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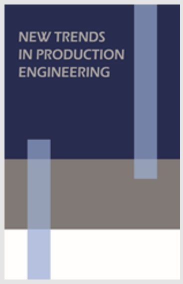

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Research on the coefficient of friction of becorit K22 and K25SB linings

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INTRODUCTION

One of the most important devices found in the mine, due for the function being performed, there are shaft lifts. Due to this, very high requirements are imposed on them in terms of safety of use and reliability. This is particularly true for rope hoist-driven hoisting machines in Polish mining they are widely used. Because there is a risk of the rope slipping, which causes damage, which in turn can lead to a threat to the crew being transported. The basic diagrams of solutions for devices using a friction drive are shown in Fig. 1 (Carbogno et al., 2007; Hansel, 2012).

The Becorit K22 and K25SB plastic linings are used for the wheels of the mining drums of mining machines. 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 claddings ensure their resistance to swelling in the event of different oils and lubricants as well as mine waters (Regulation, 2004).

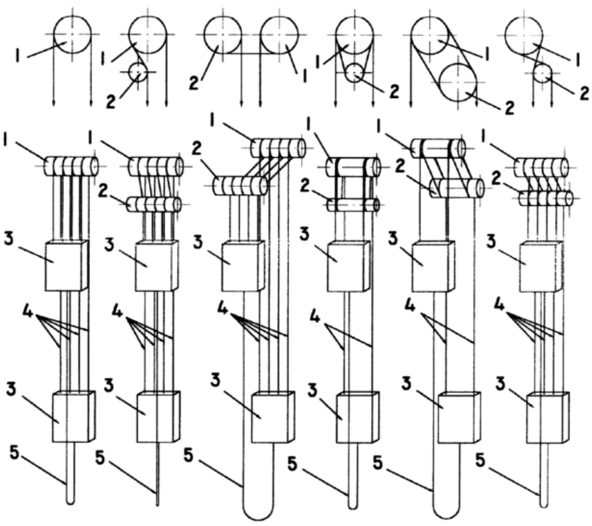

Fig. 1 Scheme of exhaust devices with friction drive:
1 – motive propeller, 2 – imprint wheel, 3 – exhaust vessels, 4 – ropes, 5 – ropes
Source: (Carbogno et al., 2007)

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The material from which the claddings are made ensures very good machinability during rolling of rope grooves with the use of turning or milling tools (Różok, 2013; Zmysłowski, 2004).
BECORIT K22 plastic cladding is particularly suitable for use in hoisting machines, where the rope base forms a large upward angle on the drive wheel grooves (max. 1°31'), which causes its lateral wear faster. BECORIT K22 material in this case provides a higher service life compared to other materials. Due to the way they are mounted on the wheel, they are made as 1-part (monolith) or bipartite (Catalogue, 2019).

TEST STAND AND APPARATUS

Experimental tests of kinetic friction were carried out in the Department of Mechanization and Robotic Mining of the Silesian University of Technology, on the position used to determine the coefficient of friction between the steel rope and the liner. Scheme of the stand together detailing its essential components are shown in Figure 2, and Table 1 presents the characteristics of the station and the scope of test parameters (Report, 2007).

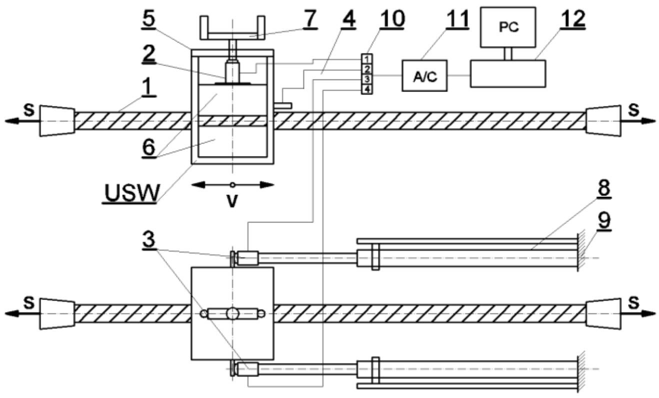

Fig. 2 Scheme of the test bench and measuring-recording system:
1 – rope, 2 – load cell tensometric sensor, 3 – strain gauge friction forces, 4 – temperature sensor (thermocouple), 5 – squeezing device for USW lining, 6 – jaws with lining, 7 – screw mechanism, 8 – hydraulic cylinders, 9 – housing of horizontal testing machine, 10 – terminal block, 11 – card A/C, 10 – PC computer, v – speed of movement, USW – a device for compressing the floor covering
Source: (Report, 2007)

Table 1 General characteristics of the test stand and scope of tests (Report, 2007)

Parameter and designation	Range	Research	Dimension
Speed of slip, v	5÷25	7	mm/s
Unit pressure, p	0.5÷4	2.0	MPa
The temperature of the rope's environment, T_o	20÷40	20, 30	°C
Sample pressure surface, A	20÷120	104	cm^2
The length of the lining test section, L	200	200	mm
Diameter of the rope (counter-samples), d	10÷60	52	mm
Strength stretching the rope, S	0÷F_c	1/7·F_c	N
Load system – mechanical. Temperature measurement – thermocouple and mercury thermometer. Measurement of clamping forces and friction forces – strain gauge. F_c – the actual force breaking the rope.			

In the case of tests carried out at a rope temperature of 30°C, the middle part of the measuring station Fig. 2 is placed in the heat chamber dimensions: 1,5 × 1 × 1 m (length, width, height). The chamber is made made of plywood and sealed. The chamber has two heaters (fan heaters by means of which the required ambient temperature of the rope is obtained (Goris, 2000).
The pressure of the jaws to the rope was obtained by means of a screw mechanism.
In the squeezing device of the lining blocks Fig. 2, one block of the liner is placed in the bottom jaw permanently connected to the USW enclosure, and the second block is placedin the movable jaw, which is affected by a strain gauge force cell (Report, 2007).
In order to secure the clamping device of the jaws with the lining blocks before the turn resulting from the helical tie-up of the strands in the rope, a guide made of four ball bearings moving on guides made of angle bars was used. The force shifting the USW device is obtained by means of two hydraulic cylinders placed symmetrically to the axis of the rope on both sides. These cylinders are set in motion by means of a hydraulic pump that allows variable speed to be obtained (Carbogno et al., 2007).
For measuring the contact forces and friction forces, strain gauges were used type CL 18 with accuracy class 0.5, resistance of extensometer 350 Ω, supply voltage 10 V and degree of protection IP54 (Report, 2007).
In the sensors used, the measurement of the measured load is carried out by means of a metal elastic element, covered with foil extensometers, connected in a full bridge system. The strain gauge bridge is completely balanced and thermally compensated. The correct measurement is possible even in the case of non-axial force. The sensors have a CE certificate. The manufacturer of sensors is the Industrial Electronics Plant of Non-electric Volume in Marki.
The temperature measurement was carried out using the contact method with the thermocouple sensor type IT-CC, equipped with a FeCu-Ni thermocouple placed in the cover made of material MO 59 nickel-plated brass. Regardless of the above solution, the temperature in the thermal chamber was measured with a classic thermometer. In addition, the ambient temperature was controlled using classic thermometers (Carbogno et al., 2007; Report, 2007).
Supervision over the implementation of research is based entirely on a computerized measurement system that works in real time to provide visualization and archiving of measured quantities. The computer measuring system consists of (Report, 2007):
1. Data acquisition workstation – PC computer.
2. Data acquisition software – enables continuous recording of measured quantities in real time with simultaneous archiving. The flexibility of the program allows its optimal configuration to any analog – digital card that gathers information about the signals at its input.
3. A/C APCI – 3300 Dual card – analog – digital card enabling direct connection to its inputs (through the screw terminal block) strain gauges and thermoelectric force sensors, which eliminates the need for additional signal amplifiers on the

outputs of the force sensors, thus reducing the interference in the track measurement. General specification of the A/C card:

- CE certificate,
- 4 analog inputs of force sensors,
- 2 analogue inputs of thermoelectric temperature sensors,
- 2 analogue inputs or 4 asymmetrical analog inputs,
- 4 sources of voltage supplying force sensors,
- resolution of 18 bits,
- accuracy of 16 bits,
- sampling 20; 40; 80; or 160 Hz,
- input voltage range 0-2.5 V,
- programmable amplifier 1; 2; 4; 8; 16; 32; 64; 128x,
- 1000 V galvanic isolation,
- 4 inputs and 3 digital outputs 24 V.

The basic test parameters that can be used on the test bench are shown in Table 1.

THE COURSE OF RESEARCH

Materials used for testing.

As the friction pair materials, the wire rope – liner was used (Report, 2007):

a) Lifting rope with a diameter of 52 mm, Warrington construction – Indoor.
b) Linings produced by the German company Becorit (a total of 8 pairs of carpet blocks):
   - Becorit lining – K22 (4 pairs of blocks),
   - Becorit lining – K25SB (4 pairs of blocks).

Blocks of friction linings provided with marked dimensions with the groove cut for the rope used is shown in Fig. 3.

c) Lubricants for Koepe rope ropes

The lubricants used in the country were used for tests of lubricated friction pair:

- Elaskon II Star,
- Elaskon III Star LM,
- Nyrosten N113,
- Nyrosten N113 FS.

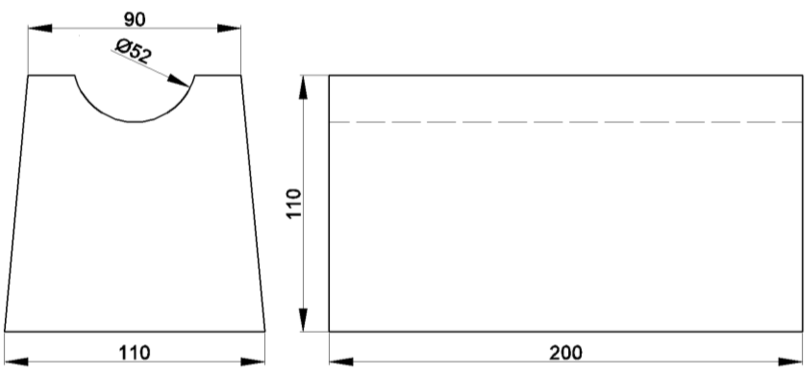

Fig. 3 Dimensions of the block of friction lining used in bench tests

Source: (Report, 2007)

Test parameters:

a) The tests were carried out for three states of friction pair rope – liner (Report, 2007):
   - dry friction pair,
   - wet friction pair,
   - lubricated friction pair.

b) The tensile strength of the rope corresponds to the tear safety factor n = 7.

c) Unit pressure of the rope on the carpet p = 2MPa.

d) Speed of slip liner v = 7 mm/s.

e) The amount of grease on the tested line – 16 g/m length of the rope (which results from the amount of 75 g/m^2 of the rope surface recommended by DIN 21258, converted to the tested rope).

f) The tests of the surface lubricated rope were carried out after 4 hours from its lubrication and after 8 hours for the applied lubricant.

g) The tests were carried out at the ambient temperature that prevailed in the laboratory (20°C-23°C) and at the ambient temperature of 30°C (in the heat chamber).

h) The relative air humidity in the laboratory was 44%-60%.

i) The measurements were repeated six times (according to the standard the first measurement was discarded and five further measurements were taken into account for further calculations).

j) For the variant tests, the friction pair of the wet liner was immersed in a container of water, and during the tests it was poured with water.

k) During the tests of the friction pair, the dry rope and liner were dry, without grease.

In the case of lubricated friction surfaces, all tests were carried out 4 hours after lubricating the rope, and for Elaskon III Star LM after 8 hours. After each test the rope was cleaned and washed clean, and then a new layer of grease was applied. The amount of grease applied was weighted. The melted grease was applied with a brush. For lubricated friction pairs, the pairs of lining blocks were used separately to avoid affecting the course of the coefficient of friction, a layer of grease applied to the liner from the previous study (Report, 2007).

For each combination of friction parameters, the measurements were repeated six times.

DETERMINATION OF THE KINETIC FRICTION COEFFICIENT

During each test, the computerized measuring system recorded instantaneous values: friction forces, rope pressure forces on the friction liner samples, rope ambient temperature and test time with a frequency of 20 Hz. The tests were conducted according to the standard DIN 21258, from April 2007, with the parameters given in chapter 3 of this article (Hansel, 2012; Pusch, 2006).

The calculation of the mean value of the kinetic friction coefficient, for a single test, was based on the instantaneous values of FT_1 and FT_2 kinetic friction forces and the value of the F_N steel rope clamping force for the samples (Figure 4), according to the relationship (1). The results obtained from the calculations are presented in the summary.

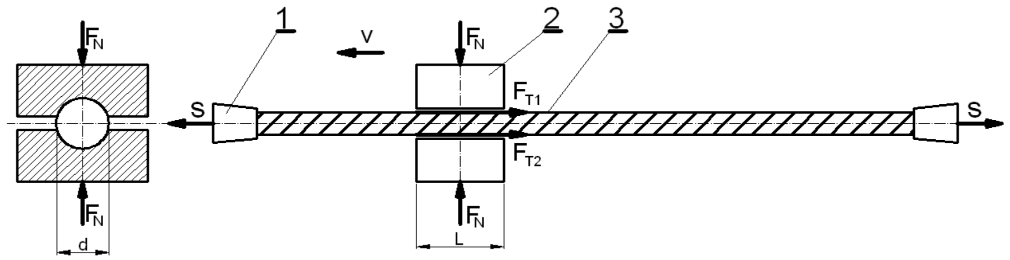

Fig. 4 Model of rope and liner cooperation adopted for laboratory tests: 1 – conical sleeves, 2 – liner, 3 – rope

Source: (Report, 2007)

$$\overline{\mu}_k = \frac{\overline{F}_T}{F_N} \tag{1}$$

where:

F_N – clamping force of the steel wire for the samples[N],

$\overline{F}_T$ – the average kinetic friction force [N].

The average value of the kinetic friction force for a single test was calculated as the ratio between the field of the graph (Figure 5) of braking (integral of the friction force curve as a function of time) and the corresponding base interval (duration of the actual test) according to the relationship (2):

$$\overline{F}_T = \frac{\int_{t_1}^{t_2-t_1} F_{T1}(t)dt + \int_{t_1}^{t_2-t_1} F_{T2}(t)dt}{2(t_2 - t_1)} \tag{2}$$

where:

t_2-t_1 – the time period of the study [s],

$F_{T1}(t)$ – friction force as a function of braking time [N],

$F_{T2}(t)$ – friction force as a function of braking time [N].

According to the requirements of DIN 21258, each measurement should be repeated six times and the average value of the coefficient of friction should be taken as the final value $\overline{\mu}_{sr}$ from five measurements.

The rope pressure on the liner is calculated according to the formula:

$$p = \frac{F_N}{A} = \frac{F_N}{L \cdot d}\text{, MPa} \tag{3}$$

where:

F_N – clamping force of jaws with linings [N],

L = 200 – length of the carpet block in one jaw [mm],

d – measured rope diameter, d = 52 [mm].

The relationship between the pressure force of the liner and the momentary friction force is determined by the formula:

$$F_T = k \cdot \mu \cdot F_N\text{, N} \tag{4}$$

where:

F_T – the average friction force [N],
F_N – the pressing force of the floor covering [N]
μ – coefficient of friction,
k – number of rubbing surfaces.
Kinetic coefficient of friction was determined from dependence:

$$\overline{\mu}_k = \frac{\overline{F}_T}{F_N} \tag{5}$$

where:
$\bar{F}_T$ – calculated average friction force during slip [N],
F_N – measured rope pressure on the liner [N].

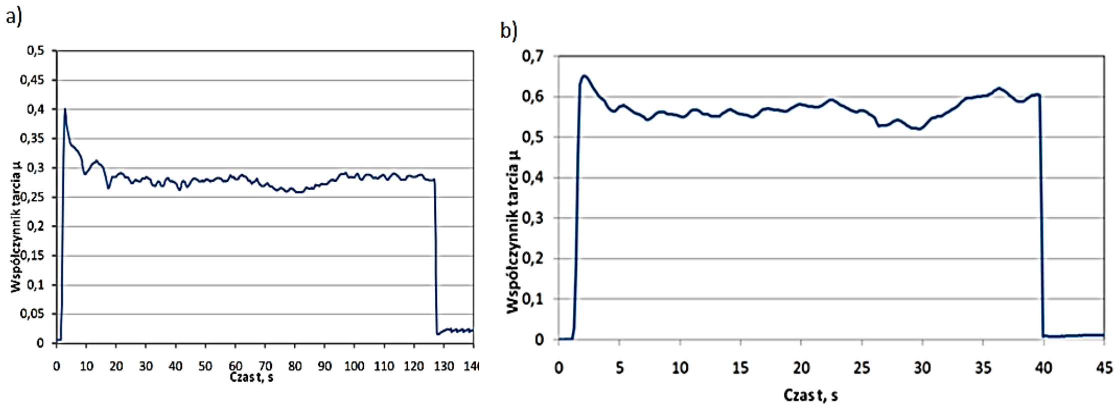

Fig. 5 An example of the course of friction coefficient recorded for one case: a – during testing of the K22 liner with Nyrosten N113 grease at 30°C, b – during testing of the K25SB lining wet at 20°C

Source: (Report, 2007)

During the tests, the computer data acquisition system registers in real time the pressing force F_N using a legalized strain gauge and friction force $\bar{F}_T$ via strain gauge force sensors mounted on cylinder rods.
The average (from a series of tests) value of the kinetic friction coefficient was calculated according to the relation (6):

$$\overline{\mu}_{sr} = \frac{1}{n}\sum_{i=1}^{n}\overline{\mu}_k \tag{6}$$

where:
n – number of repetitions of a given test,
n = 6, the first measurement is rejected.

CONCLUSION

1. The tests of friction coefficient of friction pair steel wire – liner were carried out based on the latest German standard DIN 21258 from April 2007 (Norm, 2007).
2. The tests were carried out for a friction pair (Star, 2000):
   - dry,
   - wet,
   - surface lubricated type approved in the country:

- Elaskon II Star,
- Elaskon III Star LM,
- Nyrosten N113,
- Nyrosten N113 FS.

3. The tests of the coefficient of friction, the surface-lubricated rope were carried out at a temperature of 23°C that prevailed in the laboratory (the standard recommends 20°C) and 30°C (in the heat chamber).
4. For the testing of the friction pair, a ø 52 mm, an anti-slip rope, the Warrington – Indoor construction and the Becorit K22 and Becorit K25SB linings were used.
5. The tests were carried out for the amount of grease 16 g/m applied to the surface of the tested rope in accordance with DIN 21258.
6. The tests show that the coefficient of friction between the rope and the tested friction lining for the different state of the friction pair is as follows:

a) Becorit lining K22:
- dryrope: μ = 0.428÷0.434, $\bar{\mu}_k = 0.431$
- wet rope: μ = 0.588÷0.613, $\bar{\mu}_k = 0.600$
- rope lubricated at temperature 23°C:
  - Elaskon II Star, μ = 0.250÷0.263, $\bar{\mu}_k = 0.255$
  - Elaskon III Star LM, μ = 0.251÷0.540, $\bar{\mu}_k = 0.253$
  - Nyrosten N113, μ = 0.251÷0.255, $\bar{\mu}_k = 0.254$
  - Nyrosten N113 FS, μ = 0.306÷0.323, $\bar{\mu}_k = 0.314$
- rope lubricated at temperature 30°C:
  - Elaskon II Star, μ = 0,248÷0,253, $\bar{\mu}_k = 0.250$
  - Elaskon III Star LM, μ = 0,248÷0,253, $\bar{\mu}_k = 0.251$
  - Nyrosten N113, μ = 0,249÷0,254, $\bar{\mu}_k = 0.251$
  - Nyrosten N113 FS, μ = 0,277÷0,287, $\bar{\mu}_k = 0.282$

b) Becorit lining K25SB:
- dryrope: μ = 0.567÷0.575, $\bar{\mu}_k = 0.571$
- wet rope: μ = 0.553÷0.566, $\bar{\mu}_k = 0.558$
- rope lubricated at temperature 23°C:
  - Elaskon II Star, μ = 0.255÷0.266, $\bar{\mu}_k = 0.260$
  - Elaskon III Star LM, μ = 0.250÷0.254, $\bar{\mu}_k = 0.252$
  - Nyrosten N113, μ = 0.265÷0.275, $\bar{\mu}_k = 0.270$
  - Nyrosten N113 FS, μ = 0.363÷0.383, $\bar{\mu}_k = 0.374$
- rope lubricated at temperature 30°C:
  - Elaskon II Star, μ = 0.243÷0.258, $\bar{\mu}_k = 0.254$
  - Elaskon III Star LM, μ = 0.249÷0.254, $\bar{\mu}_k = 0.252$
  - Nyrosten N113, μ = 0.251÷0.265, $\bar{\mu}_k = 0.256$
  - Nyrosten N113 FS, μ = 0.280÷0.295, $\bar{\mu}_k = 0.289$

7. The tests of surface-lubricated ropes were carried out 4 hours after lubrication except for the Elaskon III Star LM grease for which friction coefficient tests were carried out after 8 hours of lubricating the rope.

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Abstract.

The article presents the method and results of experimental tests of the coefficient of friction between a steel rope and friction lining. The BECORIT K22 and BECORIT K25SB floor coverings were tested. The tests were carried out in accordance with the recommendations of the new German standard: DIN 21258 – Lubricants and impregnating agents for drive discs and transport ropes in mining – safety and testing requirements. The authors in this article emphasize that the Becorit K22 and K25SB linings are used for the wheels of propeller drums of mining machines. 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 ensure their resistance to swelling in the event of different oils and lubricants as well as mine waters. The material of which the claddings are made ensures very good machinability during rolling of rope grooves with the use of turning or milling tools. BECORIT K22 plastic cladding is particularly suitable for use in hoisting machines, where the rope base forms a large overlap angle on the wheel grooves (max 1°31'), which causes its lateral wear faster. BECORIT K22 material in this case provides a higher service life compared to other materials. Due to the way they are mounted on the wheel, they are made as 1-piece (monolith) or bipartite. In this article, moreover, the structure and principle of operation of the measuring station on which the tests were carried out are presented in great detail.

Keywords: steel rope, coefficient of friction, lining