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EVALUATION OF THE KINETIC FRICTION COEFFICIENT BY USING „DISC-BLOCK" FRICTION PAIR OF DIFFERENT WOODEN SAMPLES

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Abstract: *The paper presents the measurement results of the kinetic friction coefficient on wooden specimens. The measurements were carried out according to the „disc-block" friction pair method. Blocks and discs are made of five different types of wood - beech, ash, oak, pine, and fir. Experimental investigations were performed for different values of disc speed (rpm) and with different normal loads on the block. The obtained results indicate that the contact pairs of wood with higher surface hardness have higher values of the kinetic friction coefficient and vice versa. The values of the kinetic friction coefficient had approximately constant values for different experimental conditions with the tendency of a slight decrease while increasing normal load and the speed (number of rpm).*

Keywords: *friction, wood, kinetic friction coefficient, „disc-block" friction pair.*

1. INTRODUCTION

Wood is a natural, heterogeneous, and hygroscopic material characterized by a number of positive properties, such as easier machining, acceptable price, low thermal conductivity, etc. [1]. In order to predict the behaviour of the wood under different exploitation conditions, and to take its advantages and eliminate disadvantages, first of all, one should be well familiarized with its aesthetic, technological, mechanical and physical properties. Knowledge of tribological properties is one of the main prerequisites for the proper exploitation of contact pairs made of wood [2].

Friction is a complex phenomenon that occurs between contacting surfaces. Experiments indicate the functional dependence of friction from a different number of parameters, such as materials, velocity, contact pressures, temperature, normal load, humidity, surface preparation, etc. Friction and wear contact pairs are held in complex exploitation conditions. In most cases, in various moving elements, friction is undesirable and harmful occurrence, and a considerable amount of mechanical energy is used to overcome the friction force [3]. As a result of friction on the contact surfaces, it leads to wear and increased heat between materials in contact [4].

The tribological characteristics of the elements of tribomechanical systems can be quantified by the intensity of the friction force, i.e., the friction coefficient [5].

Two types of friction coefficients can be distinguished [6]:

- static friction coefficient (μ_s) - represents the friction opposing the onset of relative motion (impending motion),
- kinetic friction coefficient (μ_k) - represents the friction opposing the continuance of relative motion once that motion has started.

Friction coefficients are defined as [6]:

$$\mu_s = F_s / F_n \quad (1)$$

$$\mu_k = F_k / F_n \quad (2)$$

where F_s is the force just sufficient to prevent the relative motion between two bodies, F_k is the force needed to maintain relative motion between two bodies, and F_n is the force normal to the interface between the sliding bodies.

Friction is an important factor to be taken into account when different types of wooden materials are utilized or processed. Friction coefficients depend on the moisture content of the wood, surface roughness of the wood, and the characteristics of the opposing surface. They vary little with different types of wood. Static friction coefficient is generally greater than those of kinetic friction, and the latter depend somewhat on the sliding speed. Kinetic friction coefficients vary only slightly with speed when the wood moisture content is less than about 20%; at high moisture content, the kinetic friction coefficient decreases substantially as speed increases [7].

Several investigations on friction of wood-based materials have been published.

Desaguliers presented data which yield coefficients of friction for unlubricated sliding of wood on wood between 0.35-0.5. Coulomb measured static friction coefficients from 0.43 to 0.67 for various samples of unlubricated wood sliding against wood, and found that lubrication with tallow reduced the values to 0.1-0.2. Bowden and Tabor reported a value of 0.6 for dry wood sliding on steel, while Rabinowicz provided data ranging from 0.45 to 0.5 for wood sliding on steel [8].

Further, Blau [6] presented friction coefficients for different wood. The values of the static friction coefficient ware in the range of 0.25 to 0.7, and the values of the kinetic friction coefficient ware in the range of 0.19 to 0.5. Glass and Zelinka [7] reported kinetic friction coefficients for different types of wood. Coefficients of kinetic friction for smooth, dry wood against hard, smooth surfaces commonly range from 0.3 to 0.5; at intermediate moisture content, 0.5 to 0.7; and near fiber saturation, 0.7 to 0.9. Seki et al. [9] evaluated the friction characteristics of wood during deformation processing with relatively high levels of pressure. The nominal friction coefficient remained at almost constant value during sliding, or it increased slightly immediately after sliding was started under each testing condition. Seki et al. [10] measured friction coefficient between metal tools and phenol formaldehyde resin-impregnated wood specimens during compression in the tangential direction at high pressure. The static friction coefficient decreased with an increase in the phenol formaldehyde resin concentration. Pitenis et al. [11] measured friction for various wood blocks sliding on a wood surface. The values of the static friction coefficient were in the range of 0.35 to 0.72. The values of static friction coefficient under dry, clean, smooth, and sanded conditions were 0.72±0.04. Eliminating sanding from the experimental procedure lowers the static friction coefficient (0.44±0.04), and introducing fine Olive wood sawdust on the sliding surfaces achieves an average static friction coefficient of 0.35±0.03. When sliding blocks are used with roughly cut surfaces sullied by the natural oils, those static friction coefficients were 0.25±0.03. Aira et al. [12] reported preliminary results of static and kinetic friction coefficients for softwood (scots pine). Friction coefficients between transverse surfaces were roughly twice as the friction coefficients between radial surfaces. Xu et al. [13] measured friction coefficients of solid wood for a “wood–wood” frictional pair under varying wood grain. The results showed that the friction coefficients of the solid wood increased linearly with the arithmetic mean deviation of the surface profile - Ra. Sathre and Gorman [14] determined the static and kinematic friction coefficient at three load stress levels for maple bearings treated. Without the presence of lubricants, static friction coefficient had a value of about 0.45 while a kinetic friction coefficient had a value of about 0.35.

Unlike with previous research, the aim of this study is to determine the kinetic friction coefficients of samples made from different types of wood, as well as for different values of normal load and speed (rpm).

2. MATERIALS AND METHODS

For the experimental investigations (Figure 1) a tribometer is used to test the tribomechanical properties of various materials, in conditions with and without lubricant.

Figure 1. Tribometer used for evaluation of the kinetic friction coefficient

Measurements of kinetic friction coefficient were carried out on a „disc-block" friction pair. Figure 2 shows the scheme for wear testing using „disc-block" friction pair on a tribometer. The contact between two surfaces is achieved on 2D line. During measurements different values of normal load on the block (F_n) and the number of disc rotations (*n*) were used and values of the kinetic friction coefficient for different contact pairs were obtained.

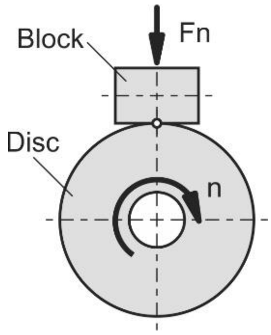

Figure 2. Scheme for wear testing using „disc-block" friction pair

Disc and block samples, used for carrying out experimental investigations, were made of five different types of wood - beech, ash and oak classified as hardwoods as well as two softwoods pine and fir. The geometry of the disk and the block are shown in Figure 3.

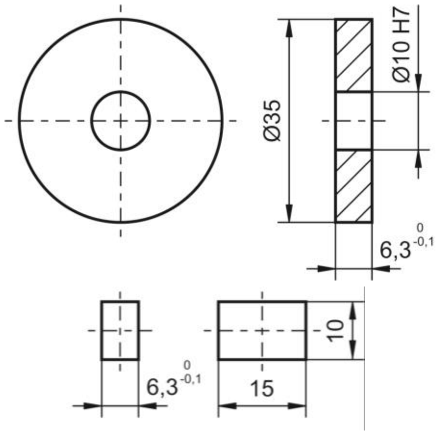

Figure 3. Geometry of disk and block

Before conduction the test, few steps were required in order to control the measurement conditions. First, raw woods (for all samples) were dried in a furnace to a moisture content of <3%. This is required due to the possibility of formation of small cracks or deformation on the surface of the wooden samples prior to their drying. After drying a total of 30 samples were made for each type of wood. Next, the physical and mechanical properties of all samples were measured. The mean arithmetic values and standard deviations of the physical and mechanical properties of the samples are shown in Table 1.

Table 1. Mean arithmetic values and standard deviations (SD) values of all samples

Characteristics	Beech		Ash		Oak		Pine		Fir	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Hardness HB	77	1.554	76	1.734	75	1.943	35	2.212	39	2.256
Modulus of elasticity E (GPa)	17	0.567	14	0.854	12	0.934	12	0.954	11	1.031
Tensile strength Rm (N/mm^2)	142	2.211	182	2.781	102	2.397	112	3.279	86	2.989
Roughness Ra (μm)	1.604	0.005	1.605	0.006	1.606	0.005	1.603	0.009	1.604	0.008

Table 2. The mean arithmetic values of the kinematic friction coefficient and standard deviation

Contact type	*n* (rpm)	F_n (N)									
		10		15		20		25		30	
		$\bar{\mu}$	σ_μ	$\bar{\mu}$	σ_μ	$\bar{\mu}$	σ_μ	$\bar{\mu}$	σ_μ	$\bar{\mu}$	σ_μ
Beech-beech	100	0.36	0.008	0.35	0.009	0.35	0.007	0.35	0.011	0.35	0.009
	120	0.35	0.008	0.35	0.009	0.35	0.009	0.35	0.010	0.35	0.008
	140	0.35	0.009	0.35	0.007	0.35	0.010	0.35	0.009	0.35	0.011
	160	0.35	0.010	0.35	0.010	0.35	0.009	0.34	0.011	0.34	0.010
	180	0.34	0.010	0.34	0.010	0.34	0.009	0.34	0.011	0.33	0.010
Ash-ash	100	0.35	0.008	0.34	0.009	0.34	0.007	0.34	0.011	0.33	0.009
	120	0.34	0.008	0.34	0.007	0.34	0.009	0.34	0.010	0.33	0.008
	140	0.34	0.007	0.34	0.008	0.34	0.010	0.33	0.009	0.33	0.009
	160	0.34	0.010	0.34	0.010	0.34	0.008	0.33	0.011	0.32	0.010
	180	0.34	0.010	0.34	0.010	0.33	0.009	0.32	0.010	0.32	0.007
Oak-oak	100	0.31	0.008	0.30	0.011	0.29	0.007	0.29	0.011	0.29	0.009
	120	0.30	0.008	0.29	0.009	0.29	0.009	0.29	0.010	0.29	0.011
	140	0.29	0.009	0.29	0.009	0.29	0.011	0.29	0.009	0.28	0.011
	160	0.29	0.010	0.29	0.011	0.29	0.009	0.28	0.011	0.28	0.010
	180	0.29	0.010	0.29	0.010	0.29	0.011	0.28	0.010	0.27	0.010
Pine-pine	100	0.24	0.012	0.23	0.009	0.22	0.007	0.21	0.011	0.21	0.009
	120	0.23	0.008	0.22	0.009	0.22	0.009	0.21	0.010	0.21	0.011
	140	0.22	0.009	0.22	0.009	0.22	0.011	0.21	0.009	0.21	0.011
	160	0.22	0.011	0.22	0.011	0.22	0.011	0.21	0.011	0.20	0.011
	180	0.21	0.011	0.21	0.011	0.21	0.010	0.20	0.010	0.20	0.012
Fir-fir	100	0.23	0.012	0.22	0.007	0.21	0.007	0.20	0.011	0.19	0.009
	120	0.22	0.011	0.21	0.009	0.20	0.009	0.19	0.008	0.19	0.010
	140	0.21	0.009	0.20	0.009	0.19	0.010	0.19	0.009	0.19	0.008
	160	0.20	0.011	0.20	0.010	0.19	0.009	0.19	0.010	0.19	0.011
	180	0.20	0.009	0.19	0.009	0.19	0.009	0.19	0.009	0.18	0.008

3. RESULTS

Experimental investigations were carried out for five different normal load values (F_n=10, 15, 20, 25, 30 N), and five different disc speeds (n=100, 120, 140, 160, 180 rpm). The actual values of the kinetic friction coefficient were recorded for 60 seconds for each measurement. Investigations were carried out at a constant temperature of 23°C, the pressure of 1 bar, and humidity of 55% for all samples. For each value of rpm and normal load a total of 30 measurements of the kinetic friction coefficient were captured. The mean arithmetic values of the kinetic friction coefficient and standard deviations are shown in Table 2 and Figure 4.

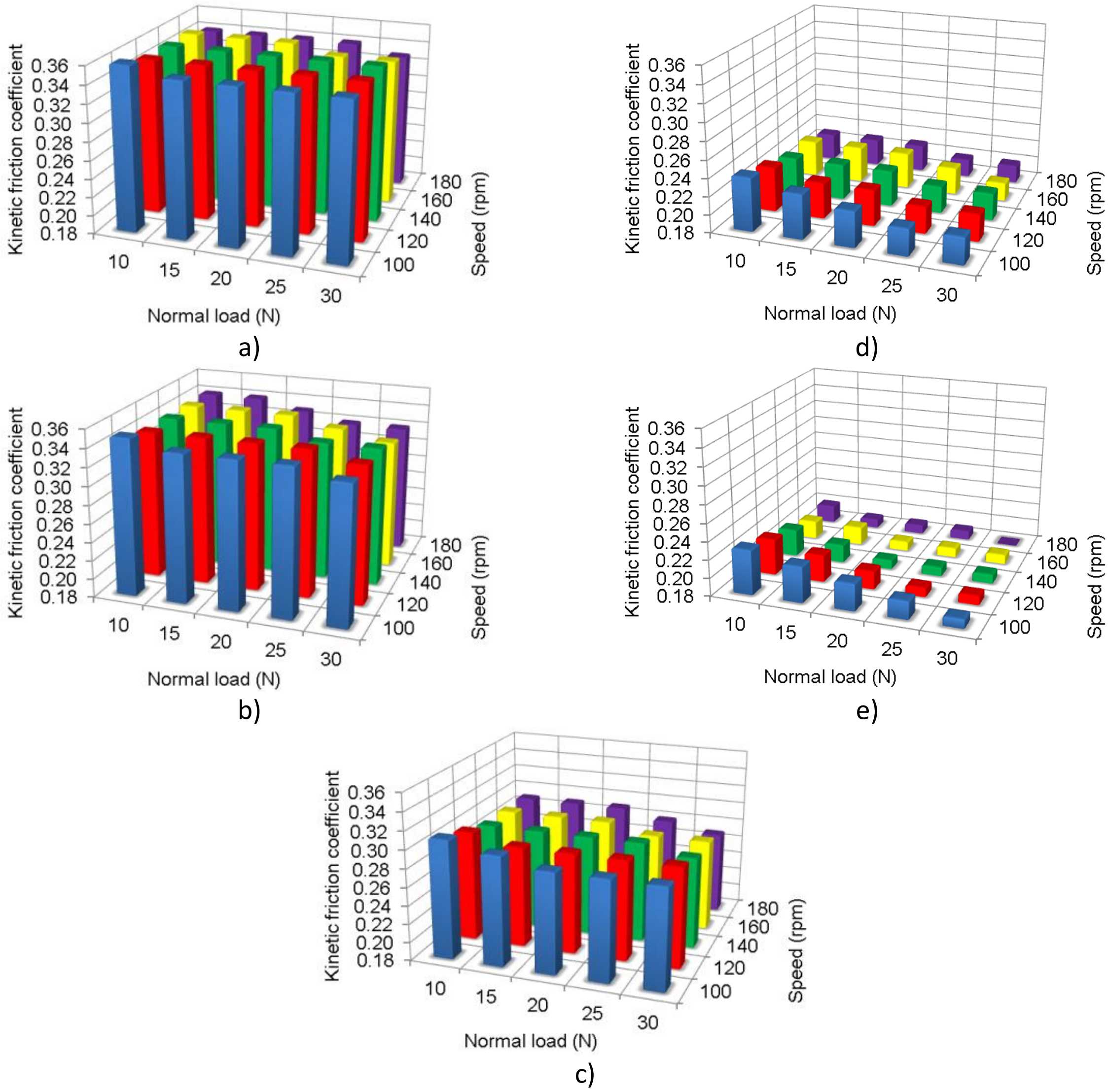

Figure 4. The mean arithmetic values of the kinetic friction coefficient for different values of normal load and speed (rpm): a) contact pair beech-beech, b) contact pair ash-ash, c) contact pair oak-oak, d) contact pair pine-pine, ande) contact pair fir-fir

For different contact pairs different kinetic friction coefficients are evaluated, as follows:

- The contact pair beech-beech has the mean value of the kinetic friction coefficient in the range of 0.33 to 0.36,
- The contact pair ash-ash has the mean value of the kinetic friction coefficient in the range of 0.32 to 0.35,
- The contact pair oak-oak has the mean value of the kinetic friction coefficient in the range of 0.27 to 0.31,
- The contact pair pine-pine has the mean value of the kinetic friction coefficient in the range of 0.20 to 0.24,
- The contact pair fir-fir has the mean value of the kinetic friction coefficient in the range of 0.18 to 0.23.

The higher values of the kinetic friction coefficient were obtained for wood characterized by higher hardness and modulus of elasticity, and vice versa. The kinetic friction coefficient has the highest values for beech wood and the lowest values for fir wood samples.

For all contact types, the mean values of the kinetic friction coefficient have:

- The highest values for the smallest number of rpm and the lowest value of the normal load,
- The lowest values for the maximum number of rpm and the maximum value of the normal load.

The mean value of the kinetic friction coefficient for certain speeds (rpm) has approximately constant value, with a slight tendency to decrease when increasing the normal load.

The mean values of the kinetic friction coefficient have a mild tendency of reduction with the increased speed for identical values of normal load.

4. CONCLUSION

Due to current trends which move towards the development and use of the tribomechanical systems without lubricant or with its minimum use, the experimental research has been carried out without the presence of a lubricant.

The mean value of the kinetic friction coefficient of contact pairs made from different types of wood ranges from 0.18 to 0.36. Higher values of the kinetic friction coefficient for contact pairs made of hardwood were obtained. For all contact pairs, it can be noticed that the kinetic friction coefficient has approximately a constant value with a low dissipation. In accordance to this, kinetic friction coefficient has a slight tendency to decrease at a higher speed (rpm) and the higher normal load.

The future research will focus on the measurements of the kinetic friction coefficient of contact pairs made of other types of wood that have different mechanical and physical characteristics, and under different experimental conditions (contact types, micro kinetic parameters, different speeds, normal loads, etc.).

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