Investigations into the wear rate of conical picks with abrasion-resistant coatings in laboratory conditions

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Abstract: As part of own works performed by the Department of Machine Engineering and Transport of AGH University of Science and Technology, investigations into the rate of conical picks’ wear were carried out. For this purpose, the previously developed methodology for running experiments at a specialist laboratory test stand was applied. Tests were carried out for a total of seven types of conical picks with the same geometric parameters, but made of various grades of steel and with the body working surface covered by abrasion-resistant materials. The conducted investigations and the analysis of results allowed recommending conical picks made of S235 steel and hardfaced with EP-TB-1-6 or EP-TB-2-46 electrodes. However, it seems advisable to continue attempts aimed at finding a protective coating for the body of the pick.

1. Introduction

The works described in this article were carried out at the Department of Machinery Engineering and Transport of AGH University of Science and Technology, where the wear of conical picks was measured at a specialist laboratory test stand for testing the resistance of getting in the process of cutting or drilling. These tests are conducted in order to develop a methodology and choose materials to protect the body, and more specifically, the working surfaces having contact with mined rock against abrasive wear, in particular in abrasive minerals. Figure 1 contains a photograph of a conical pick the body of which has worn off and exposed the insert made of sintered carbide. Further use of this pick will result in the insert falling out as well as the wear and destruction of the pick. Therefore, providing protection for this part of the pick by subjecting it to thermal treatment or covering its surface with abrasion-resistant materials should increase the durability of these tools. It is noteworthy that currently one can find conical picks with bodies protected in the process of hardfacing with abrasion-resistant materials. However, the cost of these tools and their problematic quality cause that they are not competitors for the currently produced conical picks of alloy steels.

Conical picks are the subject of research and development works carried out in many centres all over the world. These investigations are mainly aimed at finding a solution that will ensure the highest resistance to abrasion. Tests were conducted for conical picks with bodies protected against abrasive wear by hardfacing, covering them with abrasion-resistant coatings or with rings made of sintered carbides [3, 10, 11, 12]. The works performed in order to explore the mechanism of conical picks’ abrasion wear [4], wear prediction [5] or the possibility of supporting the cutting process [7] were...
conducted. Tests were carried out for sintered carbide [13] and for a complete conical pick [14] or for conical picks that make up the cutterhead [6].

Also, implementation works aimed at applying modern tools and machines in difficult conditions [1, 9] as well as alternative tools in the form of discs [8] were carried out. The works were also focused on the procedures of evaluating the quality of conical picks enabling the best offer to be selected by the user during public tenders [2].

Measurement of conical picks’ wear rate is aimed at determining their durability. It must always be performed in the same conditions so that the results are credible, repeatable and probabilistic. This will allow for evaluating and comparing the conical picks’ durability. In industrial conditions the durability of picks is usually defined as the ratio of the number of picks to the amount of output. It is the most frequently the number of picks used to obtain 1000 Mg or m³ of output, whereas in laboratory conditions the wear rate (durability) of the pick or picks can be the most effectively determined by the loss of mass in relation to the volume of rock sample cut by this pick or picks.

Figure 1. Conical picks on a screw cutterhead: a) with an exposed insert made of sintered carbide, b) with a slipped insert of sintered carbide.

In this case, wear rate tests were carried out for conical picks made of various grades of alloy steels, having the same constructional parameters and working part surfaces protected by various hard materials in the process of hardfacing. As mentioned before, the investigations were conducted at a specialist test stand at the Department of Machinery Engineering and Transport of AGH University of Science and Technology.

2. Subject of research
Investigations into the rate of wear were conducted for seven types of conical picks made of various types of steel, commercial or hardfaced with different electrodes, which, in principle, increase their durability. All the picks had a working length of 90 mm and tip angle 2βu = 90°, equipped with tips made of sintered carbide having a diameter $\phi$22. The following picks were selected for tests:

- commercial picks made of 35HGS steel, thermally treated to reach the working part hardness of 54 HRC – 4 picks – marked as NS-01 (Figure 2a),
- picks made of 35HGS steel, where the working part surface was hardfaced with a Capilla HR MAG electrode by the TIG method – 4 picks – marked as NS-02 (Figure 2b),
- picks made of 35HGS steel, where the working part surface was plasma hardfaced with a Capilla HR MAG electrode – 4 picks – marked as NS-03 (Figure 2c),
- commercial picks made of S255 steel, thermally treated to reach the working part hardness of 45 HRC – 4 picks – marked as NS-04 (Figure 2d),
- picks made of S235 steel, manually hardfaced with an EP-TB-1-6 electrode having a hardness of approximately 50 HRC – 2 picks, and picks made of the same steel, hardfaced with an EP-TB-2-46 electrode having a hardness of ca 60 HRC – 2 picks – marked as NS-05 (Figure 2e),
commercial picks made of 35HGS steel and thermally treated to reach the working part hardness of HRC 48 – 4 picks – marked as NS06 (Figure 2f),
- picks made of 35HGS steel, manually hardfaced with an EP-TB-1-6 electrode having a hardness of 50 HRC – 2 picks, and picks made of the same steel, hardfaced with an EP-TB-2-46 electrode having a hardness of 60 HRC – 4 picks – marked as NS-07 (Figure 2g).

A total of twelve technically sharp commercial picks (NS-01, NS-04, NS-06) and 16 picks with the working body covered with abrasion-resistant coatings (NS-02, NS-03, NS-05, NS-07) were selected for tests. The NS-04 and NS-05 picks were made of S235 steel, whereas the NS-06 and NS-07 picks – of 35HGS steel. It should be noted that two picks made of S235 steel were coated with two different abrasion-resistant layers (NS-05, NS-07) so as to evaluate the adhesion of these layers to various grades of steel; during investigations they were positioned in the same holders.

3. Research plan and methodology
To assess the durability of picks provided for tests, the rate of their wear was assumed to be the ratio of the total loss of the picks’ mass to the volume of output obtained in the process of artificial rock cutting. The adopted definition of the parameter determining the durability of picks as well as requirements regarding the rate of their wear resulted in the necessity of adopting the following research plan:
– preparation of a cement-sand sample (cement, sand, aggregate, water) having a required and empirically determined single-axis compressive strength,
– preparation of a test disc with appropriate holders,
– preparing and marking the picks to be tested as well as measuring their mass,
– mounting 4 conical picks on the test disc,
– cutting in laboratory conditions, with a constant value of feed rate and cutting,
– disassembly of picks and measurement of their mass,
– measurement of the volume of output obtained during the work of picks subjected to testing,
– calculation of C2 coefficient, determining the picks’ wear rate.

Implementation of the adopted research plan and methodology required determining or adopting the following major parameters related to the process of cutting with the picks in question:
– cutting a cement-sand sample consisting of cement, sand and basalt aggregate with uniaxial compressive strength $R_c = 30\text{÷}35$ MPa,
– sample mass density $\gamma_w = 2.3 \text{ Mg/m}^3$,
– volume of whole sample at the test stand $V_p = 8.125 \text{ m}^3$,
– reference volume of the sample (for one set of picks) $V_w = 0.5 \text{ m}^3$,
– advance speed: $v_{pu} = 0.05 \text{ m/min}$,
– number of revolutions of the test disc: $n = 42 \text{ rpm}$,
– length of the cut: $50 \text{ mm}$,
– web cut: $152 \text{ mm}$,
– diameter of the test disc with picks: $\phi 1863 \text{ mm}$.

When the picks’ mass before and after tests as well as the volume of output obtained with these picks have been determined, it is possible to determine the parameter characterizing the examined picks’ wear rate. The rate of picks’ wear (durability) should be determined from the following dependence.

$$C2 = \frac{\Delta m}{m} \frac{V_w}{V_u}$$

(1)

where:

$C2$ - picks’ wear rate,
$\Delta m$ - loss of pick’s mass during tests (body and tip), g
$m$ - picks’ mass before tests, g
$V_w$ - reference volume of the sample, $\text{ m}^3$
$V_u$ - volume of the sample cut during tests, $\text{ m}^3$.

Investigations into all types of picks were conducted in accordance with the provided research plan and methodology. It should be noted that the lower the value of $C2$, the lower is the pick’s wear. Laboratory tests are particularly recommended in this case, but they need to be carried out at a special test stand fulfilling the requirements of the adopted research methodology. For this reason, the investigations in question will be done at a test stand for testing the process of cutting with cutterheads possessed by KIMiT AGH (Department of Machinery Engineering and Transport of AGH University of Science and Technology).

4. Description of the test stand
The investigations were conducted at a laboratory test stand for testing the process of cutting or rotary drilling with single cutting tools or cutterheads. It is used for complex laboratory tests connected with the broadly understood process of rock cutting. The test stand enables particular cutterheads to cut an artificial or natural rock sample in laboratory conditions. The test stand consists of three main subassemblies (Figure 3):
– cutterhead drive assembly,
– sample mounting and driving assembly,
measurement and control system.

The cutterhead drive assembly is based on a foundation and consists of an AC induction motor powered by a DTC indirect frequency converter having an output of 250 kW (supply voltage – 3x400V; number of revolutions - 1487 rpm). The torque from the motor shaft is transmitted onto the shaft of the cutterhead by a mechanical transmission gear with a transmission ratio $i = 28$.

Additionally, a torque meter has been mounted on the motor drive. The system configuration allows for the drive’s work in two ranges, so-called constant torque control (up to 50 rpm) and constant power control (up to 120 rpm). At its end, the drive assembly is equipped with a spline, on which the cutterhead has been mounted.

A rock sample moves longwise and crosswise in relation to the cutterhead. Both the longitudinal and transverse movement of the rock sample is forced by hydraulic servomotors, which enable achieving a feed rate within a range of 0 to 9.9 m/min, feed force up to 150 kN, longitudinal travel up to 2.5 m, and transverse travel up to 1.3 m. The length of the rock sample reaches 2.5 m, the width 1.3 m and the height 2.5 m.

The test stand enables testing cutterheads with a maximum diameter of 2.2 m and a maximum web of 1.0 m. The output obtained in the process of cutting is provided into a container moving on guide bars together with the sample subjected to cutting. Such a solution enables collection of the output in a continuous way during the cutting process.

**Figure 3.** Laboratory test stand for investigating the process of cutting or rotary drilling with single cutting tools or cutterheads: a) operator’s cab; b) concrete sample with its mounting and feed assembly as well as a test cutterhead; c) cutterhead drive assembly.

The system for controlling and recording particular values related to the cutting process is placed in the cab which reduces the level of noise and contamination. The control system was created using
PLC controllers. A touchpad and remote control are used to visualize and control the process. The operator can change all the process parameters and monitor the values being measured and recorded on a current basis. The measurement system consists of sensors that enable, either directly or indirectly, the following values to be measured and recorded:

- longitudinal feed rate,
- transverse feed rate,
- cutterhead’s rotary speed,
- cutting resistance torque,
- longitudinal feed resistance force,
- transverse feed resistance force.

Additionally, the test stand provides the possibility of measuring dust during tests and analysing the grain size distribution of the obtained output.

5. Research and preparation of results

The translational motion of the rock sample and the rotary movement of the cutting element cause the destruction of the artificial rock’s cohesion by cutting it with picks. Then it is possible to measure the mass loss of the working picks and the volume of output obtained after tests. Therefore, it is very important to provide constant and repeatable conditions of measurement throughout the picks’ wear tests.

Before starting the tests, the following were done:
- inspection of the construction and operation of the test stand and drive,
- inspection of the measurement system,
- mounting the tested picks on the cutting element by means of an appropriate adapter (Figure 4),
- setting the feed rate, cutterhead revolutions and web.

Tests were done for seven sets of picks. The picks were prepared in a way enabling their direct assembly on the test disc. The investigations were carried out in accordance with the established research plan.

The picks on the test disc formed a pick system, the diagram of which has been presented in Figure 5. The picks were located on the circumference, at 90° intervals. Each set of picks was mounted in holders installed on the disc, which were numbered 1 to 4. Upon completion of the cutting process, the picks were photographed (Figure 6) and their mass was measured.

Figure 4. Examples of conical picks prepared for tests.
Figure 5. Diagram of the applied pick system with the marking of picks’ numbers.

Figure 6. Selected picks after tests: a) commercial NS-01, b) hardfaced NS-02, c) hardfaced NS-03, d) commercial NS-04, e) commercial NS-05, f) hardfaced NS-06.
Next, the volume of output $V_u$, which was different for each sample (each type of pick) was determined. Based on the obtained values, parameter $C_2$ defining the picks’ wear rate was calculated, in accordance with the adopted research plan and methodology. Examples of test results for NS-01 commercial picks have been given in Table 1.

**Table 1.** Test results and parameters determined for NS-01 commercial picks.

| No. | Position of pick on the test disc | Producer marking | Pick’s mass | Pick’s mass loss | Volume of output $V_u$ [m$^3$] | C2 [-] |
|-----|----------------------------------|------------------|-------------|-----------------|-----------------------------|--------|
|     |                                  |                  | before test $m$ [g] | after test $m_p$ [g] | $\Delta m = m - m_p$ [g] |        |
| 1   | 1                                | –                | 1855.12     | 1388.06         | 467.06                   | 1.23   |
| 2   | 2                                | –                | 1843.75     | 1249.77         | 593.98                   | 0.103  |
| 3   | 3                                | –                | 1845.04     | 1374.34         | 470.70                   | 1.24   |
| 4   | 4                                | –                | 1844.09     | 1356.70         | 487.39                   | 1.29   |

Mean value of $C_2$ parameter of the pick’s relative mass loss $\textbf{C2: 1.33}$

6. Research results analysis

The conducted tests and the obtained results enable evaluating the durability of particular picks and the influence of protective coatings on this durability. It should be clearly emphasized that the picks in question always cut in the same conditions (cutting and feed rate, pick system, rock sample), according to the research plan and methodology, and the measure of the rate of individual and average wear is $C_2$. The value of this parameter indicates the pick’s wear rate, and the lower this parameter is, the higher is the pick’s durability.

The lowest mean value of $C_2$ was noted for NS-05 picks ($C_2 = 0.41$), and the highest for NS-02 picks ($C_2 = 1.48$). In the first case, the picks had a protective coating on the working part, which was made in the process of hardfacing with an EP-TB-2-46 electrode, whereas in the second case – with a Capilla HR MAG electrode (hardfacing by the TIG method).

The protective coating does not protect the pick if it is not suited to the conditions of its work. Picks without a protective layer (NS-01, NS-04, NS-06), made of alloy steel and subjected to thermal treatment, have comparable durability. Therefore, NS-05 picks, followed by NS-03 and NS-07 are recommended for work with abrasive rocks (Table 2).

A similar trend can be observed when considering the individual $C_2$ parameter and the position of the pick on the test disc. In this case, however, the assessment is similar, though less unambiguous. It is clearly visible – as could be expected – that the wear rate strongly depends on the position of the pick, i.e., the cutting resistance (the order of picks entering the rock mass).
Table 2. Mean C2 values and research observations – summary table.

| No. | Pick                        | C2  | Remarks                                      |
|-----|-----------------------------|-----|----------------------------------------------|
| 1   | NS-01 commercial picks      | 1.33| three picks worn asymmetrically, one pick worn symmetrically, all picks without carbides |
| 2   | NS-02 hardfaced picks       | 1.48| one pick worn asymmetrically, three picks worn symmetrically, all picks without carbides |
| 3   | NS-03 hardfaced picks       | 0.53| two picks worn asymmetrically; two picks worn symmetrically, only one pick without carbide |
| 4   | NS-04 commercial picks      | 1.36| four picks worn symmetrically, all picks without carbides |
| 5   | NS-05 hardfaced picks       | 0.41| four picks worn symmetrically, all picks with carbides |
| 6   | NS-06 commercial picks      | 1.08| one pick worn asymmetrically, three picks worn symmetrically, all picks without carbides |
| 7   | NS-07 hardfaced picks       | 0.76| four picks worn symmetrically, two picks without carbides |

7. Summary
The conducted investigations into the rate of picks’ wear in the process of artificial sample cutting indicate that their durability is strongly influenced by the type of protective coating on the pick’s working part, the grade of steel used to produce the picks’ bodies as well as the position of the pick on the cutterhead. It is therefore suggested that further searches for a protective layer to be applied on the pick’s working part should be undertaken so as to establish which protective coating is the cheapest and the best for increasing picks’ durability, in particular in hardly accessible and/or abrasive rocks.

References
[1] Boloz Ł and Krauze K (2018) Ability to mill rocks in open-pit mining. In: 18th International Multidisciplinary Scientific Geoconference, Exploration and Mining, SGEM2018, Albena, Bulgaria, Voume 2, pp. 41-48.
[2] Boloz Ł (2018) „Results of a study on the quality of conical picks for public procurement purposes”, in Proceedings of the international conference on Human safety in work environment: operating machinery and equipment: integrated management systems: quality - environment - safety, 23-27 october 2018, Gdańsk-Nynashamm-Sztokholm-Tallin-Sztokholm-Nynashamm-Gdańsk, pp. 687-693.
[3] Chang, Soo-Ho, Lee Chulho, Kang Tae-Ho, Ha Taewook, Choi, Soon-Wook (2017) Effect of hardfacing on wear reduction of pick cutters under mixed rock conditions. Geomechanics and engineering, 13(1), pp. 141-159.
[4] Dewangan, Saurabh, Chattopadhyaya, Somnath (2015) Critical Analysis of Wear Mechanisms in Cemented Carbide. Journal of materials engineering and performance, 24(7), pp. 2628-2636.
[5] Gajewski J, Jedlinski L and Jonak J. (2013) Classification of wear level of mining tools with the use of fuzzy neural Network. Tunnelling and underground space technology, 35, pp. 30-36.
[6] Gospodarczyk P, Kotwica K and Stopka G (2013) A new generation mining head with disc tool of complex trajectory, Archives of Mining Sciences, 58(4), pp. 985–1006.
[7] Kotwica K (2011) The influence of water assistance on the character and degree of wear of cutting tools applied in roadheaders. Archives of Mining Sciences, 5(3), pp. 353-374.
[8] Kotwica K (2018) Atypical and innovative tool, holder and mining head designed for roadheaders used to tunnel and gallery drilling in hard rock. *Tunnelling and Underground Space Technology, 82*, pp. 493-503.

[9] Krauze K and Boloż Ł (2018) Disc unit dedicated to mine abrasive rocks and in particular copper ores. In: 18th International Multidisciplinary Scientific Geoconference, Exploration and Mining, SGEM2018, Albena, Bulgaria, Volume 2, pp. 311-318.

[10] Krauze K, Boloż Ł and Wydro T (2015) Parametric factors for the tangential-rotary picks quality assessment, *Archives of Mining Sciences, 60*(1), pp. 265-281.

[11] Krauze K, Boloż Ł, Wydro T and Mucha K (2017) Durability testing of tangential-rotary picks made of different materials. *Mining – Informatics, Automation and Electrical Engineering*, no. 1, pp. 26-34.

[12] Krauze K, Skowronek T and Mucha K (2016) Influence of the hard - faced layer welded on tangential – rotary pick operational part on to its wear rate. *Archives of Mining Sciences, 61*(4), pp. 779 – 792.

[13] Nahak, Sakuntala, Dewangan, Saurabh, Chattopadhyaya and Somnath (2015). Discussion on Wear Phenomena in Cemented Carbide. In: Global Challenges, Policy Framework & Sustainable Development for Mining of Mineral and Fossil Energy Resources. Dhanbad: GCPF, 11, pp. 284-293.

[14] Songyong L, Huifu; J and Xiaohui L (2017) Experimental research on wear of conical pick interacting with coal-rock. *Engineering failure analysis, 74*, pp. 172-187.