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Methods for quantitative assessment of conical pick's wear rates

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Abstract

Mechanical rock cutting is widely employed in both the mining and construction industries. One of commonly used techniques is cutting with conical picks, which can process various rock types, including hard-workable and abrasive rocks. However, in highly demanding conditions, such as metal ore mining, the service life of conical picks is significantly limited. Therefore, researchers are constantly searching for methods to extend their operational lifespan, i.e. to improve their durability. Appropriate laboratory testing procedures are required to evaluate the durability of conical picks and compare various design or material solutions. The article presents a method for assessing wear rates of conical picks with the use of a dedicated laboratory test rig. A comprehensive procedure for quantitative quality assessment, including the unit price of picks, has been proposed. This approach enables direct comparison of products offered by different manufacturers, facilitating the selection of the most cost-effective and efficient solution. The procedure has been validated in practice during research commissioned by Polish coal companies and in numerous independent research projects. Several methods for calculating wear rate indicators have been discussed. The analysis has confirmed the robustness of the proposed methodology and its resistance to undesirable fluctuations in selected parameters. The paper outlines various formulas for determining the mass wear rate of conical picks and discusses alternative approaches to calculating performance indicators. The developed procedure allows the selection of picks to be optimised by adjusting the weighting of price-related factors according to current financial and operational requirements. The applicability of the method has been illustrated with two case studies: the first relates to tender procedures conducted by a Polish coal company, whereas the second concerns research aiming to identify materials or coatings capable of enhancing the durability of conical picks relative to widely available commercial solutions.

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1. Introduction

Cutting heads are the working elements of many machines, such as longwall shearers, roadheaders, as well as road and floor miners operating in the rock industry (Krauze, 2000). Today, conical picks are standard tools applied in cutting heads of various cutting machines. A typical conical pick is constructed of a shank part 3 and a working part 2, in which the tip 1 is brazed (Fig. 1a). Such picks can vary in size and shape depending on their application (Fig. 1b). The basic idea behind the operation of the conical pick is that it can rotate freely about its axis during mining, so that the wear is symmetrical. The tip retains a shape close to its original form (Fig. 1c).

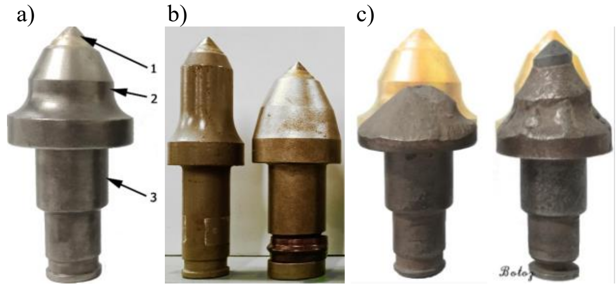

Fig. 1. Conical picks used in cutting heads: a. pick construction (Bołoz, 2025), b. examples of picks (Vargová et al., 2023), c. examples of worn picks (Bołoz, 2025)

Worn picks are replaced by new ones. In practice, the consumption of picks can be expressed in picks per 1,000 Mg (1 Gg) of excavated material. The consumption thus determined can range from 1.6 pieces/1Gg to as many as 80 pieces/1Gg (Prokopenko et al., 2016), (Akintunde et al., 2023), (Li et al., 2015). It strongly depends on the mechanical properties of the rock being excavated (Biały, 2015; Biały et al., 2021).

Wear is a natural process, but it is not only a challenge for cutting tools (Nikolić et al., 2021; Vicen et al., 2022). Wear reduction brings significant economic benefits. It is not only the cost of purchasing tools that matters, but also the impact of the reduced number of picks that are transported and replaced, and the possibility of implementing Industry 4.0 (Ingaldi and Ulewicz, 2025; Midor, 2017; Midor and Žarnovský, 2016).

Manufacturers do not define the quality or durability of their picks in a way that allows the user to objectively compare the picks and choose the optimal one before the purchase. Therefore, a method of testing conical picks, with the possibility of taking their price into account, has been developed to select the best offer on the basis of a numerical wear rate. (Krauze et al., 2015), (Bołoz, 2023).

The durability of conical picks is the most crucial element describing their quality; hence, this article focuses on studying and determining the wear rates of picks. The research presented here was conducted on a special test rig for cutting heads (Fig. 2) at the AGH Department of Mechanical and Transport Engineering (Bołoz, 2025).

Fig. 2. Test rig for cutting heads

2. Literature review

The issue of cutting tools used in mining has for many years been the subject of research in academic and industrial institutions. There are numerous publications and monographs that address both scientific and practical aspects, including implementation and operational experience (Biały, 2024, 2005; Jonak, 2002, 1998; Kotwica, 2012; Kotwica and Klich, 2011; Podgórski and Jonak, 2006; Sikora et al., 2000; Skotnicka-Zasadzien and Biały, 2011).

Durability and wear rate of conical picks can be tested on various test rigs (Bołoz and Biały, 2023), (Dewangan et al., 2015), (Choudhary et al., 2017), (Bołoz, 2019). The test rigs, called LCMs (Linear-Cutting Machines), are frequently applied designs. They come in various sizes and are used to test cutting resistance, dust generation, and tool wear (Slouka et al., 2022), (Li et al., 2019), (Dewangan et al., 2022), (Wang et al., 2022). The second group includes stations with a rotating cutting head that operates similarly to those found in mining or excavation machines. These rigs most accurately replicate the real cutting process (Liu et al., 2015), (Liu et al., 2017), (Fu et al., 2015). The wear rate tests of the picks described in this article were performed according to a dedicated, repeatable procedure, which has been implemented in Polish coal mining companies and frequently used in research on newly developed conical picks. It is important to note that the full-scale test rig accurately replicates the real cutting process (Bołoz, 2025).

3. Methods and testing tools

Under industrial conditions, the service life of cutting picks is usually defined as the ratio of the number of picks exchanged to the amount of mined rock. The service life defined in this way relates to the specific operating conditions of the picks, which are constantly changing. Hence, it was necessary to develop a method for laboratory tests to ensure that the wear rate measurement was carried out under controlled conditions and the results were reproducible and comparable. The developed method involves cutting a rock sample with four identical picks. The wear rate is then calculated based on the weight loss of the picks and the volume of the sample they have cut. The tests of all picks are carried out on the same sample and for the same cutting parameters. This approach makes it possible to evaluate the picks with the use of a dimensionless, numerical indicator, compare different picks, and select the most suitable one. The wear rate of picks should be calculated using one of the following formulas (Bołoz, 2025):

$$X1 = \frac{\Delta m}{m} \cdot \frac{V_w}{V_u} \tag{1}$$

$$X2 = \frac{\Delta m_{max}}{m \frac{V_u}{V_w}} \tag{2}$$

$$X3 = \frac{m}{\Delta m} \cdot \frac{V_u}{V_w} \tag{3}$$

Where:

X1, *X2*, *X3* - indicators determining the mass wear rate, -,
Δm - loss of the pick mass during tests (body with the tip), g,
m - mass of the picks before tests, g,
V_w - reference/sample volume, m^3,
V_u - volume of the sample cut by the picks during testing, m^3,
Δm_{max} - maximum loss of the picks' weight, g.

Depending on the formula used, the wear rate can be described by a linearly increasing characteristic *X1*, a linearly decreasing characteristic *X2* or a hyperbolically decreasing characteristic *X3* as the loss of the picks mass increases. In the case of the linear characteristic described by formula *X1*, the pick with the lowest wear rate also has the lowest indicator value. The indicator *X1* is directly proportional to the consumption of the picks' mass. For the *X2* and *X3* characteristics, the higher the indicator's value, the slower the picks' wear. The indicator *X2* is linearly inversely proportional to the mass loss, while *X3* decreases hyperbolically. Due to the course of the applied hyperbola, picks with low mass loss obtain a high value for the indicator *X3*, while picks with a higher mass loss have comparable values for this indicator. The *X2* indicator for the pick with the highest weight loss takes on a zero value. Thus, regardless of the price, this pick is not considered when making the best choice. The user of the picks following this procedure can decide which formula suits the company's needs. An error analysis of the presented method was carried out and for the typical values of parameters, the average error does not exceed 0.7 % and the maximum error is around 1.0%.

Determination of the wear rate for a set of picks in a series requires choosing the calculation method. This indicator can be an average of the indicators for individual picks. It can also be calculated for the sum of the weight loss of the four picks, and, similarly, for the average values of the weight loss of the picks. Hence, the indicator values take the following forms:

The indicator represents the average of the indicators for individual picks:

$$X1_j = \frac{1}{4}\sum_{i=1}^{4} \frac{\Delta m_{ji}}{m_{ji}} \cdot \frac{V_w}{V_{u_j}} \quad (4)$$

$$X2_j = \frac{1}{4}\sum_{i=1}^{4} \frac{max_{ji}(\Delta m_{ji}) - \Delta m_{ji}}{m_{ji}} \cdot \frac{V_w}{V_{u_j}} \quad (5)$$

$$X3_j = \frac{1}{4}\sum_{i=1}^{4} \frac{m_{ji}}{\Delta m_{ji}} \cdot \frac{V_{u_j}}{V_w} \quad (6)$$

Where:
i - individual picks in the tested series, $i = (1, \ldots, 4)$,
j – subsequent pick series, $j = (1, \ldots, 8)$ or $j = \{S25, P25, ZB25, S22, P22, SB22, E22, CE\}$,
$X1_j$, $X2_j$, $X3_j$ - indicators of the j-th pick series, -,
Δm_{ji} - mass loss of the *i*-th pick in the *j*-th series, g,
m - mass of the *i*-th pick in the *j*-th series before tests, g,
V_w - reference/sample volume, m^3,
V_u - volume of the sample cut by the *j*-th pick series during testing, m^3,

The indicator is determined for the sum of the weight of the picks and the sum of their weight loss:

$$X1_j = \frac{\sum_{i=1}^{4} \Delta m_{ji}}{\sum_{i=1}^{4} m_{ji}} \cdot \frac{V_w}{V_{u_j}} \quad (7)$$

$$X2_j = \frac{max_j\left(\sum_{i=1}^{4} \Delta m_{ji}\right) - \sum_{i=1}^{4} \Delta m_{ji}}{\sum_{i=1}^{4} m_{ji}} \cdot \frac{V_w}{V_{u_j}} \quad (8)$$

$$X3_j = \frac{\sum_{i=1}^{4} m_{ji}}{\sum_{i=1}^{4} \Delta m_{ji}} \cdot \frac{V_{u_j}}{V_w} \quad (9)$$

The indicator is determined for the value of the average weight of the picks and the average loss of the picks' weight:

$$X1_j = \frac{\frac{1}{4}\sum_{i=1}^{4} \Delta m_{ji}}{\frac{1}{4}\sum_{i=1}^{4} m_{ji}} \cdot \frac{V_w}{V_{u_j}} \quad (10)$$

$$X2_j = \frac{max_j\left(\frac{1}{4}\sum_{i=1}^{4} \Delta m_{ji}\right) - \frac{1}{4}\sum_{i=1}^{4} \Delta m_{ji}}{\frac{1}{4}\sum_{i=1}^{4} m_{ji}} \cdot \frac{V_w}{V_{u_j}} \quad (11)$$

$$X3_j = \frac{\frac{1}{4}\sum_{i=1}^{4} m_{ji}}{\frac{1}{4}\sum_{i=1}^{4} \Delta m_{ji}} \cdot \frac{V_{u_j}}{V_w} \quad (12)$$

The application of formulas 7-8 and 10-12 results in the same indicator values, due to the reduction of the "1/4" factor in the fractions. Therefore, indicators based on the average weight of the picks were not used in the calculations.

Users assess the value-to-quality ratio when choosing the best picks. Increasing the durability of the picks requires more advanced technical measures, which also increase the price. The relative influence of the price and durability on the user's choice was determined using the weighted criteria method, which is a typical multi-criteria optimization method. The procedure provides the possibility of determining the influence of the price share criterion and the durability criterion in offer evaluation. If the price K of the pick and the determined wear rate are known, the number of points P is calculated. The formula for P assumes that the weighting W of the pick quality is in the range $0 \div 100$. In practice, the weighting of the quality criterion was in the range $W = 35 \div 70$, as illustrated by the examples of three companies. For a low value of the quality weighting (e.g. $W < 20$), there is a risk of choosing a pick which is characterised by a low price and at the same time very low quality. Similarly, in the case of high values (e.g. $W > 80$), the most expensive offer may prevail, even if the durability of the picks is only slightly higher than a clearly cheaper offer (Bołoz and Midor, 2019). As a result, a P value of no more than 100 is obtained. The higher the value P, the more favourable the offer (Bołoz, 2025):

$$P_{X1} = \frac{min(X1_i)}{X1_i} \cdot W + \frac{min(K_i)}{K_i} \cdot (100 - W) \quad (13)$$

Where:
P - number of points of picks, $P \leq 100$, -,
i - consecutive number of the offer, -,
W - weighting of quality share in the final evaluation of the picks, $W = 0 \div 100$, -,
$X1$ - pick wear rate indicator, -,
K - cost of a pick, PLN,
$X1_i$, K_i - indicator $X1$ and price K for the *i*-th offer, -,
$\min(X1_i)$, $\min(K_i)$ - minimum values of $X1$ and K_i among all the offers.

If indicators X2 or X3 are used, the formula for the number of points takes the following form:

$$P_{X2,3} = \frac{X2,3_i}{max(X2,3_i)} \cdot W + \frac{min(K_i)}{K_i} \cdot (100 - W) \quad (14)$$

4. Pick testing for public tenders

The described procedure has been implemented in three Polish coal companies. Altogether, ten underground mines were included in the tendering procedures. Each tender consisted of multiple tasks involving one type of pick. Picks from five manufacturers were examined for the purposes of four separate tenders. The tenders involved the supply of more than

720,000 picks in a period of one or two years (Bołoz and Midor, 2019). Assuming an average pick value of PLN 110, we obtain an amount of almost PLN 80,000,000.

A multivariate analysis revealed that the use of a specific formula for the wear rate *(X1, X2, X3*) and the weighting of the quality criterion *W* significantly influences the selection of a specific offer, on the basis of the score *P*. The analyses were based on actual pick quality tests for one of the tenders. The results developed after the tests have been summarised in the tables below. Table 1 presents the wear rates of picks from each manufacturer. For each indicator, the number of points P was calculated with varying weightings for the price *W*. The results for *X1, X2* and *X3,* respectively, are shown in Table 2, Table 3 and Table 4.

Table 1. Results of pick wear rate tests (average of 4 picks)

No.	Manufacturer	Mass before g	Mass after g	Loss g	Mined volume m^3	Indicator X1 -	Indicator X2 -	Indicator X3 -
1	P1	1354.31	3146.5	7.85	0.0269	1.077	1.001	0.928
2	P2	1359.79	13528	7.04	0.0265	0.977	1.298	1.024
3	P3	1399.22	1392.1	71.5	0.0277	0.922	1.275	1.084
4	P4	1395.73	1389.2	6.52	0.0269	0.868	1.484	1.152
5	P5	1427.27	1416.9	10.37	0.0246	1.477	0.000	0.677

Table 2. Summary of the results of the optimal choice for the weighting value W - indicator X1

No.	Manufacturer	X1 -	price PLN	P - W = 90	P - W = 70	P - W = 40	P - W = 35	P - W = 10
1	P1	1.077	100	81.03	81.91	83.24	83.46	84.56
2	P2	0.977	160	85.31	78.16	67.43	65.64	56.70
3	P3	0.922	90	94.17	**94.23**	**94.32**	**94.34**	94.41
4	P4	0.868	130	**96.54**	89.62	79.23	77.50	68.85
5	P5	1.477	85	62.92	71.16	83.52	85.58	**95.88**

Table 3. Summary of the results of the optimal choice for the weighting value W - indicator X2

No.	Manufacturer	X2 -	price PLN	P - W = 90	P - W = 70	P - W = 40	P - W = 35	P - W = 10
1	P1	1.001	100	69.21	72.72	77.98	78.86	83.25
2	P2	1.298	160	84.03	77.16	66.86	65.14	56.56
3	P3	1.275	90	86.76	88.47	**91.03**	**91.46**	**93.59**
4	P4	1.484	130	**96.54**	**89.62**	79.23	77.50	68.85
5	P5	0.000	85	10.00	30.00	60.00	65.00	90.00

Table 4. Summary of the results of the optimal choice for the weighting value W - indicator X3

No.	Manufacturer	X3 -	price PLN	P - W = 90	P - W = 70	P - W = 40	P - W = 35	P - W = 10
1	P1	0.928	100	81.03	81.91	83.24	83.46	84.56
2	P2	1.024	160	85.31	78.16	67.43	65.64	56.70
3	P3	1.084	90	94.17	**94.23**	**94.32**	**94.34**	94.41
4	P4	1.152	130	**96.54**	89.62	79.23	77.50	68.85
5	P5	0.677	85	62.92	71.16	83.52	85.58	**95.88**

When the price share of the picks is taken into consideration, the indicator values make it possible to identify the optimal offer. The influence of the applied indicator and the weighting *W* on the evaluation of the offer is expressed as *P* points. The optimal values for a given level of quality weighting (i.e. the highest *P* value) are highlighted in red. It is worth noting the disparity in price and durability; the durability of picks from P3 and P4 manufacturers is similar despite the significant price difference. Determination of the weighting *W* at the start of the pick selection procedure allows selecting the optimal pick in an objective, unambiguous and defensible way. Picks from manufacturers P3 and P4 usually get the highest number of points. Only when the quality weighting was low *(W* = 10), manufacturer P5 won in two cases.

5. Research into different materials and tips

In search of new materials for the bodies and coatings of conical picks, cooperation was established with various research centres engaged in materials engineering. The research subjects were picks made of prototype materials or with a prototype coating. The tests were carried out on eight series of four identical picks.

Tests were carried out on the following picks:

- S22 - reference (commercial) with ϕ22 carbide,
- S25 - patterned (commercial) with ϕ25 carbide,
- P22 - hardfaced with ϕ22 carbide,
- P25 - hardfaced with ϕ25 carbide,
- ZB25 - titanium nitride (TiN) coated with ϕ25 carbide,
- SB22 - subjected to special thermo-chemical treatment, with carbide,
- E22 - cast with ϕ22 carbide,
- EC - cast with a ceramic insert instead of a carbide tip.

After the tests, the picks were cleaned and prepared for the measurement of their weight. Next, based on the values obtained, the wear rate indicators were calculated. The values of the wear rate indicators are presented graphically in Fig. 3. Detailed conclusions regarding individual picks can be found in another article (Krauze et al., 2017). This article, however, focuses on how wear rates are calculated.

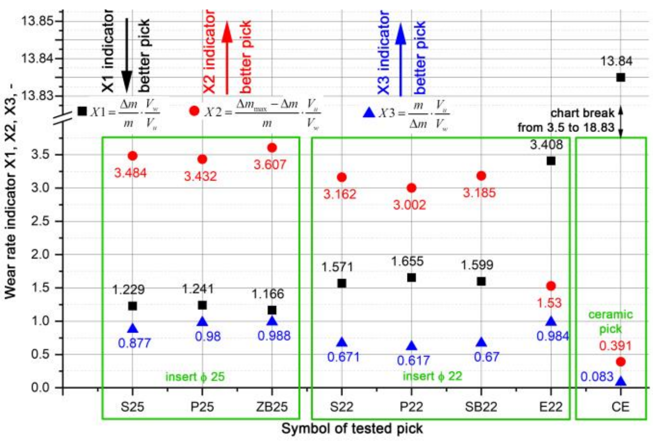

Fig. 3. Graphical presentation of the results of pick wear rate tests (based on (Bołoz, 2025))

The use of different indicators results in different values of pick wear rates (Fig. 3). In Table 5, three calculated indicators of the tested picks are listed in order from best to worst. It can be observed that the indicators *X2* and *X3* demonstrate a high sensitivity to the mined sample volume, and, therefore, can only be used for tests where the volume is the same or at least similar.

Table 5. Summary of the picks from the best to worst, depending on the wear rate adopted

No.	Indicator X1 -	Indicator X2 -	Indicator X3 -
1	ZB25 = 1.166	ZB25 = 3.607	ZB25 = 0.988
2	S25 = 1.229	S25 = 3.484	E22 = 0.984
3	P25 = 1.241	P25 = 3.432	P25 = 0.980
4	S22 = 1.571	SB22 = 3.185	S25 = 0.877
5	SB22 = 1.599	S22 = 3.162	S22 = 0.671
6	P22 = 1.655	P22 = 3.002	SB22 = 0.670
7	E22 = 3.408	E22 = 1.530	P22 = 0.617
8	CE = 13.840	CE = 0.391	CE = 0.083

In the above analyses, the arithmetic mean of the indicators of individual picks was used to determine the wear rate for a set of picks. According to the formulas presented earlier, the indicator for a set of tools can be calculated as the sum of the picks' weight loss. The indicator values based on both approaches have been illustrated in the graphs in Fig. 4.

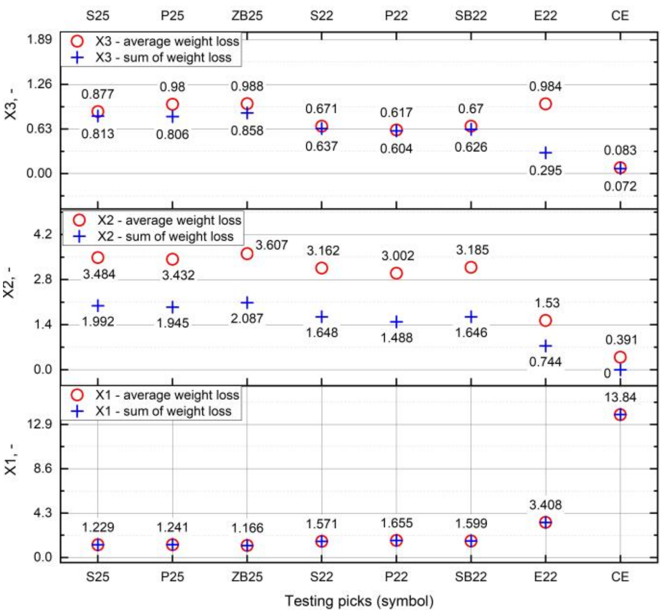

Fig. 4. Wear rates by the method of calculation

It is noteworthy that the indicator X1, in addition to its low sensitivity to changes in the volume of the mined sample, remains almost insensitive to the way it is calculated (Fig. 4). The values of the indicator slightly differed only in the case of the picks marked E22 and CE due to the two- and fourfold decrease in the volume of the mined sample. However, these minor variations did not exceed 0.5% and 0.15%, respectively. In the case of the E22 picks, the difference was greater due to differences in weight loss, which was several times higher than for individual picks in this series. Indicator X2, after changing the calculation to total loss or average loss, reacted in the desired manner by eliminating the CE pick, with the highest weight loss, while it did not exclude the next pick, E22. The X3 indicator significantly changed the value for the E22 pick due to significant differences in wear between the picks in this series. The X2 indicator was highly sensitive to differences in the volume of the mined sample. If it is unnecessary to automatically eliminate the picks with the highest weight loss during testing, X1 is the recommended indicator. The X1 indicator is not very sensitive to changes in the volume of the mined sample and to differences in the wear of individual picks. However, despite the little influence of the method of calculating X1 on its value, it is advisable to determine the average value from the indicators calculated for individual picks of the tested set, according to the methodology employed in this research.

6. Summary

Mechanical rock mining is extensively employed in many industries. To solve the problem of short tool life, research in this field is conducted in many centres all over the world. Testing of mining tools under real conditions is not comparable and seldom performed due to the costs and the specific nature of the mining industry. Laboratory testing is repeatable and enables measuring many quantities that cannot be measured in real conditions.

The unique test rig presented in this article enables testing the tool wear rates in laboratory conditions, but with real process parameters. Unlike in the case of other well-known test rigs, during the tests four picks are operated simultaneously with the use of a single tool. The test results allow the pick quality to be described quantitatively by providing a numerical wear rate. Such tests make it possible to compare different materials, design solutions, and pick manufacturers.

The results can be directly applied to select the optimal offer for public tenders. The results presented in this study show significant differences in the wear rate of picks from different manufacturers, even though each manufacturer claimed to offer high quality products, meeting all the requirements. According to the presented methodology, the wear rate can be determined with the use of three formulas. For indicators *X1* and *X3*, the worst pick scored 41% higher than the best one. On the other hand, in the case of indicator X2, the worst pick was automatically rejected by being assigned zero points; hence, the differences for the other were up to 14%. It was also discussed how the selection of the optimal offer was affected by adopting different price weightings. A variation of the price weighting from 10% to 90% was simulated. The different share of price in the total score and the use of a different wear rate influenced the selected offer. Three of the five picks were the best offers, depending on the combination of these two quantities.

The paper also presents the results of tests on picks with different tips and materials for eight series, consisting of four identical tools. In addition to different wear rates, different methods were used to calculate the resulting value. The total loss of the picks' weight and the average value of the indicator were taken into account, and the results varied depending on the indicator used.

The results of the wear rates of different types of picks show a wide variation in their quality, regardless of whether the picks were commercial picks, prototype solutions, or coatings. Tests carried out for tendering have shown that the wear rates of picks the same geometry but from different manufacturers can differ by more than a factor of two. However, considering the proper price/quality ratio before choosing the supplier allows identifying the best offer for the user. Tests of standard picks and those reinforced by hardfacing with wear-resistant materials have shown that a properly selected and manufactured layer reduces the wear rate by a factor of three during tests.

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