Study on friction behaviour of brake shoe materials for mining hoist

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Abstract. The friction coefficient in the brake linkages has an important influence on the braking efficiency and safety of machines. The paper presents a method for the study of the friction coefficient of the friction couple brake shoe-drum for mining hoist. In this context, it is interesting to define the friction coefficient, not just according to the materials in contact, but according to the entire ensemble of tribological factors of the friction couple.

1. Introduction
Friction can be defined as a complex process of molecular, mechanic and energetic nature. Dry friction is characterized by direct immediate contact of the surfaces in relative motion. No lubricant film is interfering between the brake-shoe friction areas, except the films absorbed from the ambient gaseous environment. The frictional properties of the brake shoe have very important influence on the braking reliability and safety of mine hoists. [1]

Most researches [1][2][3][4][5] show that the friction depends on speed, pressure, temperature, air humidity, real contact surface, chemical composition of materials etc. In these conditions, the friction coefficient, presented in many tables, has just informative values without presentation of experimental conditions of the measuring process.

In this context it is interesting to define the friction coefficient, not just according to the materials in contact, but also according to the entire ensemble of tribological factors for friction couple brake shoe-drum for mining hoist.

2. The analysis of tribological factors of friction couple for mining hoist
By corroboration of the data established by Czihoş [6] and Crudu [7] with the aspects specific to the braking system in case of mining plants, the structuring of the parameters of the shoe – drum represented in figure 1 has been carried out.

The friction materials are equipped with different types of braking system, functioning in different mediums, therefore demanding separate analysis for each particular case, for the tribological factors of friction.

The braking systems are equipped with different friction materials and they function in different environments, therefor they demand separate analysis of the tribological factors for each case.

The brake drum of the mining hoist is made of steel or cast iron. As many theoretical and experimental researches have proved, the most recommended material for the brake drum and the
brake disks is cast iron (it has better thermo-physical properties than steel and a better stability of the friction coefficient). However, most of the brake drum are made of steel [8][9]. The materials from which the brake drum of the mining hoist are made must have the following characteristics: good thermal conductivity; high friction coefficient between it and the friction lining; resistance to wear.

Figure 1. Tribological parameters on which the friction coefficient depends.

Brake shoes used for mining hoist are made of composite materials. The introduction of different fillings in the composition of friction materials influences the working conditions and the friction characteristics in different ways [1].

The filling used in the past was usually asbestos, due to some specific properties: mechanical strength, high temperature resistance, low heat conductivity and good resistance to wear. At present, it is necessary to replace it with other types of materials for environmental reasons. Therefore, the following are used as fillers: glass fibers, mineral fibers, Kevlar, ceramic materials, etc. [10] [11].

Inserting metal dust creates favorable conditions for removing the heat from the friction surfaces and increases the stability of the friction coefficient.

The main characteristics that are imposed on the friction linings are [4][6][10]: high and as stable as possible friction coefficient between them and the brake drum, resistance to wear, low friability, good processability anti-inflammability.

The normal force between brake shoe and drum is variable during braking. Regarding the variation of the force N during braking N (t), researches in the field have established that N varies according to a linear law as follows: [12]:

\[ N = c \cdot N_{\text{max}} \cdot t_f, \]  

where:
- \( c \) – variation (non-uniformity) coefficient of the pressure force of the shoes on drums,
- \( N_{\text{max}} \) – maximum value of the normal force,
- \( t_f \) – braking duration.

It follows that the braking pressure is variable.

The angular speed of the drum is also variable during braking.

The variation function is [6]:

\[ \omega = \omega_0 \left( 1 - \frac{t}{t_f} \right) \]  

(2)
In which $t_f$ is the braking duration, $\omega_0$ is the angular speed of the rim at the beginning of braking speed. In conclusion, the sliding velocity is also variable.

Temperature of the braking surface influences the coefficient of friction. During the braking process, the friction work is converted into heat at the level of friction surfaces, thus endangering the quality of braking [1].

Experimental research has shown that the most intensely heated are the brakes of the mining hoists with cages, which descends the weights and having synchronous drive without dynamic braking [8]. The thermal condition of the brakes depends on the physical properties of the materials of the friction torque (shoe - drum) and on the construction of the brake [9].

In the case of shoe brakes about 95% of the heat produced on the friction surfaces is taken over by the drum and only 5% is taken over by the shoes [12].

3. Experimentation
The objective of the experimental research is to establish the friction coefficient of the friction material between brake shoe and drum when it is subjected to compressive loads, high temperature and environmental humidity.

The FF-30 non-asbestos brake shoe was selected as the experimental brake shoe material. The drum was made of steel S235JR SR EN 10025-2, 2004.

FF-30 is an ecologic non-asbestos friction material, with a good braking/engagement/clutch release efficiency, good wear characteristics and good mechanical resistance, during the working temperature range. It contains mineral fibers, pulverous inorganic materials, phenol-formaldehyde resin and powder synthetic rubber, complying with the requirements of the legislation in force on environmental and work safety.

The friction experimental stand, figure 3, was created with the target to simulate the operating conditions of drum brakes of mining hoist.

The block diagram for the friction experimental stand is presented in figure 2:

![Figure 2. Block diagram of the experimental stand.](image-url)
The drum is 120 mm in diameter and it is in contact with the assay sample (2) made from friction material type F - 30 having a 225 mm$^2$ contact surface. The assay sample is fixed in a vertical device (3). On the vertical device is applied the set weight which is used to adjust the load gradually (Fn). The device is a charging equipment with standard weights. The movement of the drum is provided by an electric engine $P=2.2$ kW, $n=1430$ r.p.m. The motion is transmitted from the engine to the drum via belt transmission.

![Figure 3. Experimental stand.](image)

The belt transmission has four positions, corresponding to four values of speed of the drum. The friction forces between the assay sample and drum move the piece (7) and determine the compression of the spring (5). The compression is measured with the dial indicator (6). Knowing the characteristic of the compression spring depending on the shift, read with the dial indicator, the tangential force is deduced.

A water sprayer with water collected from mine was used for the simulation of humidity of technical environment. The humidity was measured with a hygrometer type testo 615.

Another condition was the heating of the drum surface at the nominal temperature of function (inspected with thermometer TMTL 260). The loads applied to the assay were of 225 N, 112.5 N, 75 N respectively the braking pressure values 1MPa, 0.5MPa, 0.33MPa. The tests were carried out for four peripheral speeds of the drum and for humidity of 60% and 90% (table 1). The time for each experiment was 2 seconds. Also each experiment was done 3 times.

| Pressure [MPa] | Temperature [$^\circ$C] | Speed [m/s] | Humidity [%] |
|---------------|------------------------|-------------|--------------|
| 1             | 30.000                 | 5.500       | 60.000       |
| 0.5           |                        | 8.000       | 60.000       |
| 0.33          |                        |             | 90.000       |
In these conditions, the determination of the friction coefficient was realized. Experiments were performed by a sequence presented in table 1.

After carrying out the experiments we get the variation charts presented in figures 4-9.

![Figure 4](image_url)

**Figure 4.** Friction coefficient for 1 MPa and 60% humidity
Figure 5. Friction coefficient for 1 MPa and 90% humidity

Figure 6. Friction coefficient for 0.5 MPa and 60% humidity

Figure 7. Friction coefficient for 0.5 MPa and 90% humidity
In order to assess the friction coupling, the following coefficients have been introduced [12]:

- stability coefficient for the friction coefficient:
  \[ \alpha_{CT} = \frac{f_{\text{cp}}}{f_{\text{max}}} \]  
  \[ \text{(3)} \]
  In which \( f_{\text{cp}} \) is the average value of the friction coefficient during braking, \( f_{\text{max}} \) is the maximum value of the friction coefficient in the braking process.

- coefficient of braking efficiency:
  \[ \beta_{\text{ct}} = \frac{\alpha_{CT}}{t_f} \]  
  \[ \text{(4)} \]
  In which \( \alpha_{CT} \) is the stability coefficient for the friction coefficient and \( t_f \) is the braking duration.

Using diagrams (3) and (4), we can determine the stability of the friction coefficient and the efficiency of the brake considering the ensemble of tribological factors (different values of speed, temperature and humidity), for different mining hoists.
4. Conclusions
This paper presents the parameters that influence the friction coefficient for the shoe brakes of the mining hoist. Then the influence of four parameters (braking pressure, sliding velocity, surface temperature and humidity) on the friction coefficient has been studied using an experimental stand.

Analyzing the resulted charts, the following conclusions occurred:
- The friction coefficient increases with the increase of relative speed;
- The friction coefficient decreases in correlation with the increase of temperature;
- The friction coefficient decreases in correlation with the increase of the contact pressure;
- The friction coefficient decreases in correlation with the increase of humidity.

The presented method allows a better assessment of the friction coefficient in tribological conditions of operation. Also for concrete operation conditions one can determine the stability coefficient of the friction coefficient based on the experimental data.

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