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# THE POSSIBILITY OF STATIC FRICTION COEFFICIENT CALCULATION

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***Abstract***
*The value of static friction coefficient varies in a large interval. It depends on numerous parameters as mechanical properties of material, surface roughness, value of the contact pressure, lubricant film properties, hardness of the contact surfaces, contact condition, contact duration and etc. The values of static friction coefficient are established by experimental examinations and information about that is presented in recommendation form for engineering practice. Most authors set the models for calculating static friction coefficient on the base of theoretical and experimental investigations. Some of these models are presented in this paper. The model which includes measuring values of contact surface roughness, contact pressure and surface hardness is established in the research carried out at the Faculty of Mechanical Engineering Nis. This model is useful in engineering practice.*

***Keywords***: *Static friction coefficient, calculation, press fit joint*

## 1. INTRODUCTION

Static friction force presents the strength of many different joints which transmit great loads. Taking into account that fact, engineers need to estimate the real value of friction coefficient that can be used in calculating of these joints strength. In the most of cases, coefficient of friction is estimated by experimental way. But, the precision of prediction of tangential strength of each new contact remains unknown even in case an experiment is performed in very detailed and precise form. Static friction coefficient doesn't have constant values but it varies in a large interval. For completely determinate tribomechanical system, it can be talked only about the mean values of friction coefficient.

The values of static friction coefficient are established by experimental examinations and information about that is presented in recommendation form for engineering practice. Usual mean values of static friction coefficient for different combinations of material is shown in Table 1 [5].

**Table 1. Mean values of static friction coefficient for different materials**

| Combinations of Materials | Static Coefficient Friction | |
|---|---|---|
| | **Clean** | **Lubricated** |
| Steel- Steel | 0.8 | 0.16 |
| Brass-Brass | 0.35 | 0.19 |
| Cast iron-Cast iron | 0.4 | 0.21 |
| Plexiglas-Plexiglas | 0.4-0.5 | 0.4-0.5 |
| Polystyrene-polystyrene | 0.3-0.35 | 0.3-0.35 |
| Polythene-Polythene | 0.2 | 0.2 |
| Teflon-Teflon | 0.04 | 0.04 |
| Aluminum-aluminum | 1.35 | 0.3 |
| Cadmium-cadmium | 0.5 | 0.05 |
| Chromium-chromium | 0.41 | 0.34 |
| Copper-copper | 1 | 0.08 |
| Iron-iron | 1 | 0.15-0.20 |
| Magnesium-magnesium | 0.6 | 0.08 |
| Nickel-nickel | 0.7 | 0.28 |
| Platinum-platinum | 1.2 | 0.25 |
| Silver-silver | 1.4 | 0.55 |
| Zinc-zinc | 0.6 | 0.04 |
| Glass-glass | 0.9-1.0 | 0.1-0.6 |
| Glass-metal | 0.5-0.7 | 0.2-0.3 |
| Diamond-diamond | 0.1 | 0.05-0.1 |
| Graphite-graphite | 0.1 | 0.1 |

Except experimental way, the value of friction coefficient can be also calculated. Most authors set the models for calculating static friction coefficient on the base of theoretical and experimental investigations. These models can be used for static and kinetic friction as well, but many dates about contact condition must be known. Some of calculation models will be described in this paper.

## 2. CALCULATION OF THE STATIC FRICTION COEFFICIENT

Coefficient of static friction $\mu_s$ in two solids surfaces contact is defined as relation between tangential force that is necessary to produce sliding and normal force between contact surfaces:

$$\mu_s = \frac{F_s}{N}$$

After Leonardo da Vinci's supposition of basic friction principles, as well as later contributions of Newton, Amontons, and Desagulies, Euler in 1725 used his prowess in mathematics to develop another useful relationship in friction:

The static coefficient of friction of a body on an inclined plane is equal to the tangent of the included angle of the plane $\mu_s = tg\alpha$.

Coulomb in 1785 added to friction knowledge by fortification that friction force is due to adhesion and the other part is due to the force required to plow surface features that stand in the way of motion.

Tomlinson in 1924 developed Molecular model of friction in which the coefficient of friction is expressed by next equation:

$$\mu = \frac{C_1 W n}{l F_N}$$

where $C_1$ is constant; $W$ is energy of one molekular conection; $n$ is number of molekular conections; $l$ is distance between molekuls; $F_N$ is normal force.

Bowden and Tabor in 1930 formulated the Adhesion friction theory which presents significant contribution for science of friction [1]. Their approach is that adhesion component of friction force is major part of its total value. In that way the relationship of friction coefficient is:

$$\mu = C\frac{\tau_0}{p_0} = \frac{\tau_s}{p_0}$$

where $C = \tau_s/\tau_0$ is constant which depend on material; $\tau_s$ is shear strength of basic softer material; $\tau_0$ is shear strength of membrane which covers that material.

Kragelskii in 1939 formulated Molecular-mechanical friction theory. Toward this theory, total friction force in contact area of tribomechanical system is a sum of molecular and deformity components. Friction force value depends on deformations type in contact zone. Deformation may be elastic or plastic depending on mechanical properties of contact bodies, normal load and surface micro-topography [2].

In elastic deformity condition in real contact zone friction coefficient can be calculated by formula:

$$\mu \cong \frac{2{,}4\tau_0\left(1-\nu^2\right)^{0,8}}{p_c^{0,2}\Delta^{0,4}E^{0,8}} + \beta + 0{,}2\alpha_{ef}\Delta^{0,4}\left[\frac{p_c\left(1-\nu^2\right)}{E}\right]^{0,2}$$

This complex equation includes characteristics of friction pair (pc – contour pressure), material features ($\alpha$ef, $\nu$, E), technological parameters-surface quality ($\Delta$ - micro-geometry roughness complex parameter) and exploitation-technological parameters which include used lubricate ($\tau$0 , $\beta$).

In plastic deformity condition in real contact zone and if most of asperities are in mutual contact, static friction coefficient can be calculated by formula:

$$\mu = \frac{\tau_0}{HB} + \beta + 0{,}9\Delta^{1/2}\left(\frac{p_c}{HB}\right)^{1/2}$$

This formula is valid in case of most engineering surfaces with roughness parameters b≈2 and ν≈2.

On the base of supposition that total friction force depends mainly on plastic deformation of surface asperities and less depends on shear of connection in roughness real area, Ludema in 1987 set the model:

$$\mu = \frac{1}{\sqrt[3]{(K^{-2}-1)}}$$

where **K** is ratio of the shear strength of surface asperities $S_1$ and the bulk shear strength $S_2$ ($K=S_1/S_2$).

Budinski in 1991 set the new model for calculating the friction coefficient. His model includes all of influence parameters: type and thickness of surface films; normal force; surface texture; solid solubility of paired materials;

presence of third bodies; sliding velocity; ambient temperature; ambient atmosphere; elasticity of the tribosystem; mechanical properties of each member of the couple; waviness. According previous coefficient of friction can be calculated by formula:

$$\mu = K_0\left[\sqrt{\frac{E_h}{E_s}} + \sqrt{\frac{\sigma_h}{\sigma_s}} + 3\sqrt{\frac{R_{zh}}{R_{zs}}}\right] + \frac{1-V}{10}\left[\frac{1-P}{\frac{\sigma_s}{50}}\right]$$

where Ko is constant for surface contamination; Eh is modulus of elasticity of the harder member of a couple; Es is modulus of elasticity of the softer member; σh is yield strength of hard member; σs is yield strength of soft member; Rzh is 10 point height of harder surface; Rzs is 10 point height of softer surface; V is sliding velocity; P is apparent applied pressure [4].

## 3. CALCULATION OF THE STATIC FRICTION COEFFICIENT FOR PRESS FIT JOINTS

Toward Molecular-mechanical friction theory of Kragelskii, static friction coefficient is a sum of molecular and deformity components. Relation of molecular and deformity components of static friction coefficient depend on contact condition respectively on deformity condition in real contact zone, and it's value for steel materials is about $\mu_d/\mu_m$=0,6-1,5 [2]. In the boundary friction conditions, penetration depth estimates friction character and the relation between deformity and molecular component of static friction.

On the base of Molecular-mechanical friction theory new useful calculating model was created. This model includes surface roughness parameters and hardness of contact surfaces and as well as ratio of the molecular and deformity components of friction coefficient which should be established by experimental way in concrete tribological condition [4].

Model for calculating the static friction coefficient is expressed in form:

$$\mu = k \cdot \Delta^{1/2}\left(\frac{p_c}{HB}\right)^{1/4}$$

where: **k** is coefficient that depends on ratio of molecular and deformity components of static friction coefficient; **Δ** is micro-geometry complex parameter [2]; $\mathbf{p_c}$ is contact pressure; **HB** is surface hardness of softer part in contact. This formula is valid in case of most engineering surfaces with roughness parameters b≈2 and ν≈2.

Procedure of static friction coefficient calculation is shown in Algorithm in Figure 1, and phases of calculation process are shown in Table 2.

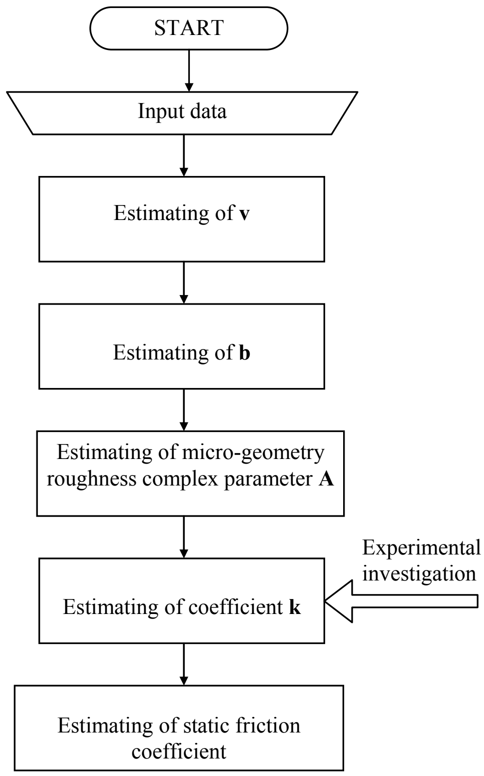


*Figure 1 Algorithm of static friction coefficient calculation*

**Table 2. Phases of calculation process**

| CALCUALTION PHASE | DESCRIBE OF CALCULATION AND EQUATION |
|---|---|
| Intake dates | Contact pressure: $p_c$<br>Surface hardness: $HB_u$, $HB_s$;<br>Surface roughness: $R_{au}$, $R_{zu}$, $R_{maxu}$, $R_{pu}$, $t_{mu}$, $p_u$; $R_{as}$, $R_{zs}$, $R_{maxs}$, $R_{ps}$, $t_{ms}$, $p_s$. |
| Estimating of roughness parameter **ν** | $\nu = 2t_m\frac{R_p}{R_a} - 1$ |
| Estimating of roughness parameter **b** | $b = t_m\left(\frac{R_{max}}{R_p}\right)^{\nu}$ |
| Estimating of micro-geometry roughness complex parameter **Δ** | $\Delta = \frac{R_{max}}{rb^{1/\nu}}$ |
| Estimating of Penetration depth | $h \approx 3{,}4R_a\left(\frac{p_c}{HB}\right)^{1/3}$ |
| Estimating of coefficient **κ** | Value is estimated toward the value of penetration depth on the base of the Figure 2 |
| Estimating of static friction coefficient | $\mu = k\Delta^{1/2}\left(\frac{p_c}{HB}\right)^{1/4}$ |

Using calculated and measured particulates in this research, the dependence curve of calculating coefficient **k** and penetration depth is formed (figure 1). That dependence was investigated and estimated by experimental way. The experiment was executed with samples of press fit joints and with samples in plate form with measuring equipment that is specially made for this research.

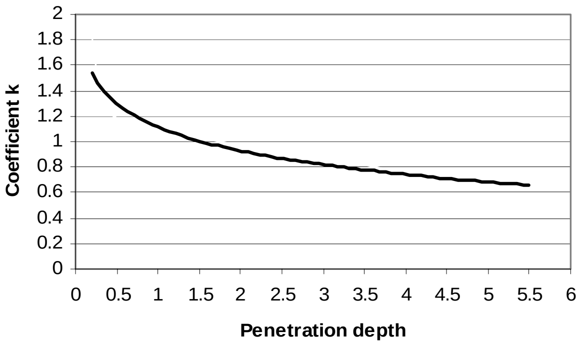


*Figure 2 Dependence of coefficient* ***k*** *and penetration depth*

Values of coefficient **k** refer to tribological conditions that consist in press fit joints of railway vehicles driving wheel sets: contact parts are made of steel; contact pressure is about 100 N/mm$^2$; surface hardness goes around 1700-2500N/mm$^2$; lubricant between samples is Loctite Wheel Mount (Loctite 311). In case of calculating static friction coefficient in various conditions (lubricant type is separately important), it is necessary to execute experimental examination and estimate coefficient **k** for that tribomechanical pair and concrete friction conditions.

Described calculating model is suitable for engineering application. It is necessary to measure roughness parameter $\mathbf{R_{max}}$, $\mathbf{R_a}$, $\mathbf{R_p}$ and $\mathbf{t_m}$, then to calculate complex parameter-Δ..

Contact pressure $\mathbf{p_c}$ is estimated on the base of normal load in contact. Surface hardness **HB** is measured.

Coefficient **k** depends on machining way, contact surface roughness and on relation of surfaces hardness in mutual contact.

## 4. EXPERIMENTAL VERIFICATION

Experimental investigation with samples in form of plates was done in order to estimate the dependence of coefficient **k** and penetration depth in described tribological conditions. Press fit joint samples were made in order to test calculation model. Surfaces of experimental samples in form of plates were machined by milling, grinding and lapping. Surfaces of experimental press fit joint samples were machined by lathe machining and grinding. The roughness parameter values of samples were measured and they are shown in table 2. Calculated values of penetration depth and measured static friction coefficient are also shown in Table 3 [4].

Comparison of calculated and measured values of static friction coefficient for 21 press fit joint samples is shown on the Figure 3.

Measured static friction coefficient values differ from calculated values for –24% to +23%. Mean values of measured and calculated static friction coefficient are almost the same.

*Table 3 Experimental measured and calculated values of Surface roughness parameters, Penetration depth and Static friction coefficient*

| Machining way | Roughness class | Surface roughness parameter **$R_a$ [μm] (measured)** | Surface roughness parameter Δ **(measured/ calculated)** | Penetration depth **h [μm] (calculated)** | Static friction coefficient **μ (measured)** |
|---|---|---|---|---|---|
| Milling | N8 | 2.7-4.5 | $4\text{-}5.8\cdot10^{-3}$ | 2.8-5.5 | 0.067-0.113 |
| Lapping | N5 | 0.35-0.45 | $4\text{-}5.8\cdot10^{-3}$ | 0.28-0.52 | 0.054-0.095 |
| Plane grinding | N4 | 0.18-0.25 | $1\text{-}2\cdot10^{-3}$ | 0.16-0.40 | 0.053-0.074 |
| Round grinding | N6 | 0.8-0.9 | $1.2\text{-}1.4\cdot10^{-1}$ | 0.6-1.5 | 0.141-0.191 |
| | N5 | 0.5-0.7 | $9\text{-}11\cdot10^{-2}$ | 0.5-0.7 | 0.148-0.173 |
| Lathe Machining | N7 | 1.7-2.7 | $1.4\text{-}2.2\cdot10^{-1}$ | 1.8-2.4 | 0.174-0.225 |
| | N6 | 0.6-1.2 | $6\text{-}8\cdot10^{-2}$ | 1.3-2.2 | 0.120-0.195 |

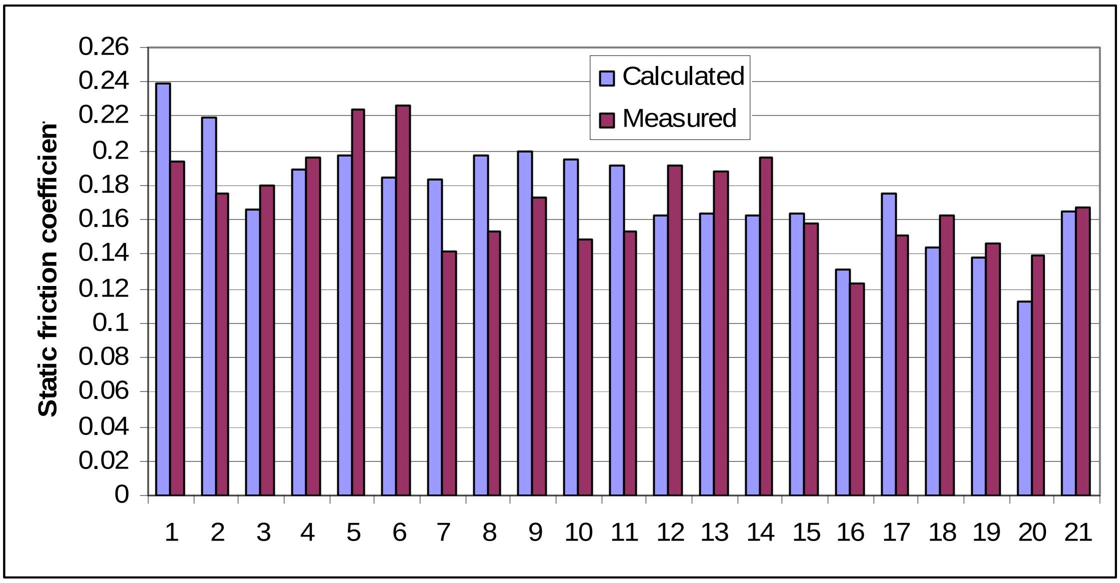


*Figure 3 Comparison of calculated and measured values of static friction coefficient*

## 5. CONCLUSION

Static friction coefficient is the most important parameter for predicting the press fit joint strength. The aim of the research, carried out at the Faculty of Mechanical Engineering Nis, was to establish the model of static friction coefficient calculation, which can be applied in engineering practice.

This model includes surface roughness parameters and hardness of contact surfaces and as well as ratio of the molecular and deformity components of friction coefficient which should be established by experimental way in concrete tribological condition. Experimental results show good correspondence between calculated and measured values of static friction coefficient.

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