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Examination of hoist drum lining

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Abstract
The safety and reliability of the mine hoisting system are essential for the effective and safe operation of an underground mine, which utilizes a mine shaft for transport and haulage. Thus, high safety and quality standards apply to each element of the hoist, including the winding machine. Therefore, it also concerns the lining of the machine's drum. This element should be characterized by specific parameters, such as hardness and the friction coefficient between the rope and the drum lining. The following article presents a procedure for the examination and results of tests conducted on samples of drum lining provided by two different underground coal mines. The aim of the research was to verify if the lining provided by the mines and previously stored by them for many years complies with the safety requirements and can be installed on the hoist drums. Moreover, the results were verified by EDS tests.

Keywords
mine hoist, winding machine, hoist drum lining, friction coefficient of headrope, mine safety, EDS testing.

Introduction

The reliability and safety of mine hoists are issues of the greatest concern for the safety and effectiveness of underground mines, which utilize mine shafts for haulage and transport. As the hoisting systems are responsible for haulage and transport of materials and staff from mine workings to the surface, each failure of a hoist may result in mine operations stoppage, which is associated with significant economic consequences (Hansel, 2000; Zmysłowski, 2004; Giraud & Galy, 2018; Czaja & Kamiński, 2016; Rokita, 2018; Kalinowski et al., 2018; Hansel, 2005; Cichociński & Ładecki, 2005; Duda & Józek, 2023).

As the mine hoisting system comprises various elements that cooperate with each other, proper care of each of them, as well as their effective cooperation, is required. Thus, an inspection is conducted for ropes, braking devices, guides, conveyances, sheave wheels, and the winding machine, encompassing all its key elements (Hansel, 2000; Giraud & Galy, 2018; Czaja & Kamiński, 2016; Hansel, 2005; Kubiś et al., 2023).

Modern winding machines, efficient, safe, and robust devices used for vertical transport in the mining industry, evolved from steam-powered hoists, which in turn replaced horse- and men-powered winches in the 19th century. It can be noticed that some of the elements were and still are present in which of the devices listed above, among them drive (manual, horse, steam, or electric), signalling system, and drum on which a rope is wound (Hansel, 2000; Czaja & Kamiński, 2016; Zabolotny et al., 2015; Mushiri et al., 2017; Gierlotka, 2008; Hu et al., 2016; Mangalekar et al., 2016; Ryndak & Kowal, 2015).

Hoist drums, although they may appear similar or even identical, differ in construction depending on the winding machine. Drums were also a subject of evolution over the decades (despite the clear resemblance between drums used nowadays and those of the 19th century), similarly to other elements of mine hoists. The greatest changes in drum construction concern their steel constructions and linings (Mangalekar et al., 2016; Hansel, 2012; Zabolotny et al., 2012; Kowal & Sinka, 2020; Wolny & Badura, 2008; Zabolotny, 2019).

Numerous types of linings were used over the years. Drums of historic winches were made of wood, and so were the linings used in the more recent winding machines. Such solutions are, in fact, still in use. Besides wood, various materials are used, including metal alloys, leather, rubber, and composites. Sometimes the lining is made of a combination of two materials listed above. Currently, composite lining is the most commonly used. In Poland, the most popular materials are solutions of Becorit and Modar material by SPOIWO, developed in cooperation with AGH UST in Krakow (Hansel, 2012; Hansel & Blecharz, 1995; Buchcik et al., 2018; Hansel, 2006; Hansel, 2007; Hansel, 2005; Krešák et al., 2021; Stawowiak & Rożenek, 2019; Carbogno, 2001; Carbogno et al., 2007).

Materials used in hoist drum lining must meet high requirements, including resistance to pressure, abrasion, high and low temperatures, changing weather conditions, aging, lubricants, brine, and other unfavourable environmental factors. Moreover, they should be machinable and formable and provide a high friction coefficient between the lining and rope (Kubiś et al. 2023). Different materials can meet the requirements presented above, including polyamides and vinyl-rubber composites. Modar linings utilize this technology (Hansel, 2012; Hansel & Blecharz, 1995; Buchcik et al., 2018; Hansel, 2006; Hansel, 2007; Hansel, 2005; Krešák et al., 2021; Stawowiak & Rożenek, 2019; Carbogno, 2001; Carbogno et al., 2007).

To ensure the safe operation of the winding machine and, consequently, the entire mine hoist, various tests are conducted, particularly regarding the hardness and friction coefficient of the drum lining. The following article presents the results of such tests of Modar lining, conducted for two different winding machines operating in the Polish mining industry. According to the manufacturer's guidelines, drum lining should be installed within five years of its production. The aim of the tests was to verify the applicability of the lining, despite its age being greater than permitted by the producer. The results were verified with EDS tests, in which samples of lining were compared with samples of newly manufactured lining (Barbacki, 2003; Wassilkowska, 2014; Zhigang, 2003; Goldstein & Newbury, 2003; Panciejko, 2010).

Materials and methods

Hardness test

Tests of the hardness of the Modar R3/Mz lining samples were conducted using the EHS1A Digital Durometer hardness tester, with the parameters presented in Table 1.

Tab. 1. Parameters of EHS1A Digital Durometer hardness tester

Parameter	Unit	Value
Number of samples simultaneously tested	pcs.	1
Number of storaged results	Pcs.	500
Measuring distance	Mm	2.5
Accuracy	Shore	± 1H
Weight	Kg	0.17
Power supply	[V/~/Hz]	1.5V*3
Measuring range	-	Shore A, B, C, D, O, OO

Friction coefficient test

Before determining the actual friction coefficient, a measuring range was specified. The average value of surface contact pressure between a rope and lining is given by the equation:

$$p = \frac{S_1 + S_2}{n \cdot D \cdot d}, MPa \tag{1}$$

where:
S_1, S_2 – forces in rope on both sides, N
n – number of headropes, pcs.,
D – drum diameter, mm,
d – headrope diameter, mm.

Based on the data provided by the collieries, the range of the surface contact pressure between the rope and lining was calculated. Thus, the range used in the test is: 1.0 MPa, 1.5 MPa, and 2.0 MPa. The assumed temperature range is between 5 °C and 25°C. Thus, the tests were carried out at temperatures of 5°C, 15°C, and 25°C.

A diagram of a test device used in the examinations is shown in Figure 1.

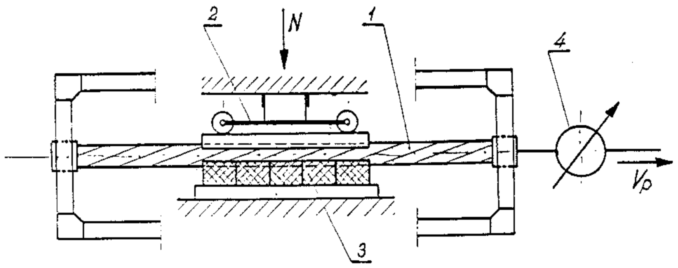


Fig. 1. Diagram of the measuring station for the friction coefficient tests; 1 – steel rope, 2 – movable cart, 3 – lining sample, 4 – measuring unit

A steel rope, tensioned by a steel frame, is pressed against a lining sample with a force of N, using a movable cart. In each lining sample, there is a groove with a radius equal to 0,53÷55 of rope diameter. The value of the force required for the induction and maintenance of the rope slip is recorded by the measuring unit.

Tests were conducted using lining samples of 150 mm in length for various temperatures and contact pressures listed above.

Values of the measured pressure were calculated using the following formula:

$$p = \frac{N}{L \cdot d}, MPa \tag{2}$$

where:
L – sample length, L = 150 mm,
d – rope diameter, d = 18 mm,
N – pressing force, N.

The Value of the friction coefficient is given by the formula:

$$\mu = \frac{T}{N} \tag{3}$$

where:
T – measured force, N,
N – pressing force, N.

EDS analysis

For the purpose of comparison of the analyzed and newly manufactured material, five samples were collected from each group (mine 1, mine 2, and the new material). Each sample was then split into two parts, of which one was tested after coating. Samples were the subject of SEM tests with EDS. A ThermoFischer Scientific Phenom

XL Desktop Microscope with a Phenom EDS attachment was used, in conjunction with Phenom ProSuite software. Accelerating voltage values were equal to 10 kV for surface imaging and 15 kV for EDS analysis. Chamber pressure was 1 Pa (low vacuum). Secondary Electron Detectors and Back-Scattered Detectors were used. Surface morphology, average surface chemical composition, and surface distribution of different chemical elements were analyzed and compared.

Report no. 1

The aim of the test was to verify whether the Modar R3/Mz lining segments owned by the mine and stored for over 10 years are still characterized by physical parameters that allow for their use in a winding machine of the modernized hoisting system of one of my shafts.

Detailed results of the hardness tests are presented in Appendix A. In total, 194 segments of the Modar lining were tested. Individual results are in the range of 93.5° to 98.5°Sh A with accuracy ±0.6°Sh A. Obtained average values of hardness of lining segments are in the range of 94.4° to 97.7°Sh A.

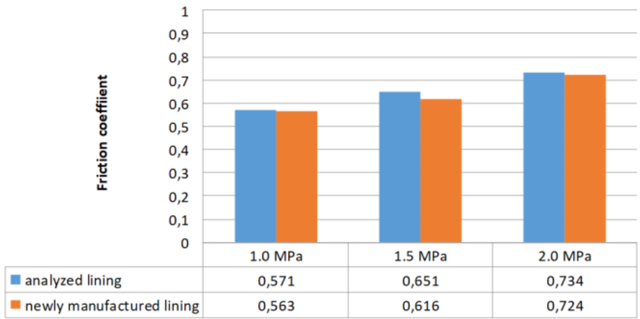
For comparison purposes, four measurements of the hardness of newly manufactured lining segments were conducted. Their results are as follows:

- 95.6°Sh A,
- 96.9°Sh A,
- 94.8°Sh A,
- 95.0°Sh A.

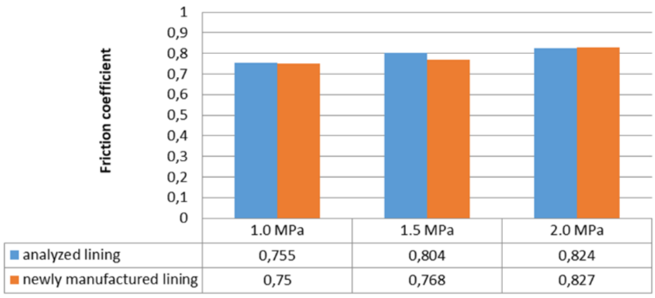
Thus, the average value of newly manufactured lining hardness is 95.0±0.6°Sh A.

Detailed results of the friction coefficient tests are presented in Appendix A. Tests were performed on both newly manufactured and examined lining segments. The research comprises an analysis of clean rope (purified from lubricant) and rope lubricated with Nyrosten N113 for both new and tested lining segments. The conditions of the tests are presented in Section 2.2.

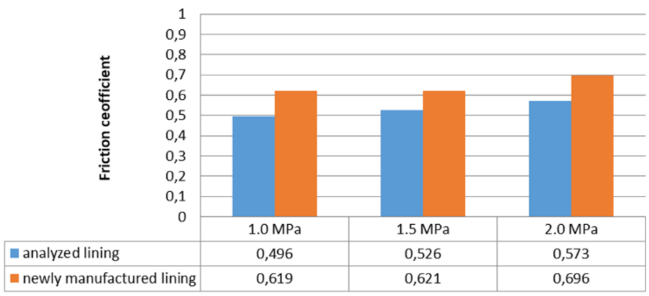
Figure 2 presents a comparison of the test results of clean rope in all analyzed temperatures. A complete set of results is provided in Appendix A.



a) Temperature 5°C



b) Temperature 15°C



c) Temperarture 25°C

Fig. 2. Comparison of friction coefficient values – clean, dry rope; a) temperature 5°C, b) temperature 15°C, c) temperature 25°C

In most cases, the values of the friction coefficient of newly manufactured lining are greater than those of the analyzed lining segments. It is a fairly obvious observation, given that the hardness value of the new lining is lower. However, the differences may be considered small, as they do not exceed 20 percent. Moreover, the value of the friction coefficient in all conditions was significantly greater than the minimum value required by the manufacturer, equal to 0.25.

Report no. 2

The aim of the test was to verify whether the Modar R3/Mz lining segments owned by the mine and stored for over 5 years are still characterized by physical parameters that allow for their use in a winding machine of a hoisting system for one of my shafts.

Detailed results of the hardness tests are presented in Appendix B. In total, 80 segments of the Modar lining were tested. Individual results are in the range of 94.0° to 97.8°Sh A with accuracy ±0.6°Sh A. Obtained average values of hardness of lining segments are in the range of 95.0° to 97.3°Sh A.

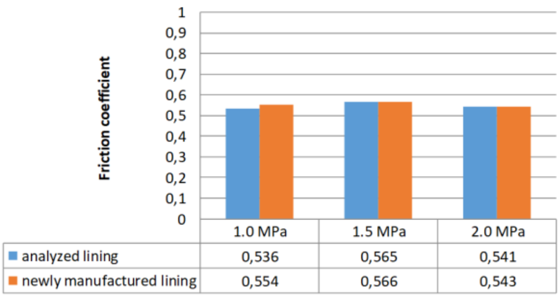
For comparison purposes, four measurements of the hardness of newly manufactured lining segments were conducted. Their results are as follows:

- 95.6°Sh A,
- 96.9°Sh A,
- 94.8°Sh A,
- 95.0°Sh A.

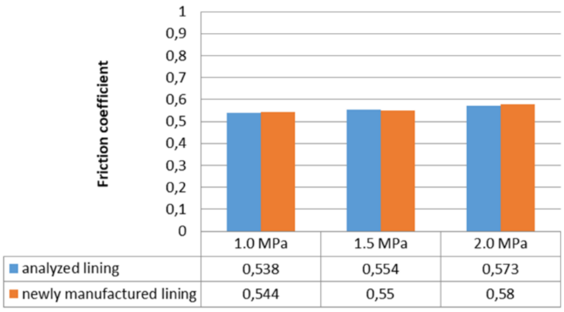
Thus, the average value of newly manufactured lining hardness is 95.0±0.6°Sh A.

Detailed results of friction coefficient tests are presented in Appendix B. Tests were conducted on both newly manufactured and examined lining segments. The research comprises an analysis of clean rope (purified from lubricant) and rope lubricated with ELASKON II STAR for both new and tested lining segments. The conditions of the tests are presented in Section 2.2.

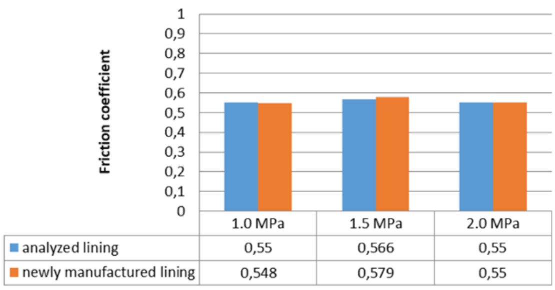
Figure 3 presents a comparison of the test results of clean rope in all analyzed temperatures. A complete set of results is provided in Appendix B.



a) temperature 5°C



b) temperature 15°C



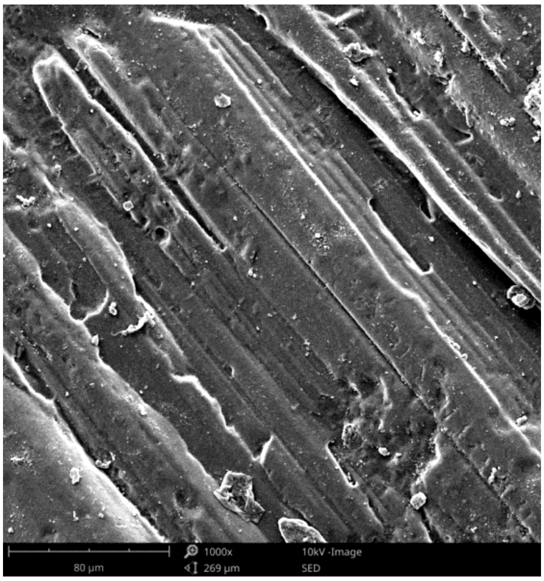
c) temperature 25°C

Fig. 3. Comparison of friction coefficient values – clean, dry rope; temperature 5°C, b) temperature 15°C, c) temperature 25°C

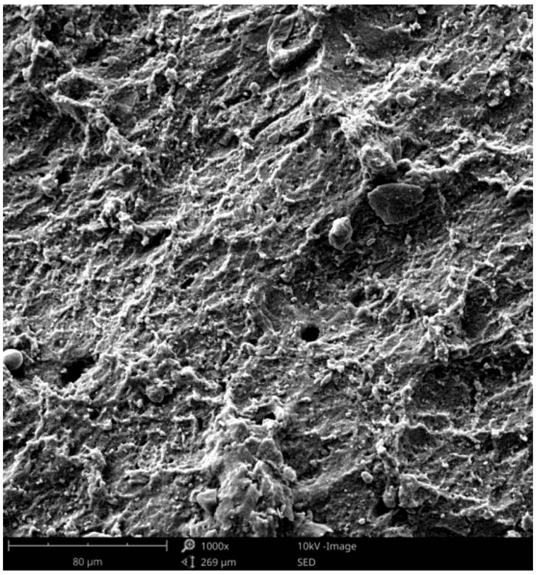
The differences between the values measured for the analyzed and newly manufactured lining are negligible and within the measuring error. Moreover, the value of the friction coefficient in all conditions was significantly greater than the minimum value required by the manufacturer, equal to 0.25.

EDS testing

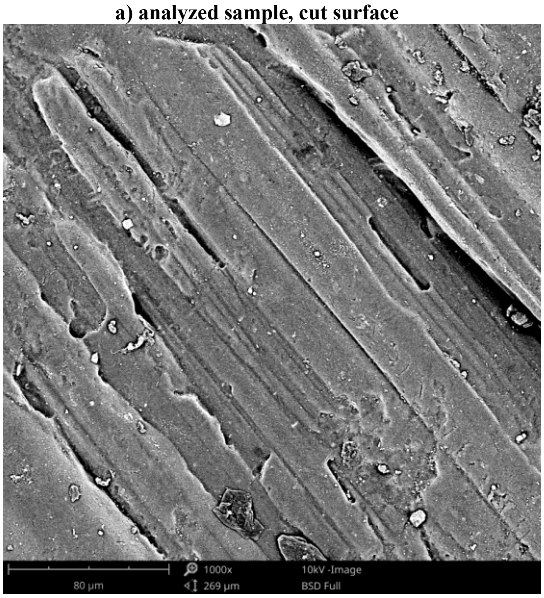
The morphology of the samples' surface was observed using different magnification ratios, including the surface of the cut (Figure 4).



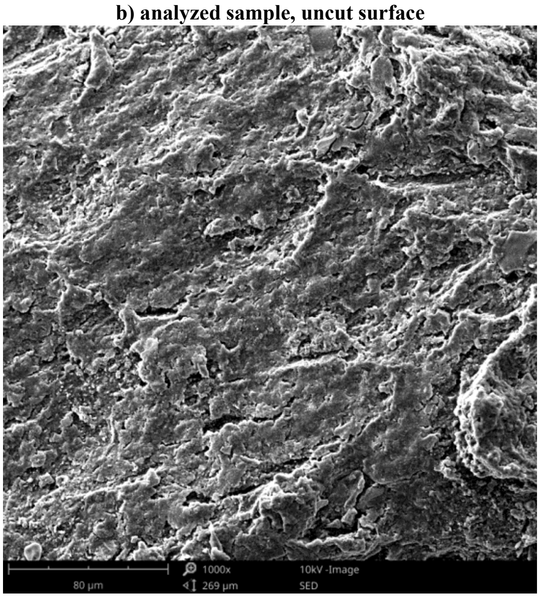
a) analyzed sample, cut surface



b) analyzed sample, uncut surface



c) newly manufactured sample, cut surface



d) newly manufactured sample, uncut surface

Fig. 4. Morphology of illustrative samples – 1000 times magnification

As the cut significantly disrupted surface morphology, comparison of the samples was based on the other surface of the samples. Analysis of the surface morphology with 1000 times magnification (Figure 4b and d) and 2000 times magnification (Figure 5) shows greater evolution of the surface of the analyzed (old) samples (this tendency shows for the majority of samples); however, there are no surface damages, such as fractures, greater porosity, pitting, or coating. It should be noted that the samples were not purified before the test, and thus, such differences may be an effect of the stained surface.

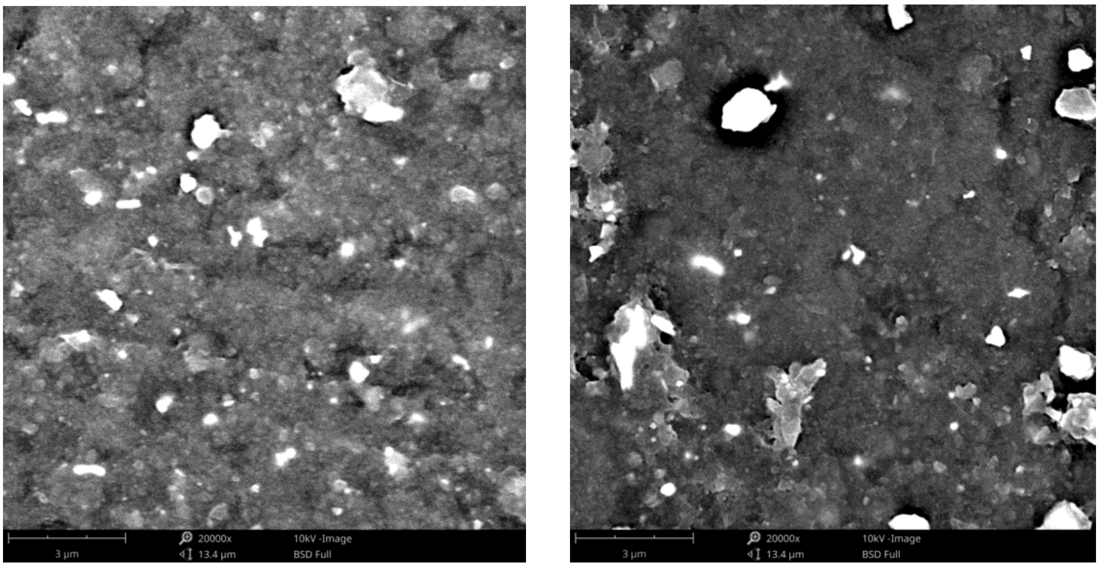


Fig. 5. Morphology of illustrative samples – 2000 times magnification

To verify the elemental composition of samples, both quantitative and qualitative, EDS analysis was performed. Illustrative results are presented in Figures 6 and 7 and in Tables 2 and 3.

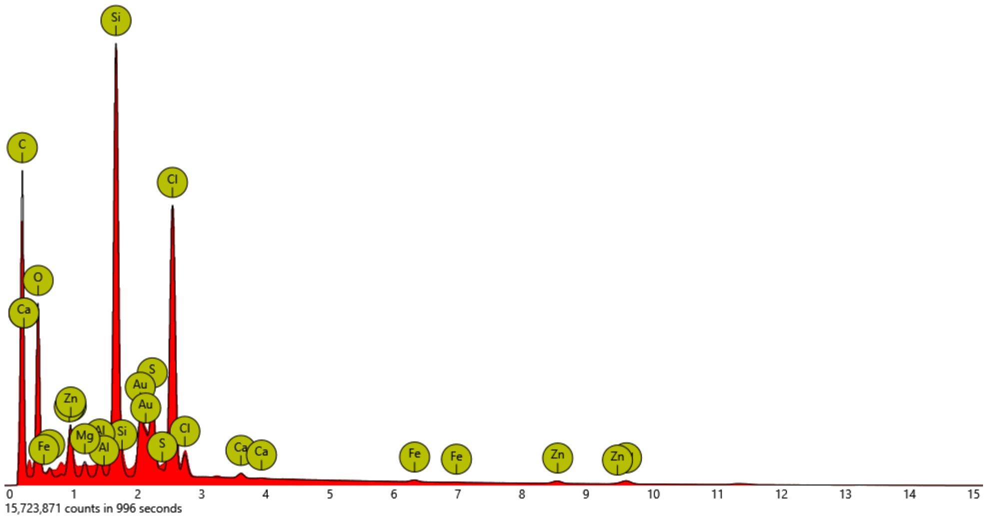


Fig. 6. Result of the EDS analysis of the old lining sample

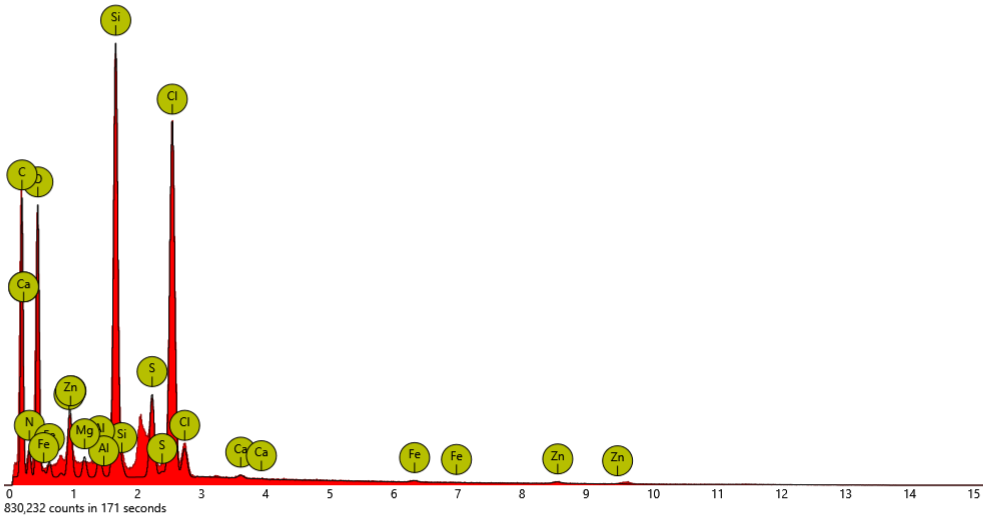


Figure 7. Result of the EDS analysis of the newly manufactured lining sample

Tab. 2. Elemental composition of analyzed samples – molar and weight content

Element	Content [%] sample 1	Content [%] sample 2	Content [%] sample 3	Content [%] sample 4	Content [%] sample 5	Content [%] average
C	51.66/38.62	55.25/41.49	50.79/38.74	52.64/39.35	55.17/42.07	53.10/40.05
O	25.90/25.80	20.61/20.61	26.80/27.23	24.84/24.73	22.87/23.23	24.20/24.32
N	8.11/7.07	10.98/9.62	9.67/8.61	7.73/6.74	8.63/7.67	9.02/7.94
Cl	5.62/12.39	4.61/10.22	4.92/11.08	6.35/14.02	5.30/11.92	5.36/11.93
Si	5.09/8.91	4.12/7.23	4.56/8.14	5.24/9.15	4.76/8.48	4.75/8.38
Na	1.28/1.83	0.60/0.87	1.29/1.88	1.16/1.66	1.13/1.65	1.09/1.58
S	1.23/2.45	1.29/2.59	1.06/2.17	1.14/2.27	1.11/2.25	1.17/2.35
Zn	0.42/1.70	0.81/3.30	0.24/0.98	0.23/0.96	0.33/1.37	0.41/1.66
Mg	0.29/0.44	0.44/0.67	0.31/0.48	0.34/0.52	0.27/0.42	0.33/0.51
Al	0.28/0.47	0.54/0.92	0.27/0.47	0.28/0.47	0.27/0.45	0.33/0.56
Ca	0.10/0.25	0.12/0.30	0.06/0.15	0.03/0.08	0.10/0.25	0.08/0.21
Fe	0.02/0.08	0.62/2.18	0.02/0.07	0.02/0.06	0.06/0.22	0.15/0.52

*content - molar/weight, %

Table 3. Elemental composition of newly manufactured samples – molar and weight content

Element	Content [%] sample 1	Content [%] sample 2	Content [%] sample 3	Content [%] sample 4	Content [%] sample 5	Content [%] average
C	51.24/37.80	54.05/40.22	53.40/39.81	55.01/40.65	50.97/37.05	52.92/39.11
O	25.21/24.80	23.22/23.02	22.32/22.17	23.00/22.92	25.94/25.42	23.93/23.66
N	8.16/7.02	7.55/6.56	8.88/7.72	6.89/6.27	9.55/8.83	8.20/7.28
Cl	5.66/9.77	5.55/12.20	6.01/13.22	6.45/14.25	4.36/9.49	5.60/11.79
Si	5.45/11.89	5.44/9.46	5.80/10.11	5.90/10.32	4.17/7.19	5.34/9.79
Na	1.33/1.88	1.47/2.10	1.33/1.90	0.93/1.33	0.83/1.18	1.17/1.68
S	0.96/1.90	1.04/2.06	1.04/2.07	1.08/2.16	1.53/3.01	1.12/2.24
Zn	0.40/1.61	0.53/2.14	0.31/1.26	0.30/1.21	0.39/1.57	0.38/1.56
Mg	0.48/0.72	0.35/0.52	0.38/0.58	0.05/0.07	0.08/0.12	0.26/0.40
Al	0.39/0.65	0.36/0.60	0.33/0.55	0.07/0.11	0.30/0.49	0.28/0.48
Ca	0.12/0.19	0.05/0.11	0.01/0.02	0.04/0.12	0.85/2.10	0.20/0.51
Fe	0.52/1.78	0.29/1.00	0.17/0.58	0.17/0.58	1.03/3.54	0.62/1.50

* content - molar/weight, %

The results of the elemental composition analysis reveal minor differences between the analyzed (old) and newly manufactured lining samples. The main elements contained are about 53% mol. Of carbon, 24% mol. of oxygen, about 8-9% mol. of Nitrogen, and 5% mol. of both chlorine and silicon.

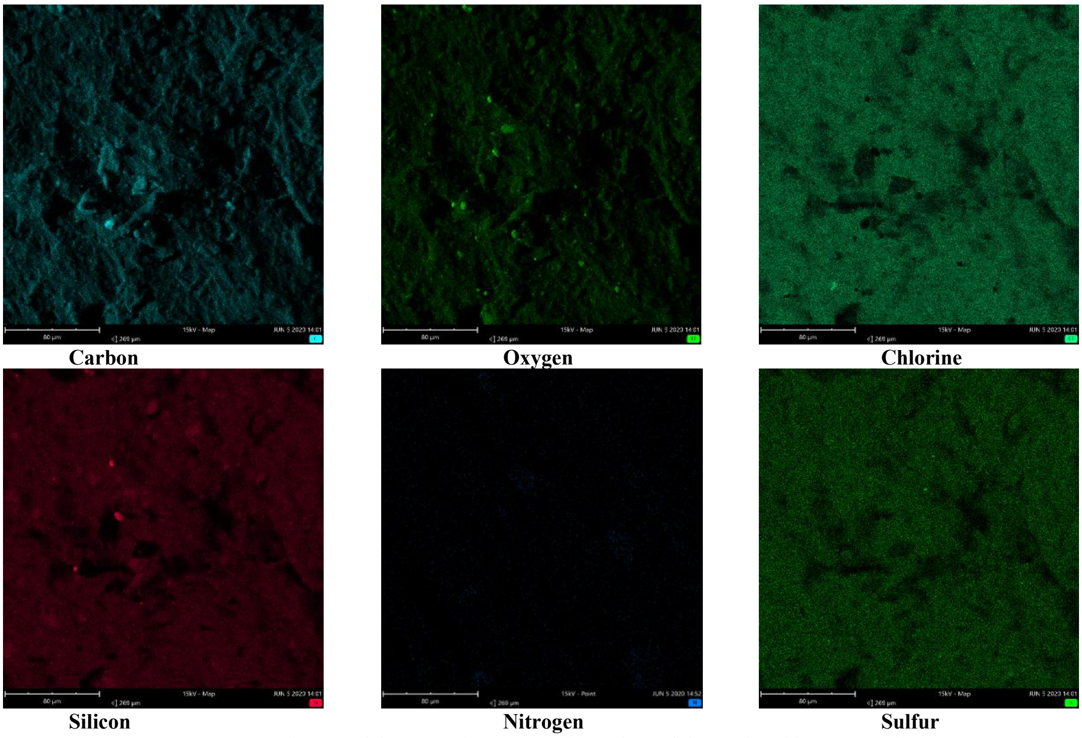


Fig. 8. Distribution of the main elements on the surface of the analyzed lining sample

Small differences between the elemental composition of old and newly manufactured lining samples show that the material does not change its composition during its storage (processes like oxidation or decay do not occur). Such findings are confirmed by the results of an analysis of element distribution on the samples' surface (Figures 8 and 9).

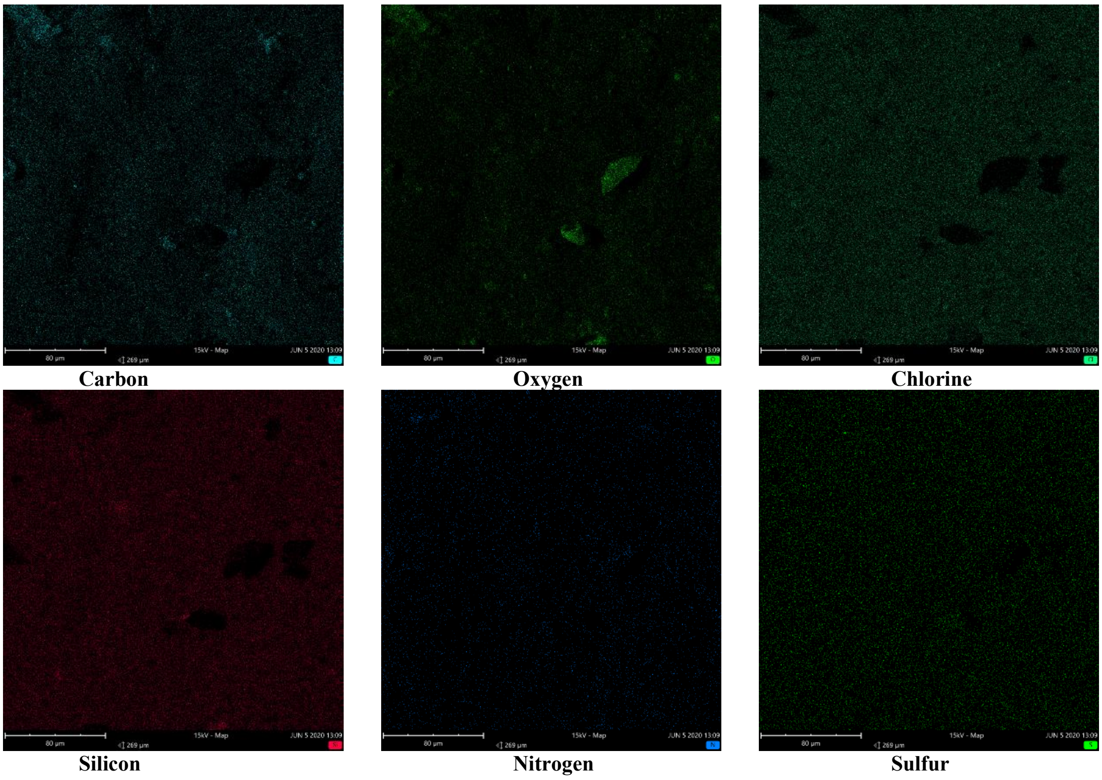


Fig. 9. Distribution of the main elements on the surface of a newly manufactured lining sample

Conclusions

The safety of the mine hoisting system, including the winding machine, is crucial for the safety and effectiveness of the entire mine. It applies to each, even the smallest element of the hoist, including winding drum lining. The lining must be characterized by specific parameters, such as hardness and friction coefficient. This paper presents a procedure for examining winding drum linings and the results of tests conducted on two sets of lining segments, provided by two different Polish collieries. Moreover, the results of these tests were verified by EDS tests.

Considering the results of the hardness and friction coefficient tests, it can be concluded that they are in the acceptable range. Taking this into consideration, the application of the provided lining segments in the winding drums of two different hoists in two separate coal mines is possible, and it should not negatively impact the safety of the hoisting systems.

However, it should be noted that only about 25% of the lining segments that are to be installed in the winding machines were tested. Before installation, remaining segments should be visually inspected to ensure that there is no visible damage or deformation.

The above conclusions were confirmed by the results of the EDS tests, as the conducted research did not show significant differences between samples, likely due to their long storage.

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