Dr hab. inż. Jarosław Brodny, prof. nzw. w Pol. Śl.
Politechnika Śląska Gliwice, Wydział Górnictwa i Geologii,

DETERMINING THE WORKING CHARACTERISTIC OF A FRICTION JOINT APPLIED IN MINING YIELDING SUPPORT

The article presents the results of stand tests and numerical analyses conducted in order to determine the working characteristic of a friction joint used in yielding supports and in friction props. A functional model was used to determine analytically the working of the friction joint. A stick-slip model of intermittent motion and a dry friction model were used to model the joint's yield capacity. The friction joint's working characteristic at axial compression and its yield capacity (i.e. joint tensile force) was determined as a result of the analysis. The results of friction joint stand tests at axial compression have also been presented in the paper and compared to the results of numerical analysis. The results obtained in stand tests and numerical analyses reveal high quantitative and qualitative consistency.

Keywords: yielding support, friction joint, mining support

1. Introduction

The Polish coal mines use commonly steel yielding supports to secure dog headings. The purpose of the support is to secure dog headings against loads originating from the rock mass.

The working principle of the yielding support consists of changing the dimensions due to external loads while preserving its function at the same time. The mutual displacement of the support's shaped sections due to an external load is ensured by friction joints. Yield in friction joints then occurs.

The working principle of yielding supports is based on the use of friction forces between the interworking shaped sections. The joints are used in steel frames of yielding supports and in friction props.

The friction joint is made up of two overlapping shaped sections pressed with clamps. The friction force between the contacting shaped sections is a result of the acting pressing force and the friction coefficient between the shaped sections. The pressing force depends on the value of the axial forces acting in the clamps bolts and on the frictional forces in a bolted joint. The work of friction joints have a decisive effect on the working characteristics of the frames and friction props, and then on the entire yielding support. The working characteristics of the frames are considered as a relationship between the external load and shaped sections displacement due to the friction joint's work.

The yield support working characteristic (so-called friction joint's operating curve) is determined in stand tests performed according to the Polish Standard. A friction joint made of straight shaped sections joined with clamps is pressed axially in such test. Relationships between the external force loading the joint and the mutual displacement of the interworking shaped sections (so-called yield) are determined in such tests.

The key parameter determined in such tests is the friction joint's yield capacity. Such capacity is the value of the joint's external loading force at which the first yield is achieved. The yield capacity is also referred to as the friction joint's tensile force. The value of the force has a practical significance for yielding support selection and use.

This paper presents the results of stand tests and numerical analyses using a functional friction joint model the purpose of which was to determine the friction joint working characteristic and yield capacity.

A model of intermittent motion with dry friction developed and used for friction joint modelling has been presented. Tensile force for a friction joint was defined for the model.

A physical model of a friction joint was next established. The model considers dry friction between the interworking shaped sections, and the external load was identified according to the kinematic force acting on the friction joint, which corresponds to the actual model. The mathematical model established was subjected to an analysis as a result of which the working characteristic of a friction joint was developed. The effect of the friction coefficient between the interworking shaped sections on the friction joint yield capacity value (tensile force value) was also identified.

The paper also presents the results of stand tests the purpose of which was to identify the working characteristics of friction joints and the tensile force values in the friction joint. The results have been compared to the results of the numerical analysis.

2. Determination of Friction Joint Working Characteristic in Stand Tests

The friction joint working characteristic is determined in tests stands in line with the Polish Standard. A friction joint in such tests is undergoing axial compression with force acting on one of the shaped sections. The force results from the displacement of a tensile machine's piston with constant speed.

Fig.1 shows the test method for a friction joint made of V29 sections connected with two SDO 29 clamps.

In the case considered, the torque for tightening the clamp mounting bolts was 400 Nm. Fig. 2 presents a friction joint's working characteristic obtained in a stand test. In this chart, *P* denotes the axial force loading the shaped section and *Z* is the yield value.

Fig. 1. The method of testing a friction joint at axial compression

When analysing the obtained characteristic, its instability should be emphasised. It is a typical feature of all working characteristics produced in stand tests. It is hard to predict the values of the forces at which subsequent yielding occurs, the value of such yielding as well as their occurrence time.

The main values determined from the friction joint's working characteristic are:

- yield capacity value (P_{z1}) ,
- minimum yield capacity value ($P_{z\,min}$),
- maximum yield capacity value ($P_{z\,max}$),

- average yield capacity value ($P_{śr}$).

The values for the characteristic presented in Figure 2 are shown on the diagram.

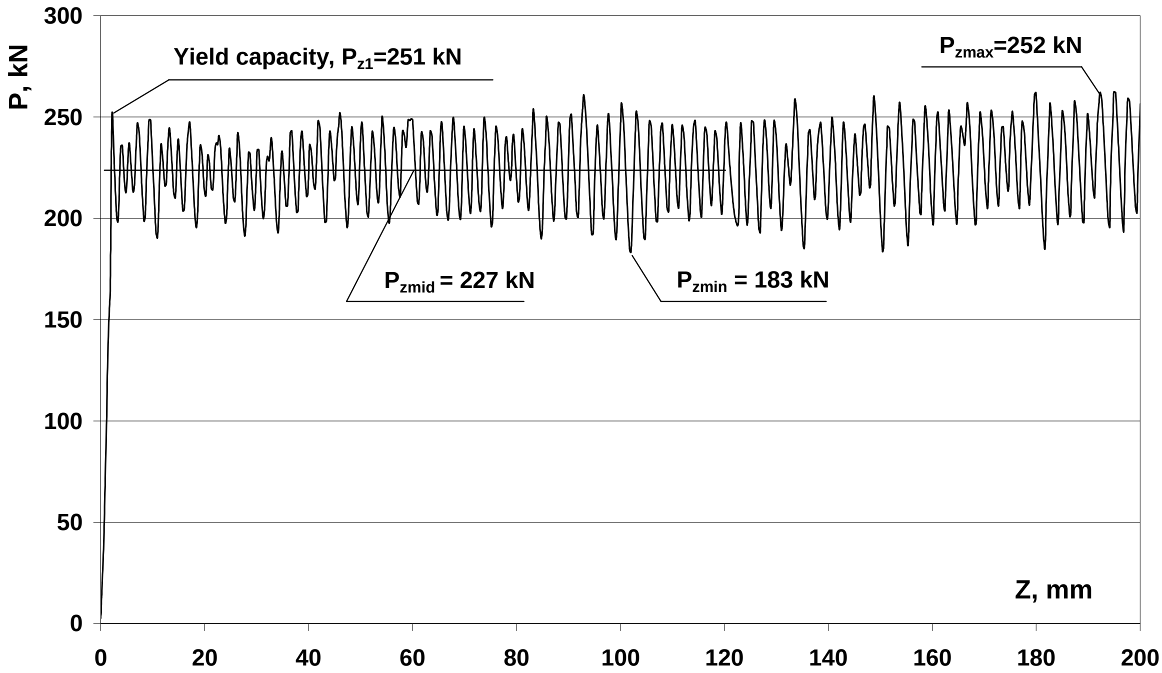


Fig. 2. A friction joint's working characteristic obtained in stand tests

3. Friction Joint Intermittent Motion and Tensile Force (Yield Capacity)

The yielding support's geometry is changed due to the mutual displacement of the shaped sections in the friction joints. The shaped sections' motion (so-called yield), depending on multiple factors, is intermittent. The key factors include the pressing force on the shaped sections as well as static and kinetic friction coefficients between the shaped sections.

A physical model of the system performing intermittent motion taking into consideration dry friction (Fig. 3) has been developed to describe the intermittent motion and identify the friction joint tensile force [1, 2, 5].

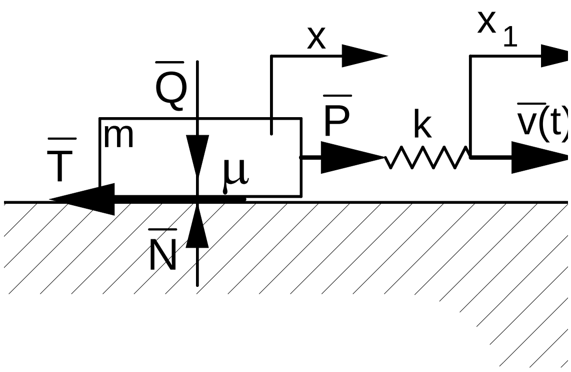
Fig. 3a presents a physical model of a system for describing the intermittent motion.

In this system, a body with *m* mass is loaded with *P* external force and *T* friction force acting on the surface of contact with a substrate. *P* force is a result of stretching a spring with *k* rigidity. The value of the force depends on *v(t)* speed of spring displacement and its rigidity. The rigidity and extension speed of the spring for the analysed system are constant.

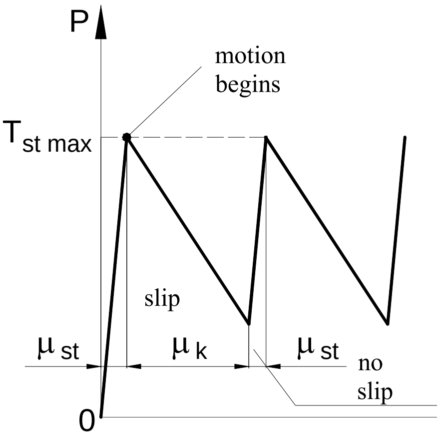
Fig. 3b presents the characteristics of *P* exciting force's relationship according to *x* displacement of *m* mass.

The characteristic illustrates the intermittent motion of a body with *m* mass. The motion is performed according to the values of static (μ_{st}) and dynamic (μ_{dyn}) friction coefficients between the *m* body and a substrate.

The *P* force value at which the motion of the body with *m* mass begins corresponds to the tensile force's value. The moment of transition from the static friction to kinematic friction is defined this way. The *P* force value at which the contact of the body with the substrate is lost depends on the value of static and kinematic coefficients and on the *m* mass pressing force (*N*) (*N* force=*Q*). The adopted friction model corresponds to the Coulomb friction model [4].



a)



b)

Fig.3. Model of intermittent motion with dry friction

The movement of the body with *m* mass can be described with the equation as follows:

$$m \cdot \ddot{x} + T = k(vt - x) \quad (1)$$

The equation describes an intermittent motion of the body with *m* mass with dry friction

The value of *T* force depends on the pressing force $N=Q=mg$ and the static (μ_{st}) and kinematic (μ_k) friction coefficients between the surface of the contacting bodies.

The relationship between the kinematic friction force and relative speed of the contacting bodies is constant in the model analysed and is $T_k = \pm m \cdot g \cdot \mu_k$. It has been assumed for the calculations that the friction force of static friction varies according to *P* force and the maximum value is reached for $P=T_{st\ max}$ ($T_{st\ max} = m \cdot g \cdot \mu_{st}$) [3].

The model presented correctly describes the working nature of the friction joint used in a yielding support and in friction props. It enables to model the intermittent motion that occurs in yielding supports. It also allows to determine the friction joint tensile force (yield capacity).

The model developed was used for determining the working characteristic of a friction joint and friction joint yield capacity and other values describing this characteristic.

4. Determination of Friction Joint Working Characteristic with Functional Model

A physical model of the friction joint made of V29 shaped sections connected with two SDO 29 clamps (Fig. 4) was established using the intermittent motion model from Fig. 3 and the friction joint test diagram in Fig. 1. It is a system with three degrees of freedom.

A friction joint in this system was modelled as two grouped masses of the interworking shaped sections. The shaped sections are pressed with *N* force the value of which is equal to the sum of axial forces in the clamp bolts. It was assumed for the model analysed that each of the bolts was tightened with the torque of 400 Nm. It equals to the axial force of 82 kN for each bolt.

A mathematical model describing a motion of m_1 and m_2 masses around their position of equilibrium, forced by *P (v, k)* load, assumes the form of the following equation:

$$m_1 \cdot \ddot{y}_1 - k_1 \cdot (y_3 - y_1) - c_1 \cdot (\dot{y}_3 - \dot{y}_1) + T = 0$$
$$m_2 \cdot \ddot{y}_2 + k_2 \cdot y_2 + c_2 \cdot \dot{y}_2 - T = 0 \qquad (2)$$
$$k_1 \cdot (y_3 - y_1) + c_1 \cdot (\dot{y}_3 - \dot{y}_1) = P(v)$$

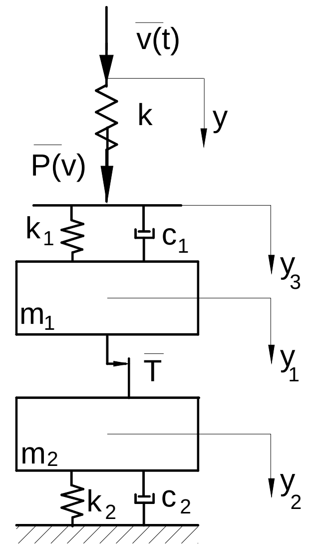


Fig. 4. Physical friction joint model

External active force P acting on the joint is a result of displacement of a tensile machine piston with v constant speed. The value of this force is calculated according to:

$$P = k(y - y_3) = k(v \cdot t - y_3) \qquad (3)$$

Two interworking shaped sections in the considered system are made of the same material and have the same dimensions. It provides, therefore, that their masses together with clamps, elasticity coefficients and damping coefficients are the same. The following is achieved by assuming $m_1 = m_2 = m$, $k_1 = k_2 = k_1$, $c_1 = c_2 = c$ for the equation (2) and including equation (3) and transforming it:

$$m \cdot \ddot{y}_1 - c \cdot \dot{y}_3 + c \cdot \dot{y}_1 - k_1 \cdot y_3 + k_1 \cdot y_1 + T = 0$$
$$m \cdot \ddot{y}_2 + c \cdot \dot{y}_2 + k_1 \cdot y_2 - T = 0 \qquad (4)$$
$$c \cdot \dot{y}_3 - c \cdot \dot{y}_1 + k_1 \cdot y_3 - k_1 \cdot y_1 + k \cdot y_3 = k \cdot v \cdot t$$

The friction force value changes according to the following relationship:

$$T = \begin{cases} T_{st} \cdot sign\ (W)\ for\ \dot{y}_1 - \dot{y}_2 = 0\ i\ |W| \geq T_{st} \\ W \cdot sign\ (W)\ for\ \dot{y}_1 - \dot{y}_2 = 0\ i\ W \langle T_{st} \\ T_k \cdot sign\ (\dot{y}_{1-2}))\ for\ \dot{y}_1 - \dot{y}_2 \neq 0 \end{cases} \qquad (5)$$

where: $W = k_1(y_3 - y_1) + c_1(\dot{y}_3 - \dot{y}_3)$; $T_{st} = N \cdot \mu_{st}$; $T_k = N \cdot \mu_k$ (6)

A numerical analysis was made for the mathematic model developed in such manner and the friction joint working characteristic was produced as a result of such analysis (Fig.5).

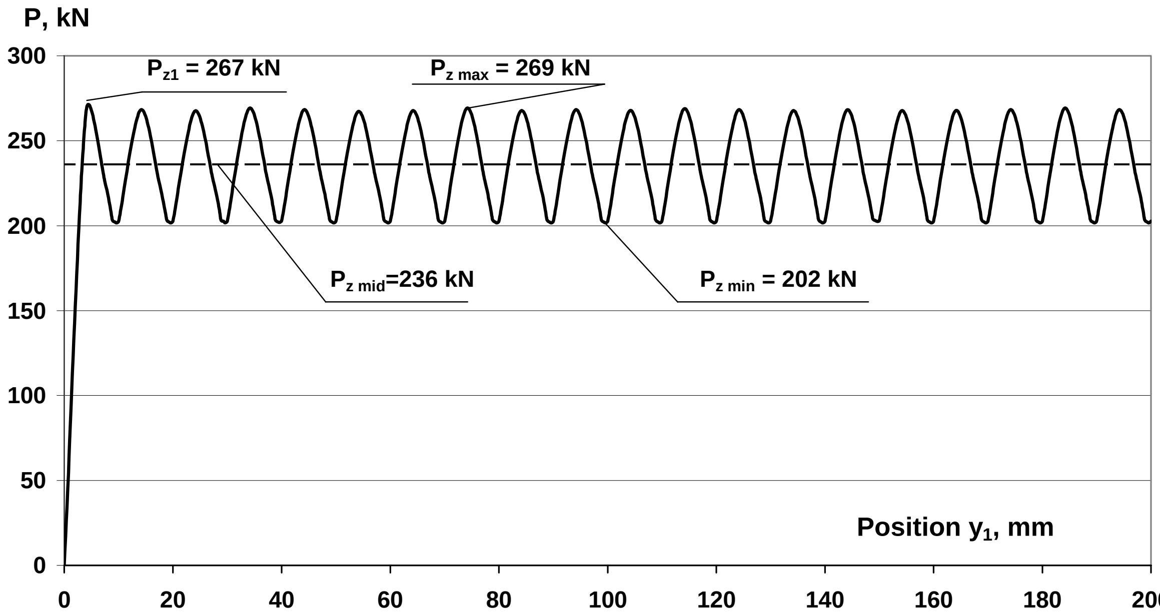


Fig. 5. The friction joint working characteristic obtained in the functional model analysis

Table 1 presents the key values describing the friction joint working characteristics obtained in a numerical analysis and stand tests. The results of stand tests presented in the table are the arithmetical means of the values for individual values from five independent tests.

Table 1

kN	Yield capacity (tensile force) P_{z1}	Maximum yield capacity $P_{z\,max}$	Minimum yield capacity $P_{z\,min}$	Average yield capacity $P_{z\,mid}$
Stand test (arithmetical average of five tests)	252	255	180	228
Numerical analysis	267	269	202	236
Deviation, %	5,9	5,5	12,2	3,6

When comparing the friction joint working characteristics produced in a numerical analysis and in stand tests, their large qualitative and quantitative consistency should be underlined. The deviations of 5.9 % for yield capacity and 3.6 % for average yield capacity should be considered negligible. Larger disparity in results in determining the minimum friction joint yield capacity is related to certain inaccuracies in stand measurements. From a practical standpoint the parameter is not too important for the functioning of support frames.

5. Summary and Conclusions

The current constructional solutions of friction joints used in yielding supports and in friction props are characterised by unstable work. It can be concluded by analysing the friction joint working characteristic determined with a stand test (Fig. 2) that the values of yields in the friction, occurrence time as well as the values of forces they occur at are hard to predict.

The actual working characteristics of friction joints are determined in stand tests. The tests require special measuring stands and are costly.

It is, therefore, purposeful to conduct work aimed at using less costly method of analysing joints' work that would correctly reflect the actual character of their work. These conditions are satisfied by applying numerical methods for analysing the work of friction joints. This requires, however, the correct modelling of the friction joint itself and its loading method.

The results produced in a numerical analysis and stand tests reveal high consistency. It can be assumed, therefore, that the model developed has fulfilled its task as regards requirements concerning the determination of values describing friction joint working characteristic.

The friction joint model established allows to determine friction joint susceptibility to variance in its specific characteristic parameters (e.g. pressing force, friction coefficients, load speed, excitation type). The model can also be used for analysing the work of the entire yield support frame.

The mapping of a yield support's intermittent motion is most essential considering its correct work allowing to model its yield.

The consistency of the characteristic obtained in a numerical analysis versus the characteristic obtained in stand tests should be noted in comparing the results obtained. The reason for that is functional model idealisation. This applies to the kinematic friction force value. The kinematic friction force value in the analysed model was adopted as constant during yield and in fact the force varies. So-called Stribeck phenomenon occurs [5]. It seems, however, that if this phenomenon is taken in account in this case, it would not substantially influence the results obtained.

It also should be noted that the results of stand tests are impacted by a number of other factors that are difficult to consider in mathematical equations. Such factors include the inaccurate fabrication of friction joint elements, inaccurate joints installation, imperfections related to external load, the deformation of joint elements during subsequent yields, the changes occurring on the surfaces where slipping occurs, etc.

It can be assumed that the presented functional model is correctly representing an actual friction joint. It proves large opportunities for simulating its work, which should be used for optimising the existing friction joint solutions and also when designing new ones.

The results and conclusions from the performed stand tests and theoretical analyses presented should be taken into account when using yield supports. They should improve working safety in the mining industry by the correct use of strength performance of the supports in use.

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