on the front part of the wings, having generally a conical shape and the wedges forming the secondary blades disposed in the continuation of the main blades on the cylindrical (lateral) side, performs the calibration of the hole and contributes to the guiding of the frill rod.

3. DETERMINATION OF THE ROCK’S ABRASIVENESS

The rock’s abrasiveness produces the wear of the active parts of the drill bit and changes in their geometry having as effect the reduction of the advance rate and drilling’s efficiency. For this reason the abrasive properties together with the mechanical ones are considered basic properties of the rocks, which influence in time the rock removing mechanism and the rock’s drillability.

In order to eliminate some of the known method’s of abrasiveness determination disadvantages and using the advantage of helical movement of etalon rod on the rock’s surface a device vas conceived mounted in an universal turning machine instead of the knife support.

In the figure 3 the principle scheme of the realized device.

The rock sample is fixed in the turning machines knife support and is rotated at a reduced rotation speed and the rod is performing an advance movement in transverse direction.

In this way the steel rod describes (fig. 4) on the sample’s surface a trace in form of Archimedean spiral with a length of about 20 meters.

Fig. 3 Device for the determination of the rock’s abrasiveness.

For the tests rock samples collected at Bărbăteni colliery and artificial (equivalent) rocks in concrete, prepared to perform also the drill tests on the drill testing rig constructed on the basis of a vertical boring machine. The artificial rocks were obtained from quartz sand mixed with cement and water, at a given composition, and their mechanical resistance, and their compressive strength were established using cubical concrete samples. The etalon rods were on OL 37 steel.

The conditions in which the tests were performed are similar both for natural and artificial rocks.

The etalon rods in OL 37 steel were weighted on an analytical scale before and after the essays of abrasiveness.

On basis of the results of weighting the diagrams of the wear of rods dependence as a function of different parameters such as rotation speed, advance force and rock type were drawn up (in figure 5 and figure 6 two examples are shown).

Fig. 5 The wear of natural rocks as a function of the compressive strenght: Clay $\sigma_{rc} = 25.8$ MPa; Sandstone clay $\sigma_{rc} = 33.0$ MPa; Limestone $\sigma_{rc} = 59.0$ MPa; Sandstone $\sigma_{rc} = 60.3$ MPa;
1. $F=10$ N; 2. $F=20$ N; 3. $F=30$ N

Fig. 4. The Archimedean spiral described by the rod on the rock sample

Fig. 3 Device for the determination of the rock’s abrasiveness.
These diagrams show an increase of the wear with the increase of rotation speed or the sliding speed of the rod on the rock’s surface. The increase of the wear is explained by the removal of larger particles of material from the rod, due to the mechanical interaction with hard mineral particles at a more intense dynamical regime. To this phenomenon contributes also the heating of the contact area at the increase of the speed, which decreases the limit of flow of the material.

Starting from these considerations, a rig was conceived for the study of the rotating drilling of rocks realized on the structure of a radial boring machine. For the envisaged rig we choose the boring machine GR50, existing in the machine tool laboratory.

This rig presents the following advantages:
- realization of a large range of rotation speeds from 36 to 1600 rpm;
- realization of a large range of advance rates, from 1 to 1000 mm/min;
- realization of a large axial force, until 15kN;
- great value of stiffness and constant value of rotation speeds and advances which ensures a high precision to the measurements;
- compact construction.

In view to perform the tests it is necessary that the rocks drilled to be well fixed, in order to ensure real like conditions. In this purpose, we uses a modular box in steel plate of 4mm thickness. It is mounted directly on the base of the boring machine.

The ensemble of the rig is presented in the figure 7. The rig is realized on the structure of the boring machine GR 50. On its main shaft, a device is mounted consisting in a clutch permitting the radial injection of water for spraying and a support for the drilling rod.

Fig. 6 The wear of artificial rocks as a function of the compressive strength:
Artificial rock I $\sigma_{rc} = 45$ MPa; Artificial rock II $\sigma_{rc} = 55$ MPa; Artificial rock III $\sigma_{rc} = 57$ MPa; Artificial rock IV $\sigma_{rc} = 58$ MPa;
1. $F = 10$ N; 2. $F = 20$ N; 3. $F = 30$ N

From these diagrams we can see also an increase of the wear at the increase of push force, fact which is expectable because the increase of the push force leads to the increase of the real contact surface, so the micro splintering effect of the asperities will be more evident.

Analyzing the abrasive action of the rocks on the rods, as a function of the compressive strength of artificial and natural rocks, we can conclude that between the compressive strength and the abrasiveness it is no direct connection.

4. TEST RIG FOR THE STUDY OF THE WEAR OF TOOLS FOR ROTATING DRILLING

The testing rig must ensure the realization of the drilling regimes with a constant advance force, constant torque and constant rotation speed an constant power, constant advance per.

The parameters which must be measured and recorded during the tests are: the rotation speed of the rod, the advance rate, the length of hole, the drilling time, the advance force, the torque at the shaft of borer.

In practice they exists many rigs for the study of the rotating drilling, in general and for the drill bits, specially. All these rigs presents some disadvantages, mainly regarding their technical characteristics, their stiffness and measurement errors of some parameters.
The parameters which must be measured and recorded during the tests performed on this rig are: the rotation speed of the drill rod; the advance rate of the tool for different cutting regimes; the length of the drilled hole; the time (duration) of the drilling; the push force; the torque at the shaft of the driller; the power consumption; the wear of the tool.

In view to measure and record the push force and the torque a transducer with tensometric gauges presented in the figure 8 was used.

This is realized from a torsion rod on which gauges were pasted. The torsion rod is realized in 41MoCr11 alloyed steel thermically treated and designed for an advance force of until 20kN and a torque of 1000 Nm.

![Fig. 8 The transducer with gauges for the measurement of the push force and torque](image)

The gauges realize the measurement of pushing force, respectively the torque at the drill rod. The transducer is mounted using a Morse cone in the main shaft of the boring machine.

For the recording of he push forces and the torque, the transducer was connected to a Data Acquisition System, consisting in a computer and two measuring bridges connected to the gauges.

### 5. THE RESULTS OF THE PERFORMED TESTS

The drilling was realized in four artificial rock blocks of concrete type, with two types of drill bits, one produced at IMMUM Baia Mare, and the other designed in the frame of the Mining Equipment Department and realized at UM Sadu. The rocks were produced by mixing quartzous sand, cement and water, with the composition and properties presented in the table 1. The testing conditions are presented in the table 2.

![Table 1. Composition and properties of the tested artificial rocks.](image)

<table>
<thead>
<tr>
<th>No.</th>
<th>Sand content [%]</th>
<th>Cement content [%]</th>
<th>Type of rock</th>
<th>Compressive strength [MPa]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>70</td>
<td>30</td>
<td>I</td>
<td>45.0</td>
</tr>
<tr>
<td>2.</td>
<td>60</td>
<td>40</td>
<td>II</td>
<td>55.0</td>
</tr>
<tr>
<td>3.</td>
<td>55</td>
<td>45</td>
<td>III</td>
<td>57.0</td>
</tr>
<tr>
<td>4.</td>
<td>50</td>
<td>50</td>
<td>IV</td>
<td>58.0</td>
</tr>
</tbody>
</table>

Table 2: Testing conditions.

<table>
<thead>
<tr>
<th>No.</th>
<th>Type of bit A ; B</th>
<th>Type of rock I – IV</th>
<th>Advance [mm/rot]</th>
<th>Rotation speed [rpm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>A ; B</td>
<td>I – IV</td>
<td>0.28;0.4;0.63</td>
<td>50</td>
</tr>
<tr>
<td>2.</td>
<td>A ; B</td>
<td>I – IV</td>
<td>0.28;0.4;0.63</td>
<td>100</td>
</tr>
<tr>
<td>3.</td>
<td>A ; B</td>
<td>I – IV</td>
<td>0.28;0.4;0.63</td>
<td>140</td>
</tr>
<tr>
<td>4.</td>
<td>A ; B</td>
<td>I – IV</td>
<td>0.28;0.4;0.63</td>
<td>200</td>
</tr>
<tr>
<td>5.</td>
<td>A ; B</td>
<td>I – IV</td>
<td>0.28;0.4;0.63</td>
<td>280</td>
</tr>
<tr>
<td>6.</td>
<td>A ; B</td>
<td>I – IV</td>
<td>0.28;0.4;0.63</td>
<td>400</td>
</tr>
<tr>
<td>7.</td>
<td>A ; B</td>
<td>I – IV</td>
<td>0.28;0.4;0.63</td>
<td>560</td>
</tr>
<tr>
<td>8.</td>
<td>A ; B</td>
<td>I – IV</td>
<td>0.28;0.4;0.63</td>
<td>800</td>
</tr>
</tbody>
</table>

A = IMMUM Baia Mare; B = UM Sadu

On the basis of the measurement’s results of the advance force and the torque, for each set of measurements performed with two kind of bits, the linear wear was measured (the width of the wear facet, Fig. 9) after each group of measurements performed at the same value of the advance (groups of measurements corresponding to rotation speed of 50, 100, 140, 200, 280 and 400rpm). For these intervals the length of the way of the edge was determined.

![Fig. 9 Removable bit with wear facette.](image)

The dependence of the facet’s width on the length of the way and the content of SiO₂ in % for the four types of artificial rocks is given in table 3.
The dependence curves of the facet’s width as a function of the length of the way are presented in figure 10.

The shape of the curves from figure 10 is explainable by the fact that as the content of cement increases, the compressive strength also increases, the content of SiO₂ which is the main factor influencing the abrasiveness decreases.

For the dependence of the linear wear on the mentioned factors we propose a regression equation of form:

$$\Delta h = a \cdot L^b$$

(1)

where: $L$ represents the length of the way of the bit’s edge;

- $a$ and $b$ are two empirical constants determined by statistic methods whom dependence on $\sigma_{rc}$ and SiO₂ content in [%] have the form:

$$a = n_1 + m_1 \cdot \sigma_{rc} \cdot [%]_{SiO₂}$$

$$b = n_2 + m_2 \cdot \sigma_{rc} \cdot [%]_{SiO₂}$$

(2)

With the values of $\Delta h = f(L)$ the coefficients $a$ and $b$ of the regressed equations are determined for different values of the SiO₂ content in [%] (fig. 11).

**Table 3. the width of the wear’s facet as a function of type of rock (content in SiO₂).**

<table>
<thead>
<tr>
<th>No</th>
<th>Type of rock</th>
<th>Length of way [m]</th>
<th>Width of the facet $\Delta h$ [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>I</td>
<td>11</td>
<td>0.50 0.89 1.00 1.11 1.50</td>
</tr>
<tr>
<td>2.</td>
<td>II</td>
<td>22</td>
<td>0.51 0.95 1.08 1.18 1.58</td>
</tr>
<tr>
<td>3.</td>
<td>III</td>
<td>33</td>
<td>0.56 0.89 1.10 1.12 1.54</td>
</tr>
<tr>
<td>4.</td>
<td>IV</td>
<td>44</td>
<td>0.49 0.88 1.02 1.09 1.48</td>
</tr>
<tr>
<td></td>
<td></td>
<td>67</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 10 Dependence of the facette’s width on the length of the way and the SiO₂ content of rock.

Fig. 11 Determination of the coefficients $a$ and $b$ of the regressed equation for different SiO₂ content.

Fig. 12 Determination of the coefficients $m_1$, $m_2$, $n_1$, and $n_2$. 
Then the values of $a$ and $b$ of the coefficients are represented as a function of the product $\sigma_{rc} \times [\%] SiO_2$, for which the values of the coefficients $m_1$, $m_2$ respectively $n_1$ and $n_2$ (fig. 12.) are obtained. For the given removable bits, the following values were obtained: $m_1=1.144 \times 10^{-6}$, $m_2=2.190 \times 10^{-6}$, respectively $n_1=0.1042$ and $n_2=0.5018$.

These values of the coefficients were obtained for average values of the rotation speed and advance corresponding to a set of measurements, so they can be used for the assessment of the wear of a bit as a function of the given parameters.

The obtained equation can be transcribed in function of the abrasiveness, measured by the loss of mass obtained at abrasiveness tests on artificial rocks.

The presented methodology can be applied for any kind of removable bit following the procedure:
- tests of wear in artificial rocks on the proposed rig;
- tests of abrasiveness on artificial and natural rock samples on which we want to assess the wear;
- establishment of the coefficients of the equation.

REFERENCES