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MASS AND VOLUME WEAR RATES OF CONICAL PICKS

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Abstract:
Mechanical mining is extensively employed in the mining and construction industries. Conical picks are essential cutting tools that experience wear during operation, necessitating their timely replacement. Prolonging the service life of these picks can significantly enhance mining efficiency and provide economic benefits. This article examines the wear of conical picks used in mining machines and explores quantitative methods for assessing their wear rates. We have compared two different types of assessment: the mass and volume methods. Laboratory tests were conducted under controlled conditions to measure the wear of the picks, utilising a laboratory scale, 3D scanning, and Archimedes' principle. The accuracy of these methods was evaluated by calculating both the wear indicators' maximum and mean squared errors. The findings reveal that both methods produce similar results under standard conditions although there are differences in accuracy. 3D scanning, while slightly less precise than the Archimedes method, offers the significant advantage of generating a 3D file depicting the tool's wear profile. In contrast, the Archimedes method is characterised by a higher repeatability and accuracy. The decision to employ mass or volume-based indicators should depend on the objectives of the test: volume measurements are recommended to compare structurally different picks, while mass measurements are adequate for picks of the same type. In summary, both methods demonstrate high accuracy and can be effectively applied in engineering practices.

Key words: conical pick, laboratory tests, wear rate, tool life, volume determination, 3D scanning

INTRODUCTION

Minerals can be mined using various methods and suitable mining machines. Some of the most commonly used are machines with cutting heads, frequently equipped with conical picks. Mechanical rock mining involves acting with a tool, or a system of tools, on the rock to convert it into granular material. There are many theoretical models describing the condition of rock destruction, taking into account the parameters of the mining process as well as the properties of the mining material [1, 2, 3]. However, laboratory tests and increasingly popular numerical studies of rock cohesion failure in the mining process are still crucial [4, 5, 6]. Irrespective of the type of rock, tools are subject to wear during mining, especially in the case of hard-workable, and abrasive rocks. Therefore, methods of mechanical mining of such rocks have been sought after for many years [7, 8, 9, 10, 11, 12, 13, 14, 15]. Different materials or coatings make it possible to extend tool life by reducing wear rates. However, a comparison of tools with one another in terms of their durability requires appropriate laboratory tests. These tests are used to determine the mass or volume loss of the tool due to excavation of the concrete sample. This paper presents the mass and volume approaches to determining the wear rate. The accuracy of determining the volume of picks using a 3D scanner and a method based on Archimedes' principle was compared. The error of the mass and volume methods, resulting from the errors of the measured intermediate values, was determined. The maximum and root mean square error of the results for both methods was evaluated, with typical values of the measured volumes.

CONICAL PICKS

Conical picks can vary in size and shape depending on their application. A standard conical pick consists of a body, i.e. a shank part 3 and a working part 2, in which the tip 1 is brazed (Fig. 1) [15].

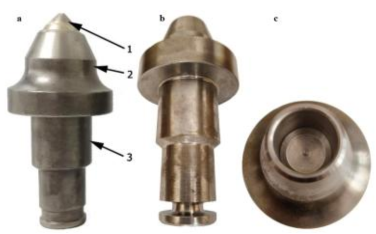

Fig. 1 Construction and basic dimensions of a conical pick: a. construction of the pick, b. pick body, c. a hole in the pick for the tip
Source: based on [7].

Cutting heads can be fitted with a dozen to more than two hundred picks. Standard longwall shearer and roadheader cutting heads are equipped with several dozen picks. The pick sometimes works for only a few hours and needs to be replaced with a new one. As indicated by various studies, picks wear can range from approximately one pick to as many as 80 picks per 1,000 tonnes of mined material [16, 17, 18].

Conical picks may exhibit various wear modes during operation. Examples of symmetric and asymmetric forms of wear are shown in Fig. 2.

Fig. 2 Examples of conical pick wear after working in a mine: a and c asymmetric, b, d, e symmetric
Source: [21].

The original shape of each worn pick has been outlined for comparison. The basic principle of conical picks' operation is that the tool can rotate freely about its axis during cutting, thus ensuring symmetrical wear and preserving the cutting edge geometry (Fig. 2d and e).

Such rotation is conditioned by the appropriate distribution of forces on the pick. The pick must be pressed against the pick holder along its axis, but if there is a bending, the pick tends to get stuck and wear asymmetrically (Fig. 2a and c) [19, 20].

The part of the pick subject to wear is made of different materials. The body is made of steel, whereas the tip – of carbide (WC-Co). The pick can be coated with a wear-resistant protective layer or reinforced with carbide tips or rings (Fig. 3).

Fig. 3 Ways of increasing the life of picks:
a. coated picks, b. pick with a carbide ring, c. pick with two carbide rings, d. pick reinforced with additional carbide tips
Source: based on [7].

The density of the steel is approximately 7.8 g/cm^3, while that of the WC-Co carbide tip reaches ca 14.5 g/cm^3. The mass determination of the wear rate is valid for testing tools of the same design. In the case of different design picks (Fig. 3) with the same wear volume, the mass ratio of the WC-Co tip and the steel body is different. Similarly, if the wear rate of picks with carbides, e.g. ϕ22 mm to ϕ25 mm, or standard picks is compared to that of a pick with a carbide ring, the wear calculated on the basis of the mass will not be reliable.Hence, to compare different pick solutions rather than the same type, it is necessary to determine the volume loss of the working part. Comparative studies of conical picks of different designs have shown that it is necessary to determine the volume loss for picks of different designs. On the other hand, choosing the same design and size with a carbide tip is sufficient to determine weight loss [7].

METHODOLOGY OF RESEARCH

In industrial practice, the service life of cutting picks is typically defined as the ratio of picks replaced to the amount of mined material. The service life determined in this way relates to the picks' specific, constantly changing operating conditions. It was therefore necessary to develop a laboratory testing method to determine their wear rate under controlled conditions, ensuring comparability and repeatability of results. The wear test method involves milling a concrete sample with the use of four identical conical picks. The wear rate is then calculated on the basis of the loss in mass and volume of the sample they have cut. All pick tests are conducted using the same sample and under identical parameters. This approach makes it possible to assess the pick using a numerical index and thus compare various pick designs (geometry, materials, coatings, carbide inserts) and identify the most effective configuration.

Laboratory tests need to be carried out on a special test rig, which is shown in Fig. 4.

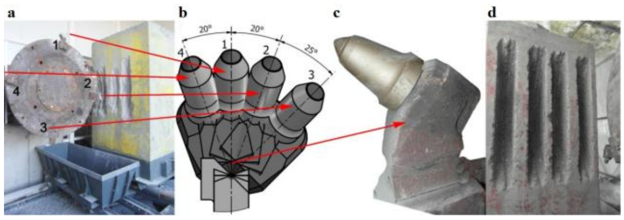

Fig. 4 Test rig for wear rate testing: a. test disc, b. arrangement of picks, c. sample pick in the holder, d. sample after testing
Source: [22].

After determining the mass of the picks before and after testing as well as the volume of the sample that has been cut with these picks, the unitless mass wear rate *C2m* is determined [7], [23]:

$$C2m = \frac{\Delta m}{m} \cdot \frac{V_w}{V_u}, \qquad (1)$$

where:
C2m – index determining the mass wear rate, -,
Δm – loss of the pick mass during testing (body including the tip), g,
m – mass of the pick before tests, g,
V_w – reference sample volume, m^3,
V_u – volume of the sample excavated during pick tests, m^3,

The volume of the excavated test specimen V_u is calculated on the basis of the cutting head's web, diameter, and cut length.

Determining the pick volume before and after tests is more complicated and time-consuming than determining the mass. It can be done using 3D scanning or a method based on Archimedes' principle. The volume wear rate index *C2V* is defined as follows:

$$C2V = \frac{\Delta V}{V} \cdot \frac{V_w}{V_u}, \quad (2)$$

where:

C2V –- index indicating the volume wear rate,

DV – loss of the pick volume during testing (body including tip), mm^3,

V – volume of the pick before testing, mm^3.

The use of a 3D scanner involves scanning the whole pick or its working part. After the resulting point cloud has been processed into a surface model, information on the volume of the component is obtained. Fig. 5a shows a scanning station equipped with a structured light scanner, the Einscan ProHD. Fig. 5b, on the other hand, contains a screenshot with a scan of the working part of the pick and the determined volume. A key advantage of 3D scanning is that the tool wear profile is recorded digitally, allowing further analysis or documentation.

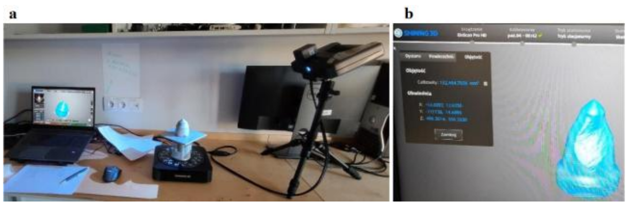

Fig. 5 3D scanning:
a. workstation with a scanner and rotary table, b. screenshot of an example pick with determined volume
Source: [7].

Tests based on Archimedes' principle are often used to determine the density of solids. Distilled, analytically pure water is used for the tests, and its density is each time determined by measuring its temperature [24]. The difference in mass, which is the mass of the displaced liquid, and the density of that liquid allow determining the volume of the object V_n according to the following formula:

$$V_n = \frac{m_p - m_w}{\rho_w(T_w)}, [m^3] \quad (3)$$

where:

V_n – volume of the object, mm^3,

m_p – mass of the object in air, g,

m_w – mass of the object in water, g,

T_w – temperature of water, C,

ρ_w – density of water at T_w, g/cm^3.

Fig. 6 shows the stand for determining the volume of conical picks, with an AXIS AG4000C balance, based on Archimedes' principle. Fig. 6a shows the working part of the pick when measuring its mass in air. Fig. 6b, on the other hand, shows the measurement of the mass of a steel shaft in water and the measurement of water temperature.

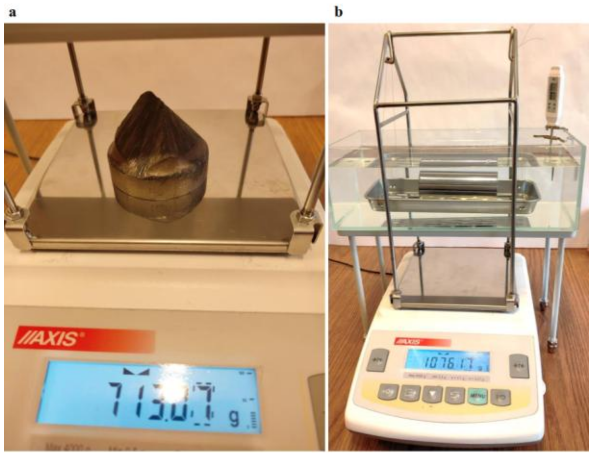

Fig. 6 Stand for determining the volume of conical picks, with an AXIS AG4000C scale, based on Archimedes' principle:
a. mass measurement in air, b. mass measurement in water with water temperature measurement

As the volume and wear rate indices were obtained by indirect measurement, the systematic error of the composite quantity was calculated in the form of a maximum uncertainty and a standard uncertainty, i.e. the maximum systematic error and the root mean square error were determined. The maximum error describes the most unfavourable case where the errors of all measured quantities reach a maximum value and the same sign, which is extremely rare. Hence, in practice, the root of the sum of the squares of the errors is used instead of the sum of their absolute values [25].

The method of error propagation (propagation of uncertainty) was applied for the calculations, using the formulae for maximum error ΔY_m and root mean square error ΔY_s in turn [25]:

$$\Delta Y_m = \pm\left[\left|\frac{\partial f}{\partial x_1}\Delta X_1\right| + \left|\frac{\partial f}{\partial x_2}\Delta X_2\right| + \ldots + \left|\frac{\partial f}{\partial x_n}\Delta X_n\right|\right] \quad (4)$$

$$\Delta Y_s = \pm\sqrt{\left(\frac{\partial f}{\partial x_1}\right)^2 \Delta X_1^2 + \left(\frac{\partial f}{\partial x_2}\right)^2 \Delta X_2^2 + \ldots + \left(\frac{\partial f}{\partial x_n}\right)^2 \Delta X_n^2} \quad (5)$$

where:

ΔY_m – maximum systematic error of the composite quantity y, unit of quantity y,

ΔY_s – systematic mean square error of the complex quantity y, unit of magnitude y,

$\Delta X_1, \Delta X_1, \ldots, \Delta X_n$, – absolute systematic errors of quantities $x_1, x_2, \ldots, x_n$, units of magnitude $x_1, x_2, \ldots, x_n$.

ERROR IN THE DETERMINATION OF VOLUMES OF SOLIDS

The calculation of the mass wear rate is subject to an error directly resulting from the accuracy class of the balance. On the other hand, in the case of volume index calculation, the error depends on the method used to determine the volume of the pick. A preliminary comparative study was conducted to establish the best method for determining volume. The tests were carried out on the steel shaft and the working parts of actual conical picks. Their volume was then determined using a 3D scanner and the displacement method. The steel shaft was additionally measured with precise measuring instruments.

The accuracy of 3D scanners has been the subject of various studies and publications [26, 27], including those concerning volume accuracy [28], but mainly for medical applications [29], [30, 31]. Many factors influence scanning accuracy. It depends on the object to be scanned and the scanning conditions, which should therefore be estimated for each case. In the case under analysis, it is the accuracy of the determined volume that is essential, not the accuracy of the scan itself. Therefore, the results obtained from the 3D scans were compared to those determined by measuring mass in air and water (Archimedes' method). In addition, the Archimedes method was compared to measurement with metrological instruments. The maximum and root mean square errors were also calculated for the measurement with instruments and the Archimedes method.

The steel shaft was measured with a Mitutoyo Absolute Digimatic 300 mm 570-302 altimeter, with a maximum error of $\Delta H = \pm 30$ µm, and an MMZc 25-50 external micrometre, with a maximum error of $\Delta D = \pm 5$ µm.

Relationships were derived for the maximum error ΔV_m and the mean error ΔV_s in order to determine the shaft volume with instruments:

$$\Delta VP_m = \pm\left(\left|\frac{\pi \cdot D^2}{4}\Delta H\right| + \left|\frac{H \cdot \pi \cdot D}{2}\Delta D\right|\right) \quad (6)$$

$$\Delta VP_m = \pm\sqrt{\left(\frac{\pi \cdot D^2}{4}\Delta H\right)^2 + \left(\frac{H \cdot \pi \cdot D}{2}\Delta D\right)^2} \quad (7)$$

where:

ΔVP_m – maximum systematic error of the *VP* shaft volume, mm^3,

ΔVP_s – systematic mean square error of the *VP* shaft volume, mm^3,

ΔH – shaft height measurement error $\Delta H = \pm 30\ \mu m$,

ΔD – measurement error of shaft diameter $\Delta D = \pm 5\ \mu m$.

Based on the above formulae, the maximum error in determining the shaft volume with instruments reached no more than 0.052% and the root mean square error was 0.037%. Volume measurement with instruments has a very high accuracy.

The relationships for the maximum error ΔV_m and mean ΔV_s for volume determination using the Archimedes method take the following form:

$$\Delta V_m = \pm\left(\left|\frac{\Delta m_p}{\rho_w}\right| + \left|\frac{-\Delta m_w}{\rho_w}\right| + \left|2\frac{m_w - m_p}{\rho_w^2}\Delta\rho_w\right|\right) \quad (8)$$

$$\Delta V_s = \pm\sqrt{\left(\frac{\Delta m_p}{\rho_w}\right)^2 + \left(\frac{-\Delta m_w}{\rho_w}\right)^2 + \left(2\frac{m_w - m_p}{\rho_w^2}\Delta\rho_w\right)^2} \quad (9)$$

where:

ΔV_m – maximum systematic error of the pick volume *V*, mm^3,

ΔV_s – systematic mean square error of the pick volume *V*, mm^3,

Δm_p, Δm_w – measurement error of the pick weight in air and water $\Delta m_{p/w} = \pm 0.05$ g,

$\Delta\rho_w$ – measuring error of the density of water $\Delta\rho_w = \pm 0.00026$ g/cm^3.

In the tests, an AXIS AG4000C scale with internal calibration was used to measure mass, with a verification interval of 0.1 g, in accuracy class II, for which the error is $\Delta m = \pm 0.05$ g. The error in the measurement of water density was determined from the density tables, taking into account the temperature measurement with a TFA 30.1013 thermometer with an error $\Delta T = \pm 0.8$ C. Based on the above formulas, it was found that the maximum error in determining the volume of the picks by means of water displacement did not exceed 0.20%. It can therefore be concluded that the volume measurement based on Archimedes' principle is very accurate.

Photographs of the steel shaft tests are shown in Fig. 7. Due to its shiny surface (Fig. 7a), the shaft has a special matte spray applied (Fig. 7b). Fig. 7c shows the shaft during scanning, and Fig. 7d shows its scan during volume determination. Fig. 7e, on the other hand, shows it during height measurement with an altimeter.

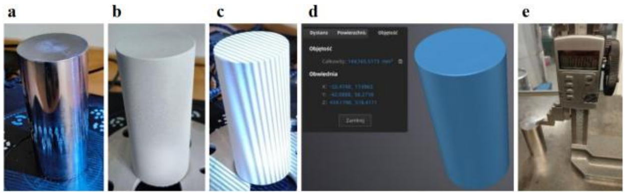

Fig. 7 Steel shaft measurement:
a. without matting on the rotary table of the scanner, b. matted, c. during scanning, d. during volume determination from the scan, e. during height measurement with an altimeter

The following average values of the steel shaft volume were obtained as a result of tests:

- measurement with instruments *VP* = 159357.862 mm^3,
- Archimedes method *VP* = 159071.362 mm^3,
- measurement by 3D scanner *VP* = 160087.634 mm^3.

Measurements were carried out in a series of 10 repetitions for each method. Due to the smallest maximum and root mean square error, the measurement with the metrology instruments was adopted as the reference. Correct determination of the solid volume using the Archimedes method resulted in a relative error of less than 0.18%. The result obtained from the 3D scan had a relative error below 0.46%.

In the next stage of the study, the volume of the actual conical picks was measured using the Archimedes method and a 3D scan. Three picks were prepared for these tests, one new and two with different degrees of wear. To facilitate the tests, the shank part of the picks was cut off (Fig. 8).

Fig. 8 Working parts of the conical picks, successively 1, 2, 3

Volume by Archimedes principle was determined according to the methodology, in a series of 10 repetitions. The measurements were highly repeatable, with only a few cases of the mass value differing by more than 0.01g. The values obtained are summarised in Table 1.

Table 1
Average values obtained during volume measurements using the Archimedes method

No.	Mass in air, g	Mass in water, g	Volume, mm³
1	713.07	621.34	91941.373
2	1108.14	972.35	136102.901
3	950.9	837.39	11377.561

These picks were then scanned in a series of 10 repetitions for each. The results were characterised by greater scatter. The picks required a matting spray. Fig. 9 and Fig. 10 show picks numbered 1 and 3 during the scanning process. The lack of matting spray resulted in low-quality scans, with little accuracy and various artefacts. The matting of the picks' surface allowed obtaining their accurate surface models.

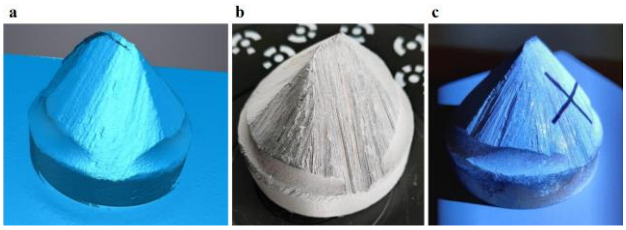

Fig. 9 Pick number 1:
a. low-quality scan, b. matted pick, c. pick during scanning

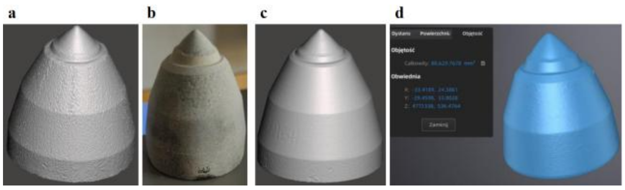

Fig. 10 Pick number 3:
a. poor quality scan, b. matted pick, c. good quality scan, d. volume measurement

The obtained scanning values are shown in the graphs in Fig. 11. The mean values of the pick volume and the relative error to the Archimedes method have been summarised in Table 2.
The scanner is characterised by lower accuracy and random errors, due to which the results may deviate from precise values. A series of measurements allowed determining that the error did not exceed ± 0.65% for this scanner model. However, random errors can result in significantly lower scanning accuracy. Tests were carried out by repeatedly determining the pick volume with the scanner, and the entire procedure, including the matting of the pick, was performed from the beginning each time. The maximum volume measurement error in the case of the Archimedes method measurement was 4.84%, which should be considered a coarse error.

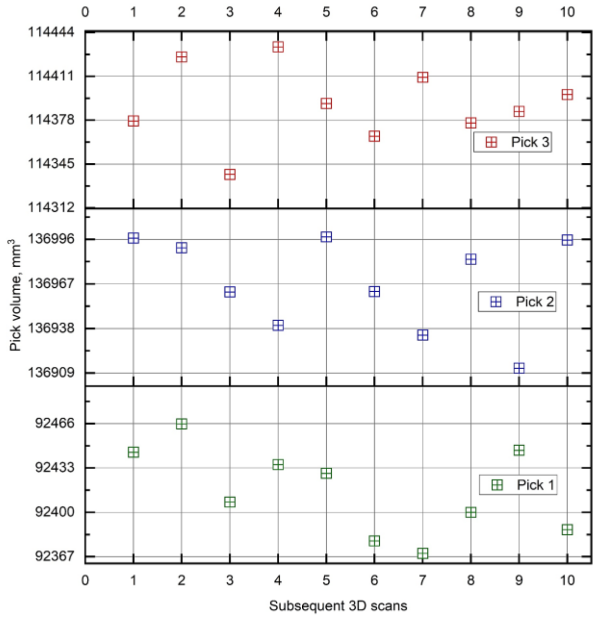

Fig. 11 Volume of the picks determined by 3D scanning

Table 2
Average values obtained from the volume measurements using the Archimedes' method

No.	Archimedes method Volume, mm³	3D scanning, Volume, mm³	Relative error, %
1	91941.373	92416.457	0.52
2	136102.901	136967.315	0.64
3	11377.561	114389.780	0.54

However, its detection requires the measurement to be performed several times.

ERROR OF THE MASS AND VOLUME METHODS

To compare the accuracy of the bulk and volume methods and the impact of using 3D scanning and the Archimedes method, the error of both methods was determined. The volume of the machined sample was determined from the length of the cut measured with a path sensor, with an error of ± 0.5 mm.
The formula for the wear rate of the *C2m* picks, taking into account the measurement of the weight of the pick before and after the tests and the quantities required to determine the volume of the machined sample, is as follows [7]:

$$C2m = \left(1 - \frac{m_{p2}}{m_{p1}}\right)\frac{V_w}{D \cdot Z \cdot L}, \tag{10}$$

where:
C2m – index determining the mass wear rate,
m_{p1} – mass of the pick before tests, g,
m_{p2} – mass of the pick after tests, g,
D – diameter of the test disc, mm,
Z – web of the test disc, mm,
L – cut length, mm.
The measured components of the wear rate formula are the weight of the pick before and after testing as well as the length of the cut, the others being constant quantities. Therefore, after calculation of the partial derivatives and substitution, the formulae for the maximum systematic error $\Delta C2m_m$ and the mean squared error $\Delta C2m_s$ take the following form [7]:

$$\Delta C2m_m = \pm\left[\left|\frac{-m_{p2}\cdot V_w}{m_{p1}^2\cdot D\cdot Z\cdot L}\Delta m_p\right| + \left|\frac{-V_w}{m_{p1}\cdot D\cdot Z\cdot L}\Delta m_p\right| + \left|\left(\frac{m_{p2}}{m_{p1}} - 1\right)\cdot\frac{V_w}{D\cdot Z\cdot L^2}\Delta L\right|\right] \quad (11)$$

$$\Delta C2m_s = \pm\sqrt{\left(\frac{-m_{p2}\cdot V_w}{m_{p1}^2\cdot D\cdot Z\cdot L}\Delta m_p\right)^2 + \left(\frac{-V_w}{m_{p1}\cdot D\cdot Z\cdot L}\Delta m_p\right)^2 + \left(\left(\frac{m_{p2}}{m_{p1}} - 1\right)\cdot\frac{V_w}{D\cdot Z\cdot L^2}\Delta L\right)^2}, \quad (12)$$

where:

$\Delta C2m_m$ – systematic error of the maximum value of *C2m*,

$\Delta C2m_s$ – root mean square bias of the *C2m* value,

Δm_p – mass measurement error of the pick $\Delta m_p = \pm 0.05$ g,

ΔL – error of trim length measurement $\Delta L = \pm 0.5$ mm.

In each case the derived formulas allow calculating the absolute error of the wear rate, the value of which depends on the values obtained during measurements. Calculations were made for different extreme values of the measured quantities to illustrate the maximum and root mean square error. The data and results, together with the calculated relative error, are summarised in Table 3. The obtained relative error values, due to the high measurement accuracy of the laboratory balance, practically do not depend on the weight of the pick, and only to a small extent are dependent on its weight loss. The most significant influence on the error is exerted by the length of the haunch. For the most common values of approximately 100 mm, the error does not exceed 1.0%, while for extremely low values it reaches ca 2.5% [7].

Table 3

Relative maximum and root mean square error of the mass wear rate (constant values: D = 1 815 mm, Z = 150 mm, V_w= 5 m^3)

No	m_{p1}, g	m_{p2}, g	L, mm	$\Delta C2_m$, %	$\Delta C2_s$, %
1	1900	1850	130	0.58	0.41
2	1900	1400	130	0.40	0.38
3	1900	1400	65	0.79	0.77
4	1900	1400	35	1.45	1.43
5	1900	1400	20	2.52	2.50
6	1100	1050	130	0.58	0.41
7	1100	700	130	0.40	0.38

Source: [7].

The maximum and mean squared error for the volume measurement and the volume wear rate C2V measurement were then determined. The relationships for the maximum error $\Delta C2V_m$ and mean error $\Delta C2V_s$ for the determination of the volume wear rate take the following form [7]:

$$\Delta C2V_m = \pm\left(\left|\frac{-V_{p2}\cdot V_w}{V_{p1}^2\cdot D\cdot Z\cdot L}\Delta V_m\right| + \left|\frac{-V_w}{V_{p1}\cdot D\cdot Z\cdot L}\Delta V_m\right| + \left|\left(\frac{V_{p2}}{V_{p1}} - 1\right)\frac{V_w}{D\cdot Z\cdot L^2}\Delta L\right|\right) \quad (13)$$

$$\Delta C2V_s = \pm\sqrt{\left(\frac{-V_{p2}\cdot V_w}{V_{p1}^2\cdot D\cdot Z\cdot L}\Delta V_m\right)^2 + \left(\frac{-V_w}{V_{p1}\cdot D\cdot Z\cdot L}\Delta V_m\right)^2 + \left(\left(\frac{V_{p2}}{V_{p1}} - 1\right)\frac{V_w}{D\cdot Z\cdot L^2}\Delta L\right)^2}, \quad (14)$$

where:

$\Delta C2V_m$ – systematic error of the maximum *C2V* indicator, -,

$\Delta C2V_s$ – root mean square bias of the *C2V* index, -,

V_{p1}, V_{p2} – pick volume determined before and after tests, mm^3.

As before, the derived formulas allow the absolute error of the wear rate to be calculated in each case. Also in this case, the length of the cut has the most significant influence on the error. For the most commonly used values of around 100 mm, the average error does not exceed 0.7% and the maximum error is around 1.0%, while for extremely short cut lengths it reaches around 3.0%.

The volume method has a larger error than the bulk method, due to the double measurement of mass and the error associated with temperature measurement, as well as the determination of water density. However, in both cases, for cuts of 100 mm in length, the error oscillates around 1% or less. Both methods are very accurate.

SUMMARY

The considerations presented in the article concern the methods and accompanying measurement errors in determining the mass and volume wear rates of conical picks. Such tests are crucial for assessing the quality of picks and selecting new materials for their construction. Correct measurements allow obtaining highly accurate results, but each measurement is subject to a specific error. Determination of mass ratios involves measuring the mass of the picks in a simple and accurate way. In contrast, determination of volume indices requires a more complex method for determining the picks' volume, which increases the measurement error. During the research, the volume of the picks was measured using a method based on Archimedes' principle and 3D scanning. Both the mass and the volume of the picks were determined twice, before and after tests, which significantly increased the error.

Determining the volume of conical picks with the use of a 3D scanner is less precise, but allows obtaining a 3D model that shows the exact form of tool wear. In contrast, the method based on Archimedes' principle has fewer errors but its only result is a larger tool volume.

To determine the accuracy of the liquid method, measurements were taken of a steel shaft that was precisely made and measured with metrological instruments. Based on the formulas derived, the maximum error in determining the shaft volume with instruments was reached no more than 0.052%, while the root mean square error was 0.037%. Due to a minor error, the instrument measurement was adopted as the reference. The correct determination of the solid volume using the Archimedes method resulted in a relative error of less than 0.18%, whereas the result obtained from the 3D scan had a relative error below 0.46%. Despite the threefold difference, a high accuracy of both measurement methods was achieved.

A series of measurements of the volume of the working parts of the picks was also carried out in order to determine the maximum error of the 3D scan, which did not exceed ± 0.65%. However, random errors can cause significantly lower scanning accuracy. Repeated measurements have shown that the scanning error can reach almost 5%.

Formulas were then derived to calculate the absolute error of the mass and volume wear rate in each case. To illustrate their magnitude, calculations were made for different values. For a commonly used cut length of approximately 100 mm, the error of both mass and volume indicators does not exceed 1.0%. Both methods are very accurate and can be effectively applied in engineering practice.

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