The new method for assessing rock abrasivity in terms of wear of conical picks

Kamil Mucha
AGH University of Science and Technology, **Poland**

INTRODUCTION

In Polish as well as in many underground mines around the world, the drilling of roadway workings and the exploitation of longwall excavations is most often carried out by means of mechanical cutting, which involves direct operation with a cutting tool or a set of cutting tools on unmined rock. One of the basic groups of machines used in underground mining are cutting machines. In the case of tunnel excavation, roadheaders are used, whereas in the case of mining works, longwall shearers (Kotwica, 2018; Bołoz, 2018).

Among picks used on mining shearers, the most commonly used are conical picks. A pick is an element that is in direct contact with the cut rock and it is the one that is the quickest to destroy and thus needs to be replaced (Krauze et. al., 2015; Kotwica, 2018; Bołoz, 2018). There are different types of wear (Figure 1), but the worst case is a loss of the carbide insert (Figure 1d).
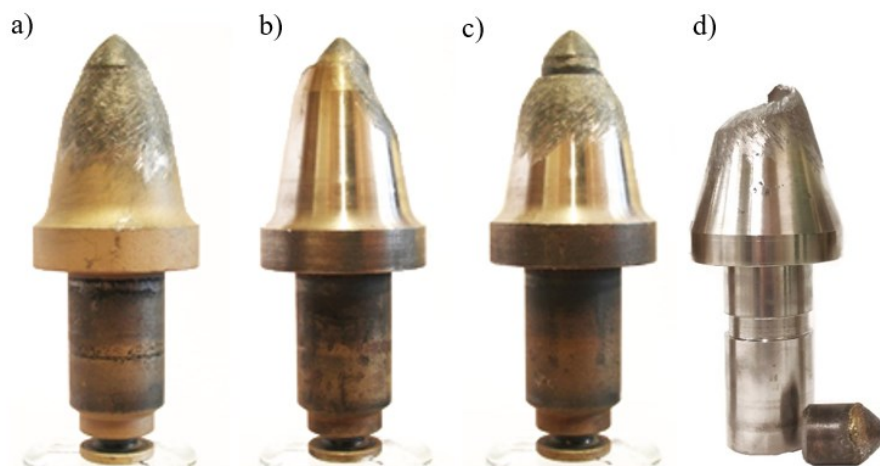

Fig. 1 Types of wear of a conical pick:
a - symmetrical, b - unsymmetrical, c - striping of the carbide insert, d - carbide insert falling out

Currently, tunnel excavations, especially those providing access, are drilled in rocks with very unfavourable parameters. This applies first of all to large

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compactness and resistance to uniaxial compression of the rock mass. More and more often one encounters hard rocks, such as sandstone, which have a structure similar to homogeneous, which causes that their mining poses serious problems, and additionally they have good abrasive properties (Kotwica, 2018; Bołoz, 2018).

Currently, the most known and proven method of testing abrasivity is the CERCHAR abrasivity test. Based on it, the CAI indicator is determined. The CERCHAR abbreviation comes from the Centre d'Etudes et Recherches des Charbonnage de France – an institute which in 1980 was the first to develop a rock abrasivity test. The test is carried out by means of a sharpened pin made of steel with line inclination angle of the cone tip of 90°, pressed against the surface of the rock sample under a load of 70 N, by means of which a groove 10 mm long is drawn (Fig. 2). The test is performed on surface of a small piece of rock cut away from a natural rough texture unmined rock. During the test, the sample is securely mounted in a clamp. A standard pin with a diameter of 11 mm and a length of 60 mm should be made of 115CrV3 steel with a hardness of 54-56 HRC. Generally, the CAI value is determined by the flattening or rounding of the tip of the pin caused by friction by the sample, which is measured under a microscope using an eyepiece micrometre. The diameter of the flattening is measured in four positions, each time the pin is rotated by 90°. On this basis, the CAI is calculated according to the following formula (1) (Plinninger et al., 2003; Käsling & Thuro, 2010):

$$CAI = 10 \cdot \frac{1}{n_i} \cdot \sum\nolimits_{n_o} d \, [mm] \tag{1}$$

where:

n_i – number of assays made;

d – resultant mean flattening of the pin caused by friction on the sample.
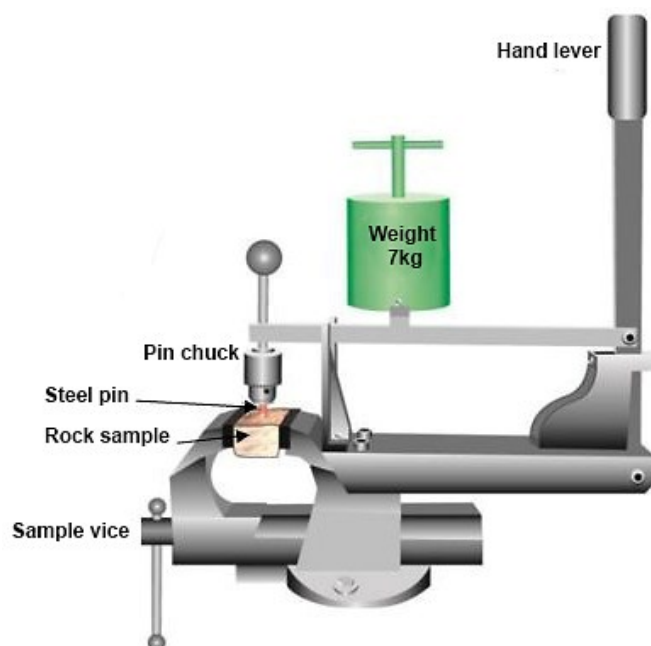

Fig. 2 Stand for carrying out the CERCHAR abrasivity test
Source: (Plinninger & Restner, 2008)

Based on many rock tests, abrasivity grades expressed in CAI values have been created. This classification is given in Table 1.

Table 1 The classification of abrasivity for CERCHAR abrasivity index

CERCHAR abrasivity index	Classification
0.3–0.5	not very abrasive
0.5–1.0	slightly abrasive
1.0–2.0	medium abrasive
2.0–4.0	very abrasive
4.0–6.0	extremely abrasive

Source: (Plinninger & Restner, 2008)

The CERCHAR method, although it is simple and easy to perform, has one main disadvantage i.e. the measurement can be made only on small fragments of rock and that is why a large spread of the obtained results is possible, depending on the test site chosen by the operator for inhomogeneous and variable rock samples. Secondly, the accuracy of this method largely depends on the skills and experience of the person performing the test, who must have sufficient experience to identify the criteria for abrasion of the rock sample, and then perform the test according to these criteria. In addition, the measurement of the pin flattening diameter requires the use of a specialized microscope and can be difficult to determine in the case of unsymmetrical or one-sided flats (Mucha, 2019).

For this reason, the need arose to develop a new method for assessing rock abrasivity, which, although to some extent, will eliminate the above-mentioned disadvantages. The second reason was the lack of an unambiguous method of assessing the rock abrasivity normalized in Poland (Mucha, 2019).

NEW METHOD FOR ASSESSING ROCK ABRASIVITY

The method involves the assessment of the mass abrasive wear of a standard steel pin, in contact with a rock sample with a constant clamping force of 300 N and moving in a uniform motion around a circle at 50 rpm for 8 minutes. The steel pin with a diameter of 8 mm and a length of 35 mm is made of S235 steel. Samples of rock for testing are taken in a form of cores with a diameter of Φ70 mm directly from a mining excavation (Mucha & Krauze, 2018; Mucha, 2019).

The test stand has been equipped with a gear motor unit with a 0.37 kW motor, on shaft of which the steel pin holder is mounted (Fig. 3a). The rock sample is mounted in a special holder, ensuring its immobilization during the test. An important advantage of the stand is the horizontal arrangement of the rock sample, which enables removal of loose rock grains from the road on which the pin moves. Thanks to this solution, the influence of loose grains on the wear of the standard pin and rock sample was eliminated. The steel pin together with the rock sample form a friction pair (Fig. 3b). Constant pressure of the rock sample to the surface of the pin is provided by a gravitational pressure system with six weights of 5 kg each. The pin speed and time are set using the touch

panel (Fig. 3c). Thanks to the control system, the engine stops automatically after a set time (Mucha & Krauze, 2018; Mucha, 2019).
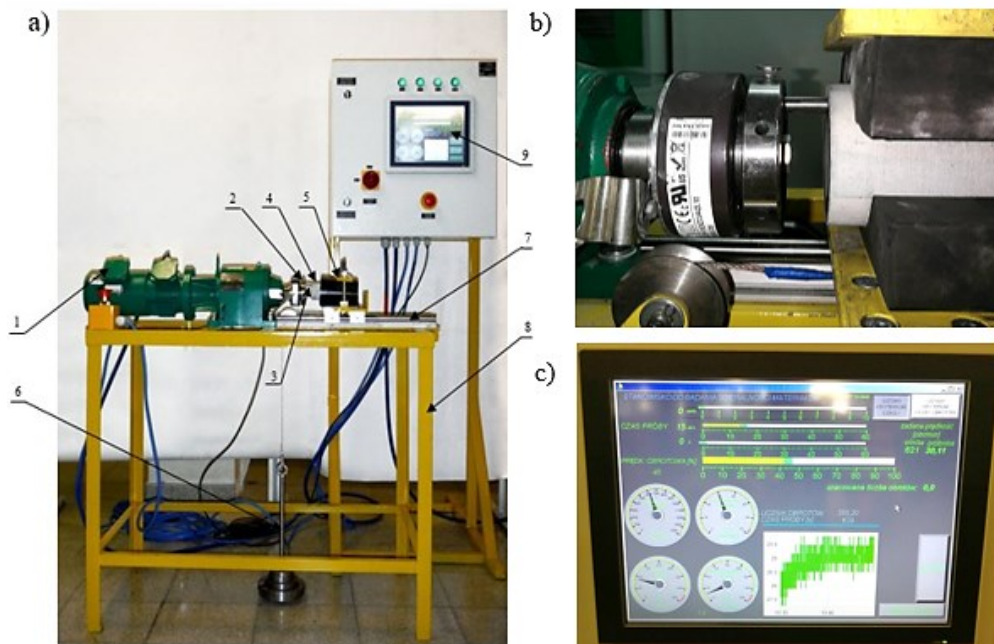

Fig. 3 Laboratory stand to assess rocks abrasivity:
a) general view, b) view of the friction pair, c) view of the control panel:
1 – drive unit, 2 – steel pin, 3 – pin holder, 4 – rock sample, 5 – rock sample holder,
6 – pressure system, 7 – sliding system, 8 – supporting structure, 9 – control panel
Source: (Mucha, 2019)

The weight of the pin as well as the sample is measured both before and after the test. The parameter characterizing the rock abrasivity is the abrasivity index W_z, which is defined as the ratio of the weight loss of the pin to the loss of the sample weight and is calculated using the following formula (2):

$$W_z = \frac{M_{pa}}{M_{pi}} \tag{2}$$

where:
W_z – abrasivity index,
M_{pi} – weight loss of the sample, g,
M_{pa} – weight loss of the pin, g.
where:

$$M_{pa} = M_{pab} - M_{paa} \tag{3}$$

where:
M_{pab} – weight of the pin before the test, g,
M_{paa} – weight of the pin after the test, g.

$$M_{pi} = M_{pib} - M_{pia} \tag{4}$$

where:
M_{pib} – weight of the sample before the test, g,
M_{pia} – weight of the sample after the test, g.

Based on the results from over 600 tests, abrasivity grades expressed in the values of the W_z index were determined. The classification is given in Table 2.

Table 2 Abrasivity classification using the AGH method

Abrasivity index W_z [-]	Abrasivity Classification
< 0.1	negligible
0.1 – 0.5	insignificant
0.5 – 0.9	very low
1.0 – 1.9	low
2.0 – 2.9	medium
3.0 – 3.9	high
4.0 – 5.0	very high
> 5.0	extreme

Source: (Mucha, 2019)

THE TEST PROCEDURE AND RESULTS

Using the developed method, it was decided to check the abrasivity of the most common gangue rocks in Polish hard coal mines. Rock samples from underground workings of five mines were collected for research, drilling in the mines is carried out by mechanical cutting using shearers. Samples were taken from mines located in Upper Silesia and Lesser Poland, i.e. from the regions with the largest hard coal resources in Poland (Fig. 4).
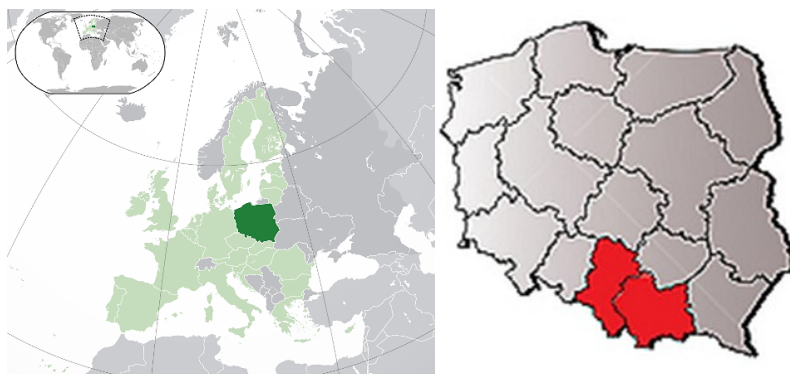

Fig. 4 Location of the area from which rock samples for research were taken
Source: (Wikipedia 2019, Megapixl 2019)

A total of 12 samples were collected, each from other excavation, which was given the appropriate markings. Among the samples taken were sandstones, claystones, mudstones and shales. For each sample, the abrasivity index W_z (Fig. 5) and uniaxial compression strength (UCS) were determined and chemical composition analysis using the XRF method was carried out.
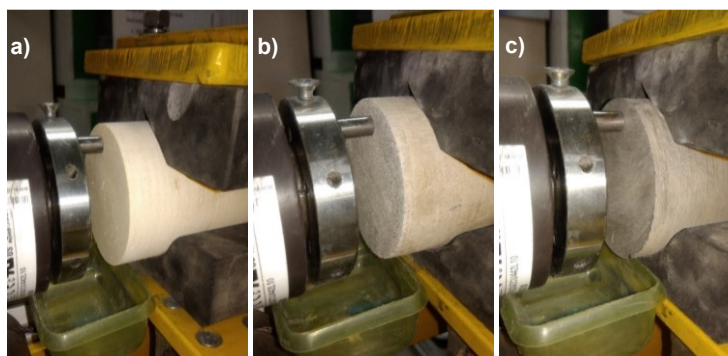

Fig. 5 View of selected samples during the abrasivity test using the AGH method:
a) sandstone, b) claystone, c) mudstone

A summary of the results obtained is presented in Table 3.

Table 3 Summary of test results

No.	Rock type	Sample code	UCS [MPa]	SiO_2 [%]	Al_2O_3 [%]	W_z [-]	Abrasivity Classification
1	medium-grained sandstone	S1	22.4	76.3	16.5	2.4	medium
2	fine-grained sandstone	S2	64.6	66.1	11.8	1.5	low
3	shale	S3	9.5	64.4	29.0	0	negligible
4	medium-grained sandstone	MS1	29.4	83.5	6.7	3.8	high
5	claystone	MS2	24.7	50.4	28.0	0.2	insignificant
6	fine-grained sandstone	MS3	19.4	75.3	11.1	1.7	low
7	claystone	MS4	28.4	62.5	28.1	0.3	insignificant
8	mudstone	J1	12.2	58.8	27.9	0	negligible
9	mudstone	J2	12.8	62.3	28.2	0	negligible
10	variegated sandstone	J3	20.8	72.2	15.3	1.6	low
11	fine-grained sandstone	P1	30.1	71.7	15.5	1.2	low
12	mudstone	B1	18.1	59.1	28.0	0	negligible

ANALYSIS OF TEST RESULTS

Rocks that have been taken from mine excavations are characterized by diverse abrasive and strength properties. The first relationship that was decided to be check was whether the abrasivity index W_z depends on the value of uniaxial compression strength UCS. As shown in Figure 6, the W_z abrasivity index shows a weak correlation with UCS within this group of rocks.
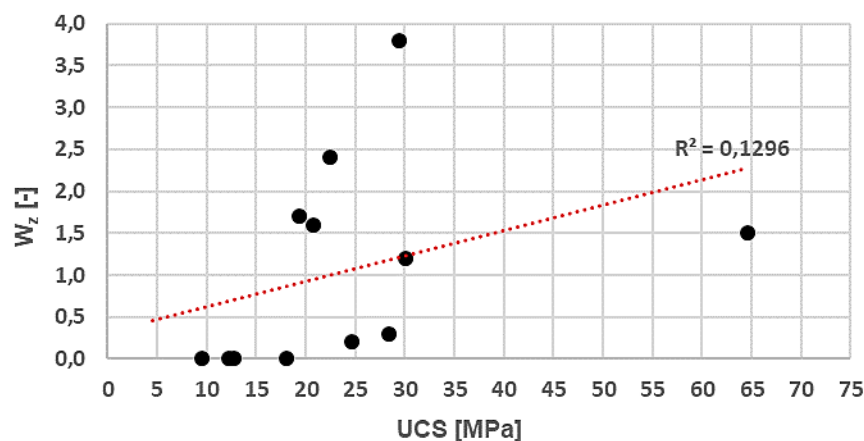

Fig. 6 The dependence of the W_z abrasivity index on UCS

However, many authors, e.g. (Yaşar & Yilmaz, 2016) showed the same correlation between CAI from the CERCHAR method and the UCS value. This weak correlation indicates that it is not possible to estimate the abrasive properties of rocks on the basis of UCS values. For example, if you consider two rocks that have exactly the same UCS value, and one of them will have a higher

abrasivity index, it will cause more tool wear. Therefore, when selecting the type of cutting tool, both indicators should be taken into account.

A definitely stronger correlation was observed between the abrasivity index W_z and the chemical composition of the studied rocks (Figures 7 and 8). The most numerous, in terms of quantity, is the percentage of SiO_2, i.e. the so-called silica. The fact that the more silica in the rock, then the rock has better abrasive properties, was known a long time ago. This is confirmed by the research of many scientists, incl. (Torrijo et al., 2019, Yarali et.al., 2008). For the group of collected rocks, the R^2 determination coefficient was 78.9% (Fig. 7), which indicates a strong correlation of these two parameters.
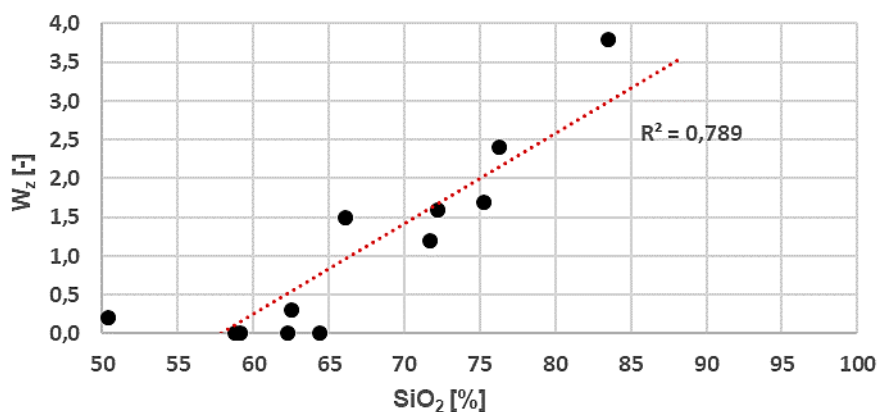

Fig. 7 The dependence of the W_z abrasivity index on the percentage content of SiO_2

The chemical compound of the second largest quantity turned out to be aluminium oxide. Its percentage content also showed a strong correlation with the value of the W_z index and for the collected rocks R^2 determination coefficient was 82.8% (Fig. 8).
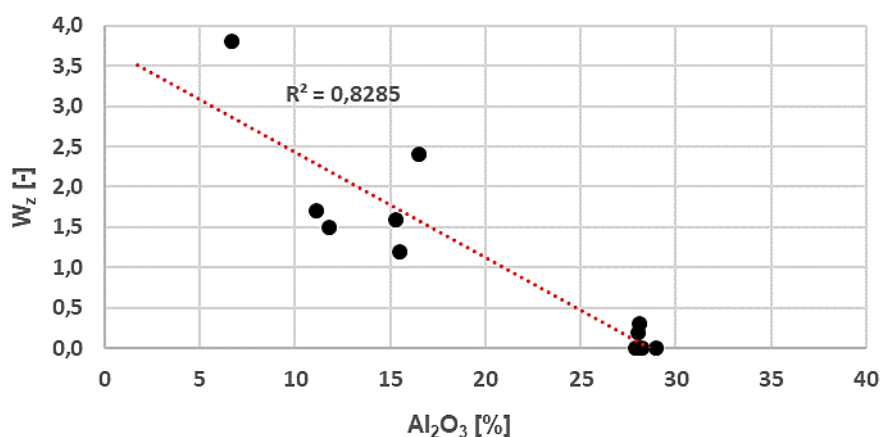

Fig. 8 The dependence of the W_z abrasivity index on the percentage content of Al_2O_3

However, in this case the situation is reversed compared to silica and the more aluminium oxide, the smaller the value of the W_z index. Such a strong correlation between Al_2O_3 and the abrasivity index CAI was also noticed by the authors of the publication (Torrijo et al., 2019).

CONCLUSION

When selecting cutting machine picks, taking into account the physical and mechanical properties of rocks, attention is paid mainly to the uniaxial compression strength (UCS). Very rarely, the user (mine) takes into account the rock abrasivity. For this reason, methods for determining rock abrasivity are not widely used. Currently, the most known method is the CERCHAR abrasivity test. The innovative method of assessing abrasivity of rocks, presented in this article, distinguishes itself from other with simplicity, collecting rock samples directly from mine excavation without labour-intensive and time-consuming preparation for testing and the fact that it eliminates the impact of loose grains on the wear of the pin as well as the rock sample.

The research described in this article allowed the use of this method of rock abrasivity assessment to determine the abrasivity indexes of rocks most abundant in the currently cut tunnel excavations in Polish hard coal mines. These rocks include sandstones, claystones, mudstones and shales. Thanks to a careful analysis of the results, the relationship between the new abrasivity index W_z and the uniaxial compression strength (USC), the percentage of SiO_2 and Al_2O_3 was obtained.

The results obtained are promising and show that the proposed method has great potential to carry out tests related to the assessment of rock abrasivity. However, it should be noted that it is still being refined and requires further testing.

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Abstract.

During the exploitation of mineral raw materials, a cutting tool is an element that is directly in contact with the unmined stone being cut. The most commonly used cutting tools include conical picks. The increasing pressure to reduce mining costs causes an increasing demand for affordable and reliable ways to increase the reliability of mining machines. Abrasive wear is the most common process affecting the wear of shearer picks, hence a good and simple laboratory method for assessing rocks abrasivity is needed. The new method was developed in the aspect of selection of conical picks with appropriate protection of the pick working part, increasing its durability. The method involves the assessment of mass abrasive wear of a standard steel pin and rock sample, and the determination of the abrasivity index W_z of the tested rock, as the ratio of the mass loss of the steel pin to the mass loss of the rock sample. The article presents the procedure of conducting tests, construction of a laboratory test stand and the use of the developed method to assess the abrasivity of gangue rocks occurring in the currently cut tunnel excavations of Polish hard coal mines.

Keywords: test method, assessment of abrasivity, conical picks, abrasive wear, underground mining