http://dx.doi.org/10.7494/miag.2019.3.539.70

MICHAŁ STAWOWIAK
ZENON ROŻENEK

An assessment of the susceptibility of Becorit K-25SB and ModarR3/Mz friction linings

The article presents an assessment of the susceptibility of friction linings from two selected manufacturers. These tests are extremely important when assessing the safety of existing and newly designed shaft lifts and ski cableways. The research was carried out on measuring equipment at the Department of Mining Mechanization and Robotization of the Silesian University of Technology, where this type of research has been conducted for years. A measuring amplifier, road transducers, force transducers and a hydraulic testing machine were used for the tests, thanks to which the pressure was applied to the rope on which the friction lining was applied. The measurements were recorded on a computer, which was a recording and measuring station, after which they were processed, saved in tables and presented to the reader in the form of graphs. The main purpose of these tests was to obtain results giving information about the rope displacement at a specific pressure to the groove of the friction lining. It is also worth mentioning that the factor that has a significant impact on the achieved values of displacements is the time of the test. It is related to the properties of the material of which the friction linings are made that are used as a running track for the ropes.

Key words: *rope, pressure, displacement, friction lining*

1. INTRODUCTION

In mining, the rope-friction drive is the most widely used drive for hoisting vessels suspended on ropes and driven by a hoisting machine. The hoisting machine itself is usually electrically driven and thus the friction rope drive is not the drive of the hoisting machine.

Very high standards were imposed on the elements of the mining shaft hoist, including hoisting machines, in terms of operational reliability and safety. These requirements also apply to the friction linings used in winding machines.

A loss of frictional coupling between the drive pulley and the carrier rope can result in extremely serious damage, economic losses and a risk to human life. The friction linings are meant to ensure the required minimum friction coefficient between the rope and the driving drum. They should be characterized by high abrasion resistance, low wear and an appropriate frictional coupling coefficient [1–3].

The mechanism of the fatigue process of the contact surface of linings is very complex. In this zone, phenomena occur that are unusual and do not define the basic strength of contact fatigue. These processes include friction, micro-slip, plastic and elastic deformation of the surface layers, heat release, the influence of shaft water and lubricants [3, 4, 5, –6, 11, 15, 16].

Compliance testing is one of the many studies performed on drive and impression wheel liners. It is defined as the deformation obtained under the effect of a unit force, i.e. the inverse of the stiffness. It is expressed by the formula [10, 17, 19]:

$$C = \frac{u}{F} \tag{1}$$

$$P = \frac{1}{C} = \frac{F}{u} \qquad (2)$$

where:

C – stiffness [mm/N],
P – compliance [N/mm],
u – displacement [mm],
F – force [N].

The Modar R3/Mz lining is a fully Polish production. It is designed for driving wheels and drums as well as for the contact wheels of mining shaft hoists. They are often used in the drive wheels of other cable transport devices, such as cableways or ski lifts.

The lining is made of a material with a composition of acrylonitrile, chloroprezenic, isoprene polymers and active silica fillers. Modar R3/Mz is characterized by [13]:

- large and stable value of the friction coefficient $\mu \geq 0{,}25$,
- minimum tensile strength 170 MPa,
- high fatigue life,
- wear resistance,
- resistance to surface pressures.

The Becorit K-25SB liner is a German-made lining (also produced under license in Poland). Made of resin-bonded duroplastic material. Thermosets are hardenable plastics. It is a group of thermo or chemically set polymeric materials, characterized by high abrasion resistance, a stable coefficient of friction, and they do not have a softening range (they pass directly from the temperature of use to the range of decomposition). These materials do not swell and show high resistance to all kinds of greases and oils [8].

Figure 1 shows an exemplary diagram of a device using a rope-friction drive [7].

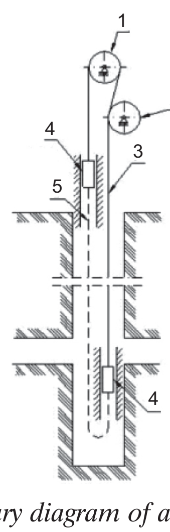

Fig. 1. An exemplary diagram of a hoisting device with a friction drive [2, 9]: 1 – driving drum, 2 – contact wheel, 3 – carrying rope, 4 – vessel, 5 – balance rope

The linings on the wheels and driving drums cooperate with various lines of the cross-sections shown in Figure 2.

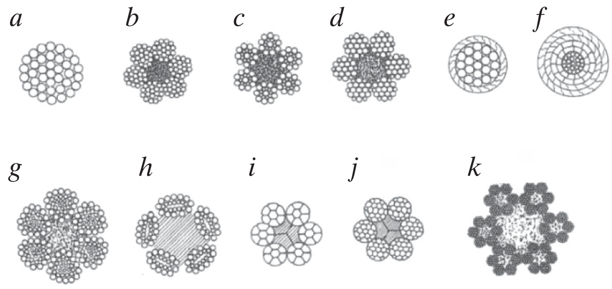

Fig. 2. Selected sections of the lifting ropes [12]: a – single thread, b – double thread, c – double thread, d – Warrington double thread, e – closed structure with one armour of wires, f – closed structure with two armours of z-wire and trapezoidal wires, g – double strand with triangular strands, h – double strand with strands, i, j – double strand with seamless strands, k – triple strands with round strands

The aim of this article is to present the methodology of conducting tests on the susceptibility of Becorit K25SB and Modar R3/Mz friction linings and which were carried out at the Department of Mining Mechanization and Robotization of the Silesian University of Technology. The scope of the work carried out included:

- preparation of the test stand with the tested items,
- conducting research,
- processing the obtained results,
- conclusions from the conducted research.

The research was conducted in two stages:

1. The first test – the initial load was 5 kN, then every 3 minutes it increased by 5 kN until it reached 50 kN – after which the sample was unloaded. The measurements were repeated five times.
2. Second test – the sample was tested for the following loads: 5, 10, 15, 20, 25, 30, 35, 40, 45, 50 kN. After reaching the desired load, it was held for 3 minutes, then the sample was unloaded. The measurements were repeated three times.

2. DESCRIPTION OF THE MEASUREMENT STATION, MATERIALS FOR TESTING

The research and measurement stand is located in the technological hall of the Department of Mining Mechanization and Robotization of the Silesian

University of Technology. It is equipped with the following elements:

- HBM SPIDER8 strain gauge measuring amplifier (Fig. 3).
- HBM 1-WA/200MM inductive transducer (Fig. 4).
- HBM C2/200kN strain gauge stem force transducer (Fig. 5).
- Measurement signal recorder with CATMAN software. HECKERT ZD 10/90 testing machine (Fig. 6).

Fig. 3. HBM SPIDER8 measuring amplifier prepared for research

Fig. 4. 1-WA/200MM distance converter, before mounting on the test stand

Fig. 5. HBM C2-200kN force transducer

Fig. 6. The HECKERT ZD 10/90 testing machine

A force transducer was placed on the surface of the mounting head of the testing machine, which was to measure the force with which the sample is loaded. In addition, the distance converter was mounted using electromagnetic holders – in line with the axis of force. The sampling frequency of the measurements was 2 Hz. The signal was sent to the recorder through the SPIDER8 measuring amplifier.

The subjects of the research were:

- Modar R3/Mz friction lining (Fig. 7a),
- Becorit K-25SB friction lining (Fig. 7b),
- closed rope (Figs. 8 and 9).

a) *b)*

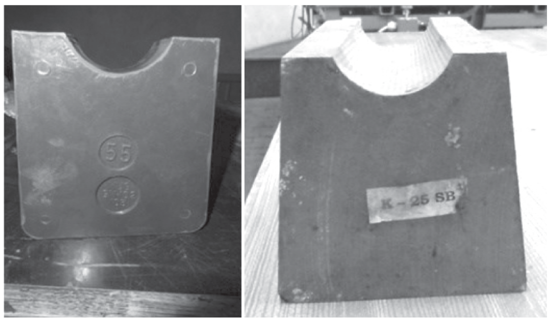

Fig. 7. Friction lining: a) Modar R3/Mz; b) Becorit K-25SB

a) *b)*

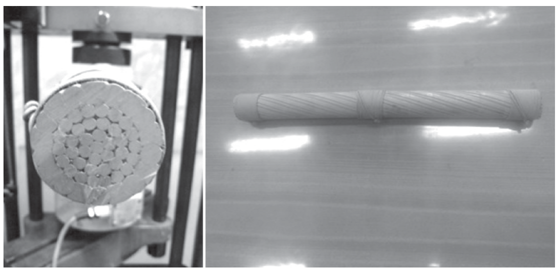

Fig. 8. Rope used for tests: a) cross-section of the rope used for tests; b) general view of the rope used for tests

3. MEASUREMENT RESULTS

In the first attempt. Figure 9 shows exemplary results of the tests of the friction pair compliance: closed rope – friction lining, carried out for ModarR3/Mz and Becorit K-25SB linings. In the first test, the following measurements were made for both the Becorit K-25SB and ModarR3/Mz friction linings. Only a part of the extensive database of results is presented.

a) Graph prepared on the basis of the results of the closed rope – Becorit K-25SB lining (Fig. 9a).
b) A diagram prepared on the basis of the results of the closed rope – ModarR3/Mz lining (Fig. 9b).

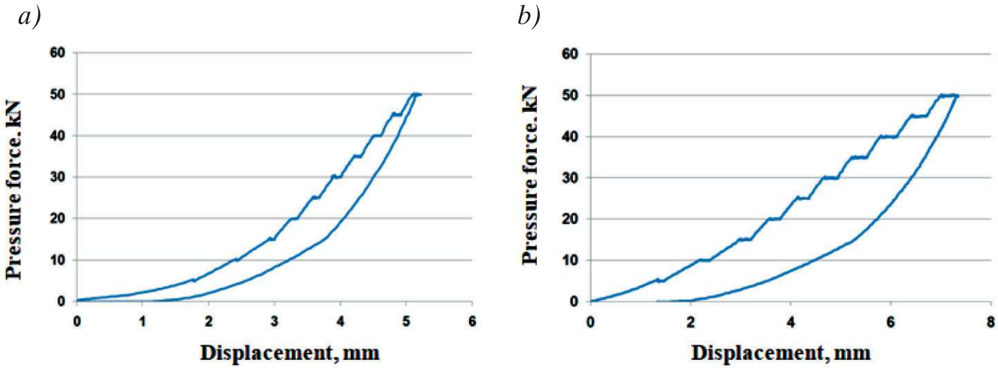

Fig. 9. Testing of the friction pair susceptibility: a) closed rope – Becorit K-25SB lining; b) closed rope – Modar R3/Mz lining

Second attempt. Figures 10a–11c show the results of the friction pair loading tests: closed rope – friction lining, carried out for the Becorit K-25SB and ModarR3/Mz friction linings. In the second test, both for the Becorit K-25SB and ModarR3/Mz friction linings, the following measurements were made. In turn, Figures 12a and 12b are graphs averaging the results of the first trial, while Figures 13 and 14 are graphs compiling the results of the second trial.

a) Graphs prepared on the basis of the test results for a pair of closed rope – friction lining Becorit K-25SB. The samples were loaded with a pressing force of 5 kN, 10 kN, 15 kN, 20 kN, 25 kN, 30 kN, 35 kN, 40 kN, 45 kN and 50 kN. Only the graphs of the pressure with the force of 5, 25 and 50 kN and from the first measurement series are presented.
b) Graphs prepared on the basis of the test results for a pair: closed rope – friction lining ModarR3/Mz. The samples were loaded with a pressing force of 5 kN, 10 kN, 15 kN, 20 kN, 25 kN, 30 kN, 35 kN, 40 kN, 45 kN and 50 kN. Only the graphs of the pressure with the force of 5, 25 and 50 kN and from the first measurement series are presented.

Tables 1 and 2 show the results of the first test for the friction pair: closed rope – Becorit K-25SB friction lining and closed rope – ModarR3/Mz friction lining.

Tables 3 and 4 present the results of the second test for the friction pair: closed rope – Becorit K-25SB friction lining and closed rope – ModarR3/Mz friction lining.

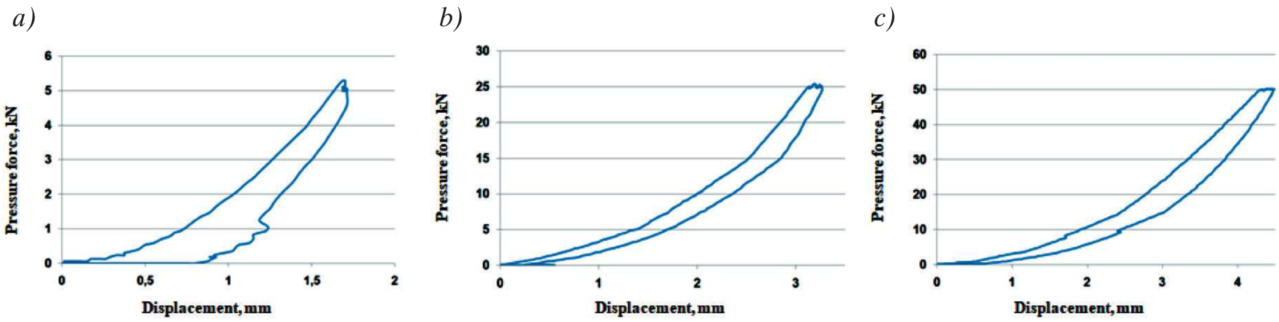

Fig. 10. Loads of friction pairs: a) 5 kN load of friction pair closed rope – Becorit K-25SB lining; b) 25 kN load of friction pair closed rope – Becorit K-25SB lining; c) 50 kN load of friction pair closed rope – Becorit K-25SB car pet

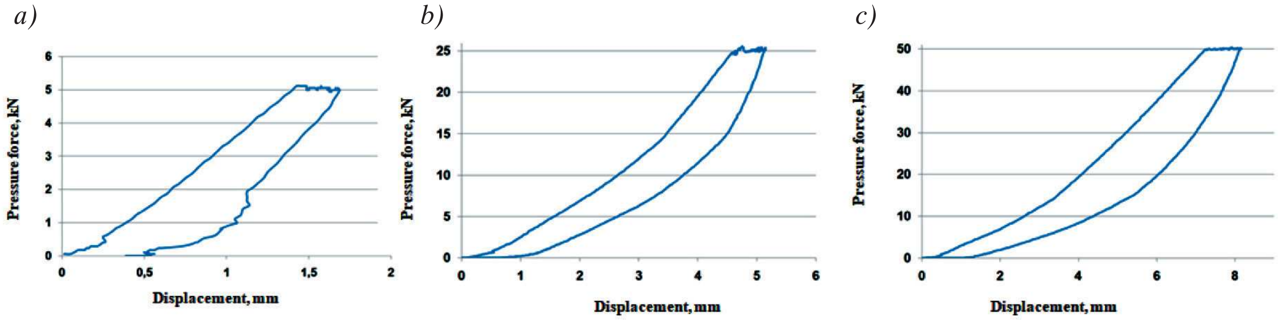

Fig. 11. Loads of friction pairs: a) 5 kN load of friction pair closed rope – ModarR3/Mz lining; b) 25 kN load of friction pair closed rope – ModarR3/Mz lining; c) 50 kN load of friction pair closed rope – ModarR3/Mz

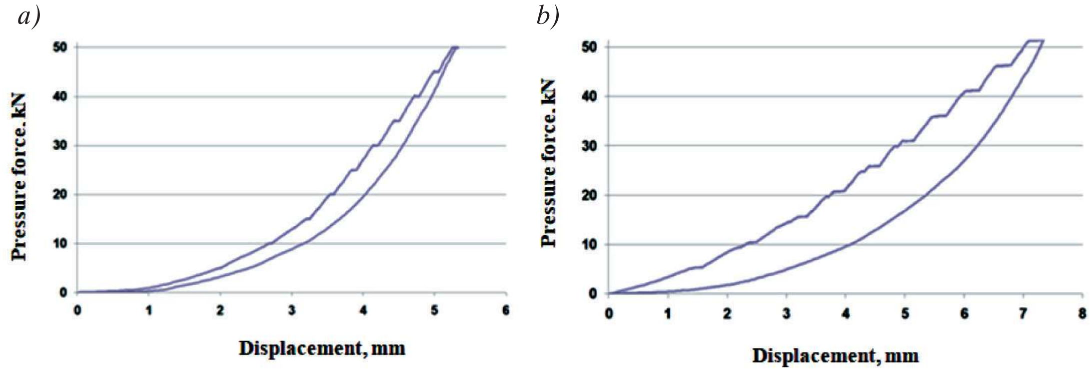

Fig. 12. Graph averaging the results of the first friction pair test: a) closed rope – Becorit K-25SB lining; b) closed rope – ModarR3/Mz lining

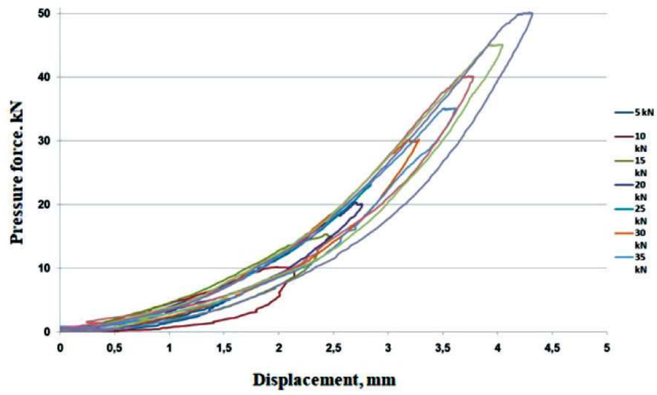

Fig. 13. Graph presenting the results of the second friction pair test: closed rope – Becorit K-25SB lining

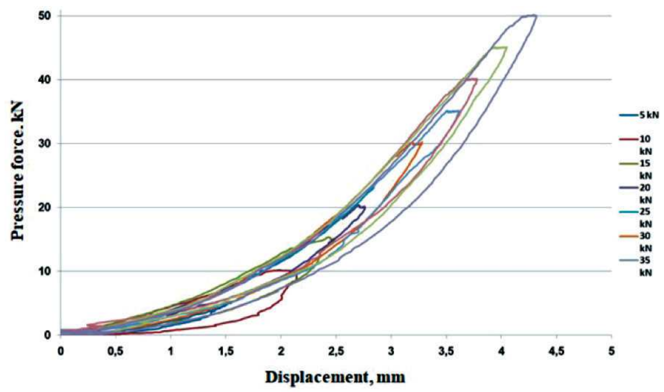

Fig. 14. Graph presenting the results of the second friction pair test: closed rope – ModarR3/Mz lining

Table 1

Results of the measurements of the first test for the friction pair: closed rope – Becorit K-25SB lining

No.	F [kN]	u_{01} [mm]	u_{02} [mm]	u_{03} [mm]	u_{04} [mm]	u_{05} [mm]	Average $u_{śr}$ [mm]	P (susceptibility) [kN/mm]
1	5	1.8	2.1	2.0	1.8	1.8	1.9	2.6
2	10	2.4	2.8	2.8	2.5	2.5	2.6	3.8
3	15	3.0	3.4	3.1	3.0	3.0	3.1	4.8
4	20	3.3	3.6	3.6	3.3	3.7	3.5	5.8
5	25	3.7	3.9	3.9	3.7	3.8	3.8	6.6
6	30	4.0	4.1	4.3	4.0	4.1	4.1	7.3
7	35	4.3	4.4	4.5	4.3	4.5	4.4	8.0
8	40	4.6	4.7	4.8	4.5	4.9	4.7	8.6
9	45	4.9	5.1	5.1	4.8	5.1	5.0	9.0
10	50	5.2	5.4	5.4	5.1	5.4	5.3	9.5

Table 2

Results of the measurements of the first test for the friction pair: closed rope – ModarR3/Mz lining

No.	F [kN]	u_{01} [mm]	u_{02} [mm]	u_{03} [mm]	u_{04} [mm]	u_{05} [mm]	Average $u_{śr}$ [mm]	P (susceptibility) [kN/mm]
1	5	1.4	1.7	1.4	1.5	1.5	1.5	3.3
2	10	2.4	2.7	2.4	2.5	2.5	2.5	4.0
3	15	3.1	3.5	3.2	3.3	3.4	3.3	4.6
4	20	3.8	4.1	3.8	3.9	3.9	3.9	5.1
5	25	4.4	4.7	4.5	4.5	4.4	4.5	5.5
6	30	4.9	5.3	5.1	5.1	5.1	5.1	5.9
7	35	5.5	5.8	5.6	5.6	5.5	5.6	6.2
8	40	6.1	6.3	6.2	6.2	6.2	6.2	6.5
9	45	6.7	6.9	6.8	6.7	6.9	6.8	6.6
10	50	7.3	7.4	7.4	7.2	7.2	7.3	6.8

Table 3

Results of measurements of the second test for the friction pair: closed rope – friction lining Becorit K-25SB

No.	F [kN]	u_{01} [mm]	u_{02} [mm]	u_{03} [mm]	Average $u_{śr}$ [mm]	P (susceptibility) [kN/mm]
1	5	1.7	1.4	1.7	1.6	3.2
2	10	1.9	2.1	2.0	2.0	5.0
3	15	2.5	2.8	2.8	2.7	5.7
4	20	3.1	3.2	3.3	3.2	6.3
5	25	3.4	3.4	3.4	3.4	7.4
6	30	3.8	3.7	3.9	3.8	7.9
7	35	4.1	4.1	4.1	4.1	8.5
8	40	4.3	4.4	4.5	4.4	9.2
9	45	4.4	4.7	4.7	4.6	9.9
10	50	4.9	5.0	5.1	5.0	10.1

Table 4

Results of the measurements of the second test for the friction pair: closed rope – ModarR3/Mz friction lining

No.	*F* [kN]	u_{01} [mm]	u_{02} [mm]	u_{03} [mm]	Average $u_{śr}$ [mm]	*P* (susceptibility) [kN/mm]
1	5	1.7	1.9	1.8	1.8	2.8
2	10	2.8	2.8	2.8	2.8	3.6
3	15	3.7	3.7	3.7	3.7	4.1
4	20	4.4	4.4	4.4	4.4	4.5
5	25	5.1	5.0	5.2	5.1	5.0
6	30	5.8	5.5	5.8	5.7	5.3
7	35	6.0	6.2	6.1	6.1	5.7
8	40	6.5	6.9	6.7	6.7	6.0
9	45	7.4	7.6	7.5	7.5	6.0
10	50	8.1	8.2	8.3	8.2	6.1

4. SUMMARY

The tests carried out on a laboratory stand at the Department of Mining Mechanization and Robotization of the Silesian University of Technology allowed the determination of the measured force valuesand the displacement of selected types of friction pairs rope – lining under the action of a specific pressure force in combination with the rope of a closed structure. The performed tests allowed for the following conclusions:

1. The maximum displacement of Becorit K-25SB in the first test was 5.3 mm.
2. The greatest displacement of the ModarR3/Mz lining during the first test was equal to 7.3 mm with a load of 50 kN.
3. In the second test, the maximum displacements were achieved: 5.0 mm for the Becorit K-25SB lining and 8.2 mm for the ModarR3/Mz lining.
4. The ModarR3/Mz lining is characterized by much greater flexibility than the Becorit K-25SB lining.
5. As regards the Becorit K-25SB lining, in the first test, the values of the susceptibility *P* were from 2.6 kN mm when loaded with a force *F* of 5 kN, up to 9.5 kN/mm when loaded with a force of 50 kN.
6. In the case of the ModarR3/Mz lining, in the first test, the values of *P* compliance were from 3.3 kN/mm when loaded with a force *F* of 5 kN, up to 6.8 kN/mm when loaded with a force of 50 kN.
7. As for the Becorit K-25SB lining, in the second trial, the values of the *P* compliance were from 3.2 kN/mm when loaded with a force *F* of 5 kN, up to 10.1 kN/mm when loaded with a force of 50 kN.
8. In the case of the ModarR3/Mz lining, in the second trial, the values of *P* compliance were from 2.8 kN/mm when loaded with a force *F* of 5 kN, up to 6.1 kN/mm when loaded with a force of 50 kN.
9. The factor that has a significant impact on the achieved values of displacements is the test duration. It is related to the properties of the material of which the friction linings are made, which are used as a running track for the ropes.

Becorit linings are used for the driving wheels of mining hoisting machines. They are characterized by high coefficients of friction ($\mu \geq 0.25$), also in cases of extreme weather conditions on the surface. The chemical properties of Becorit linings make them resistant to swelling in the presence of various oils and greases as well as mine waters. The material from which the linings are made ensures very good machinability when turning rope grooves with turning or milling knives. Becorit cladding is particularly suitable for use in hoisting machines, where the rope base creates a large in-run angle on the grooves of the drive pulley, which causes its lateral wear. Becorit material provides in this case a longer service life compared to other materials.

ModarR3/Mz linings are characterized by high values of friction coefficients (frictional coupling), they are intended for wheels and propellers of mining shaft hoists, cablewaysand ski lifts, impression wheels of multi-rope mining shaft hoists with machines placed on atower etc.

References

[1] Brodny J., Żołnierz M.: *Układ pomiarowy do wyznaczania współczynnika sprzężenia ciernego*, Patent nr P.407885, Politechnika Śląska, Gliwice 2014.

[2] Carbogno A.: *Testy współczynnika tarcia między różnymi okładzinami ciernymi, a liną stalową smarowaną smarem Elaskon*, Międzynarodowe Seminarium na temat stanu techniki w dziedzinie ochrony przed korozją i smarowania lin stalowych. Materiały na konferencję: Elakson Sachsen, Zabrze 2001, pp. 143–150.

[3] Carbogno A.: *Ocena sprzężenia ciernego podczas eksploatacji w warunkach górniczych*, in: *Liny wyciągowe w górniczych wyciągach szybowych*, Wydawnictwo Centrum Badań i Dozoru Górnictwa Podziemnego, Lędziny 2001, s. 163–175.

[4] Carbogno A., Mateja S., Pypłacz J.: *Dosmarowywanie lin w górniczych w trakcie pracy wyciągu szybowego*, Wydawnictwo Centrum Badań i Dozoru Górnictwa Podziemnego, Lędziny 2004.

[5] Carbogno A.: *Wybrane problemy dotyczące sprzężenia ciernego między linami stalowymi, a kołem pędnym*, Praca BK. Politechnika Śląska, Gliwice 2006.

[6] Carbogno A., Slanina F.: *Wpływ smarowania lin nośnych na bezpieczeństwo pracy górniczych wyciągów ciernych*, Wydawnictwo Centrum Badań i Dozoru Górnictwa Podziemnego, Lędziny 2006, pp. 136–146.

[7] Carbogno A., Żołnierz M., Adamecki D.: *Badanie współczynnika tarcia pary ciernej lina stalowa – wykładzina koła pędnego*. Wydawnictwo Centrum Badań i Dozoru Górnictwa Podziemnego, Lędziny 2007, pp. 127–138.

[8] Carbogno A., Żołnierz M.: *Badania laboratoryjne podatności wykładzin ciernych typu Becorit K22 oraz K25SB*, Praca BK, Politechnika Śląska, Gliwice 2008.

[9] Carbogno A., Żołnierz M., Mateja S.: *Badania współczynnika tarcia lin o powierzchniowym styku drutów*, Wydawnictwo Centrum Badań i Dozoru Górnictwa Podziemnego, Lędziny 2011, pp. 56–62.

[10] German J.: *Podstawy mechaniki pękania*, Wydawnictwo Politechniki Krakowskiej, Kraków 2011.

[11] Goris H.: *Nyrosten N113 – środek konserwujący dla lin wyciągów systemu Koepe*, Materiały firmy Nyrosten, 2007.

[12] Hansel J., Kawecki Z.: *Transport pionowy*, Akademia Górniczo-Hutnicza, Kraków 1989.

[13] Hansel J.: *Wykładziny kół i bębnów linowych*, Wydawnictwo Politechniki Krakowskiej, Kraków 2012.

[14] Kustra T.: *Badania laboratoryjne podatności wykładzin ciernych typu Becorit K-25SB i Modar R3/Mz*, Politechnika Śląska, Projekt inżynierski, Gliwice 2016.

[15] Norma DIN 21258: *Schmier und Tränkungsstoffefür Treibscheiben – Förderseileim Bergbau – Sicherheitstechnische Anforderungen Und Prüfung*. April 2007.

[16] Pusch J.: *Wtórne smarowanie stalowej liny – założenia i możliwości techniczne*, Wydawnictwo Centrum Badań i Dozoru Górnictwa Podziemnego, Lędziny 2006, pp. 167–177.

[17] *Rozporządzenie Rady Ministrów z dnia 30 kwietnia 2004 r. w sprawie dopuszczenia produktów do stosowania w zakładach górniczych w Polsce*, Dz.U. z 2004 r. nr 99, poz. 1003.

[18] Różok A.: *Badanie współczynnika tarcia okładziny kół pędnych górniczych maszyn wyciągowych*, Politechnika Śląska, Projekt inżynierski, Gliwice 2013.

[19] Technologie zur Nachschmierung von Koepe-Förderseilen mit Elaskon III Star LM, Materiały firmy Elaskon, 2000.

[20] Zmysłowski T.: *Górnicze maszyny wyciągowe*. *Część mechaniczna*, Wydawnictwo Śląsk, Katowice 2004.

MICHAŁ STAWOWIAK, Ph.D., Eng.
Department of Mining Mechanization and Robotization
Faculty of Mining, Safety Engineering and Industrial Automation
Silesian University of Technology
ul. Akademicka 2, 44-100 Gliwice, Poland
michal.stawowiak@polsl.pl

ZENON ROŻENEK, Ph.D., Eng.
KAZ Serwis Sp. z o.o.
ul. Jasna 3B1, 44-122 Gliwic, Poland
z.rozenek@kaz-serwis.pl