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COMPARISON OF ANTIFRICTION PROPERTIES OF POLYMER COMPOSITES AND BRONZE

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Original scientific paper

Polymer-based composites have been increasingly implemented as engineering material and as material for the fabrication of slide bearings. Their tribological properties and friction coefficient can be tested by laboratory procedures [1]. Polymer-based composites can replace bronze as engineering material for slide bearings in some applications. As an engineering material, bronze has a long history of implementation in various machines. Because of wide selection of literature and carried out studies on this material there is a certain amount of safety when selecting a construction element. The objective of this work is to study the friction coefficient of the polymer-based composite material compared to bronze as engineering material that has had a long history of application.

Keywords: *bronze, composite, friction, surface pressure*

Usporedba anifrikcijskih svojstava polimernih kompozita i bronce

Izvorni znanstveni članak

Kompoziti na bazi polimera postižu sve značajniju primjenu kao konstrukcijski materijal te kao materijal za izradu kliznih ležajeva. Njihova tribološka svojstva i faktor trenja moguće je ispitati laboratorijskim postupcima [1]. Kompoziti na bazi polimera mogu zamijeniti broncu kao konstrukcijski materijal za klizne ležajeve u pojedinim aplikacijama. Bronca kao konstrukcijski materijal posjeduje dugu povijest primjene u raznim strojevima. Zbog velikog izbora literature i provedenih ispitivanja na tom materijalu imamo određenu dozu sigurnosti prilikom izbora nekog konstrukcijskog elementa. Cilj ovoga rada je ispitati faktor trenja kompozitnog materijala na bazi polimera u usporedbi s broncom kao konstrukcijskim materijalom koji ima dugu povijest primjene.

Ključne riječi: *bronca, kompozit, površinski pritisak, trenje*

1 Introduction

Polymer-based composite materials are starting to have increasing application as engineering material since they have very good mechanical properties, relatively simple material machining, and low mass [1]. Except in stationary conditions of work some composite materials have shown good mechanical properties regarding the resistance to wear in contact with materials of higher strength and hardness such as steel [2].

Composite materials based on polymer matrix and with epoxy resin as reinforcing agent affect the mechanical and thermal properties that are related to the tribological properties and the friction coefficient.

For example, addition of fibreglass increases the strength of composite thus influencing the increase in the bearing capacity of the slide bearing, but fibreglass can influence the increase of the friction coefficient and reduction of maximal peripheral velocity of the shaft in the slide bearing [1].

El-Sharbiny [3] proved in his paper that mechanical properties of the composites depend on the direction of the fibres and the load acting on them. The minimal wear and the lowest friction coefficient are obtained in cases when the fibres are normally oriented to the direction of the sliding plane [2, 4], and it also results in increased elasticity in this case of fibre orientation [5].

Thermoset composite features greater elasticity than bronze, which during work at loads greater than the allowed ones can cause deformation of the slide bearing which may lead to damage of the sleeve and the slide bearing [6].

The implementation of composite materials has certain advantages compared to bronze and it is possible to isolate four most common cases in which the use of composite materials is recommended [1, 7, 8]:

1) In case when lubrication by means of liquid lubricants is not efficient due to heavy working conditions such as high or low working temperature and corrosive atmosphere;
2) In case when lubrication using lubricants is not permitted because of environmental pollution or using some other media e.g. in food industry;
3) In case when lubrication using lubricants is not possible due to difficult machine servicing;
4) In case when the lubrication fluid is at the same time the working fluid of low viscosity e.g. in vertical water pumps.

The composite materials that can satisfy the abovementioned conditions belong to the group of thermoset composites. Thermoset composite material is a good thermal insulator which makes the cooling of the bearing difficult and affects the reduction of the permitted loading i.e. sliding speed [9, 10]. During work without lubrication the peripheral sliding speed lower than 10 m/s [1] is recommended. In the fourth case where in the majority of cases lubrication is performed by water that has good cooling function depending on the water flow through the bearing, the $P–v$ (pressure – peripheral velocity) value is much higher.

Thermoset composite as engineering material for slide bearings is more elastic than bronze, 50 ÷ 60 times [5].

Higher elasticity of thermoset composite leads to increased vibration attenuation, and the possibilities of higher load of the bearing edges which can result from shaft bending [5]. In loading higher than the permitted there may come to increased deformation of the composite material and this can cause damage to the sleeve and slide bearing so that in design one has to take into consideration the permitted *P*–*v* values and the thickness of the bearing wall [4, 11].

Bronze, as engineering material, features good mechanical and tribological properties [12]. It is usually used as material for the fabrication of slide bearings in vertical pumps, water turbines, etc.

Bronze as engineering material has lower elasticity than the thermoset composite which affects the lower permitted load of the marginal pressures due to shaft bending.

2 Description of the problem

There are not many studies about thermoset composites as bearing material, related to their mechanical and tribological properties. The tribological properties of polymer composites are not always the only reason for their selection. Commercial reasons such as price, material availability, impact on the environment, compatibility with other materials, method of technological machining to final dimensions also affect their proper selection. Thermoset composites as engineering materials are used in various applications such as the slide bearings in vertical water pumps, Pelton and Francis turbines, slide bearings of worm conveyors in food industry where they reach a long service life [5]. Bronze as material which has a long implementation history is used in a wide range of applications [13]. In certain applications bronze can be substituted by composites due to lower resistance to wear, and unstable prices on the market. In heavy working conditions such as steelworks or in working machines where the replacement of slide bearings is very complicated such as the fillers of PET packaging in food industry bronze is being gradually withdrawn from the application and is being substituted by materials of better tribological properties [14]. The improvement of mechanical properties of polymer-based composites can be achieved by the addition of various fillers, fibres and lubricants for the reduction of the coefficient of friction and wear [1] [8].

This paper will perform the determination of the dynamic friction coefficient of thermoset composites and bronze for the area of peripheral velocities from 1,5 to 3,9 m/s, with variable load in the range from 220 N to 605 N with lubrication by means of fluid of 150 $\mathrm{mm^2/s}$ viscosity. Also with the stipulated maximal *P*–*v* values the phenomena that occur in case of bearing overload will be studied, since there is little knowledge for this area of load. The behaviour of slide bearing in case of overload is sometimes an important factor in selecting the appropriate material. When working under stipulated working conditions and in case of overload the tribological properties of test specimens will be tested and the surface roughness on all samples will be measured.

3. Experimental procedures

3.1 Tested materials

Testing was carried out for two engineering materials that are often used in the application of slide bearings. In this experiment a machine with disc [15] will be used to test the materials that are often used as engineering material for slide bearings, and that is bronze CuSn14 and thermoset composite.

Thermoset composite (Orkot C322) has been selected as comparison material in testing with bronze because it features good sliding properties and unlike thermoplastic materials they can work at a temperature of up to 130 °C, without resulting in any major reduction of mechanical properties of the material. In case of thermoset composite during operation there is no absorption of impurities into the surface such as sand and metal particles whose presence on the slide bearing can damage the steel sleeve [16, 5]. The producers of bearing materials give recommendations for maximal *P*–*v* values under certain working conditions such as adequate lubricant, lubricant flow for cooling, etc. What happens when a certain working parameter is changed, such as the replacement of low-viscosity lubricant by high-viscosity lubricant often fails to be studied nor is it mentioned in literature with the data provided by the producer for their bearing material [3]. Bearing material like bronze can be used with lubricants of different viscosities depending on the *P*–*v* value, whereas thermoset composite materials in the majority of cases are used with low-viscosity lubricants, which gives them great application in the medium such as salt water [5, 2, 1]. The objective of the work is to test experimentally the behaviour of bronze and thermoset composite under the conditions of nominal and increased *P*–*v* values, and to test the friction coefficient under the mentioned working conditions. The selected test specimens of material CuSn14 and thermoset composite were produced by particle separation machining from semi-products. The test specimens are of cylindrical form and of dimensions presented in Fig. 1. In order to reduce the number of influential factors on the performance of the test, the roughness of each test specimen was controlled. The surface roughness for CuSn14 ranges from $Ra = 0{,}65$ μm to $Ra = 0{,}69$ μm whereas in case of thermoset composite the roughness is from $Ra = 1{,}37$ μm to $Ra = 1{,}50$ μm. The differences in roughness between the materials are the consequences of material machinability and the impossibility to get lower roughness in thermoset composite by means of the used mechanical machining. The material that is used as the opposite harder surface is steel 16MnCr5, thermally machined and ground to the roughness of $Ra = 0{,}4$ μm.

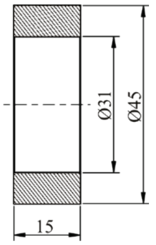

Figure 1 Dimensions of test specimens

3.2 Selection of lubricant

For the selected revolution velocities and loading according to *P*–*v* diagram [5] given by the material manufacturer The area of application regarding the temperature is up to 100 °C where the quality level satisfies the ISO 6743-6 (CKC) regulations. The selected oil is mineral-based, and Tab. 1 provides the properties of the selected oil. When choosing the lubricant for lubrication one should take into account the level of pH values of the lubricant and the additives that are contained in the lubricant. Various alkali, hydrocarbons, and acids that serve to enhance the properties of a lubricant may aggressively act on the thermoset composite and bronze which causes the reduction in mechanical properties of the composites and leads to the damage of the bearing. [17].

Table 1 Physical and chemical properties of the applied lubricant

Density at 15 °C	Kinematic viscosity		Viscosity index	Flash point	Flow temperature
	40 °C	100 °C			
kg/m^3	mm^2/s		-	°C	°C
0,902×10^{-3}	150	13,1	85	210	−20

Data exist that organic lubricants are the most efficient in lubricating polymers and polymer composites [18]. The wear rates of polymer materials in organic lubricants are somewhat lower in relation to consistent lubricants, water and corrosive fluids (FeCl3) [1].

Bronze as material features high resistance to the action of various types of lubricants so that its mechanical properties are not affected a lot by the type of lubricant [19].

3.3 Instrumentation

The experiments were performed by using the test device for testing friction with rotating disk and theoretical line contact. The testing device according to Fig. 2 consists of a rotating disk made of the test material, loaded with steel plate. The loaded plate realizes over a lever the contact between the rotating disk and the stationary plate. The device is designed so that over the measuring shaft connected to the electric motor with rotational speed regulation it ensures the rotation of the disk and measuring of the friction momentum. The system of levers according to Fig. 2 is used to load the rotating disk by means of a plate located in the housing with the measuring of the vertical force that acts on the rotating disk. The dimensions of the disk, i.e. the external diameter is 45 mm and the width is 15 mm, and the dimension of the loading plate is 35 × 35 × 35 mm.

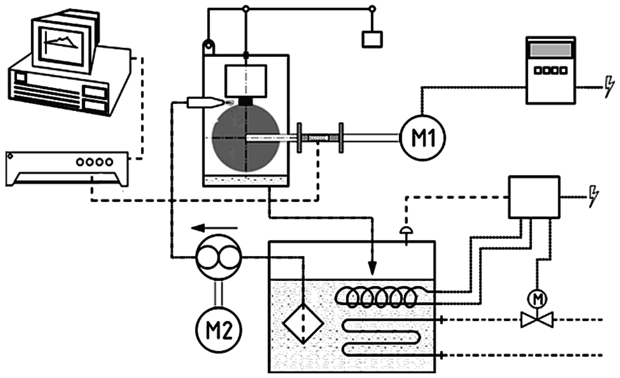

Figure 2 Scheme of the testing machine

The shape of the loading plate has been selected with the aim of increasing the surface pressure (contact in line) i.e. obtaining the marginal values at P–v diagram for composite material and bronze. By increasing the contact surface the surface pressure is reduced, but also the possibility of temperature transfer from the rotating disk to the plate is increased, where it comes to higher heat conduction over the loading plate. By careful mounting an approximate contact line between the rotating disk and the pressure plate has been achieved.

Lubrication is done by spraying of oil between the steel pressure plate and the rotating disk as can be seen in Fig. 3 so that during work there is prevailingly mixed friction.

3.4 Implementation of measurements and selection of test parameters

By continuous measuring of T momentum necessary to overcome the resistance of the movement of the rotating disk and continuous measuring of the normal force F_n which acts on the plate and the rotating disk with the known disk radius according to Fig. 4 it is possible to obtain the force of friction F_tr according to expression (1) whereas the dynamic friction coefficient is obtained according to Eq. (2). The selected sample frequency 60 Hz is sufficient to insure sufficient number of data for the calculation of the dynamic friction coefficient and following of the tendency of the coefficient change in time.

$$F_\mathrm{tr} = \frac{T}{r_1}, \tag{1}$$

$$\mu_\mathrm{din} = \frac{F_\mathrm{tr}}{F_\mathrm{n}}. \tag{2}$$

According to Hertz theory the pressure width $2a$ on the test specimen has been obtained from Eq. (3) which can be seen in Fig. 4. The width of the pressure shows deformations of the disk, i.e. the width of contact that depends on the disk module of elasticity and pressure plate module of elasticity. Tab. 3 shows that the contact width is greater than in thermoset composite, also in Tab. 3 one can see the data calculated from the previous expressions for the combination of the test disks with steel pressure plate.

$$a = \sqrt{\frac{8 \cdot F_\mathrm{n} \cdot r_1}{\pi \cdot E \cdot B}}. \tag{3}$$

For carrying out the test a mixed factor plan of experiment 2×3^2 has been selected, where they are two numeric variables at three levels and one categorical variable at two levels. Tab. 2 shows the variables that have been varied in minimally three repeating, which yields a total of 54 different experiment conditions.

Table 2 Test variables

	Level 1	Level 2	Level 3
Normal force F_n, (N)	222	413	610
Rotational speed n, (1/min)	610	1230	1620
Test material	CuSn14		Orkot C322

The values of the force F_n and the rotational speed velocity n, have been selected on the basis of P–v diagram for test materials with the aim of selecting the marginal values and values above the critical values for the thermoset composite. The calculation of pressure on the test specimen caused by force F_n has been determined by Eq. (4) where it is necessary to calculate the module of elasticity for two different materials in contact which can be obtained by means of Eq. (5).

$$p=\sqrt{\frac{F_\mathrm{n}\cdot E_\mathrm{e}}{2\cdot\pi\cdot r_1\cdot B}}, \tag{4}$$

$$E_\mathrm{e}=\frac{1}{2}\cdot\left[\frac{1-\nu_1}{E_1}-\frac{1-\nu_2}{E_2}\right]. \tag{5}$$

Where E_1, and E_2 are modulus of elasticity for each test material, E_e is equivalent modulus of elasticity. B is width of the test specimens in mm.

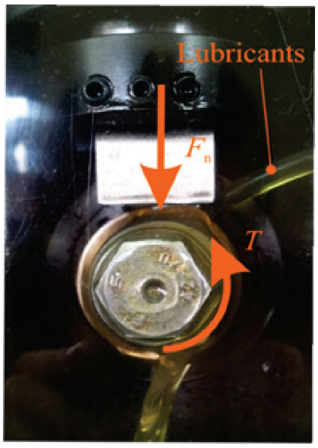

Figure 3 Lubrications of the testing specimens

The test was carried out on six different disks, three disks of CuSn14 and three of thermoset composite, with a total of nine measurements each. The recording of the signal was performed sequentially according to the experiment plan without interrupting the process for three different experiment conditions. At the beginning of the experiment before measuring each specimen was left in service under the load of F_n= 410 N and n = 1230 1/min in the duration of 5 min, with the aim of running-in and after that the experiment was carried out. Fig. 5 shows a segment of output signals for three areas of variations according to the experiment plan which has been carried out without stopping the process. Each of the experiment conditions was recorded in the duration of approximately 30 s, and during this time before experiments it has been concluded that there is stabilisation of the friction coefficient. The amount of up to 30 s yields 1800 specimens the friction coefficient data whereas for the final value on the average 2/3 of end specimens were taken, thus eliminating the influence of system mass acceleration for individual working point of the experiment.

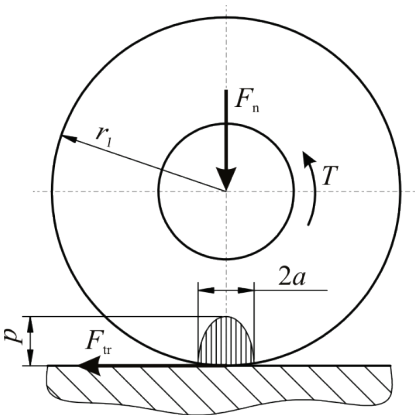

Figure 4 Pressure on the bearing

The experiment performed in parts of three measurements was selected with the aim of maintaining the impact of temperature within the range of 40 ± 10 °C and the possible influence on the result of the value of the friction coefficient due to the change in temperature of oil and oil viscosity. Such division provides a total of 18 experiment blocks. With the selection of adequate blocks this has been reduced to the minimal influence of other unknown values on the obtained result.

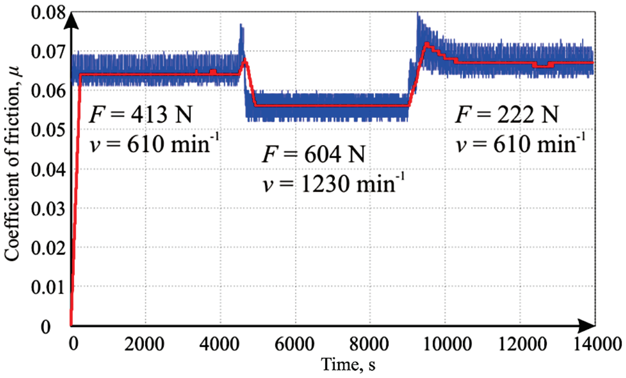

Figure 5 Change of friction according to the change in force and velocity in time for CuSn14

Table 3 Change of pressure in the variation of normal force

Test material	Poisson ratio ν	Young's modulus E / MPa	Equivalent modulus of elasticity E_e / MPa	Pressure p / MPa F_{n1}=222 N	Pressure p / MPa F_{n2}=413 N	Pressure p / MPa F_{n3}=613 N	a / mm F_{n1}	a / mm F_{n2}	a / mm F_{n3}
CuSn14	0,34	110 000	151 779	126,053	171,931	207,920	0,072	0,101	0,124
C322	0,31	3 908	8 488,96	29,811	40,660	49,172	0,31	0,43	0,52

4 Result and discussion

The obtained results were processed by means of the Design Expert software and ANOVA variance analysis was performed. The analysis showed that for the input parameters, forces (222, 413, 610 N), rotational speeds (610, 1230, 1620 1/min) i.e. peripheral speeds (1,41; 2,89; 3,81 m/s), type of material (CuSn14, thermoset composite) the friction coefficient is significantly influenced by the rotational speed and type of material, whereas the impact of normal force is negligible in relation to the friction value.

The influencing parameters are presented in Tab. 4, parameters that need to be taken into consideration if model reliability is to be increased. By performing the Kolmogorov-Smirnov test and verification of variance χ^2 Fig. 6 shows the results of the normality of the residue which proves the validity of the statistical model for the description of the described data.

Fig. 7 shows that the change of friction coefficient in relation to the rotational speed in the range from 610 to 1620 1/min acts differently on CuSn14 than on thermoset composite. At lower speeds bronze features a lower friction coefficient than thermoset composite on all the studied loading levels. By increasing the speed to 1230 1/min there comes to approximate equalization of the friction coefficient values for both materials with a slightly higher value in case of CuSn14. With further increase in the rotational speed up to 1620 1/min the friction coefficient decreases in case of thermoset composite, whereas in case of CuSn14 the friction coefficient decreased slightly in relation to the rotational speed of 1230 1/min. The estimated standard deviation provides information about the reliability interval of the obtained results, i.e. the greater the estimated standard deviation, the greater is the dispersion of results. Fig. 8 shows the standard deviations of the results at different levels of the influencing parameters, speed and type of material. It can be noticed that thermoset composite features maximum standard deviation at the speed of 610 1/min whereas with further increase in speed it records significant decline to its lowest value. With further increase of speed up to 1620 1/min there is increase in the estimated standard deviation. The average standard deviation in the field of test speeds amounts to 0,001857. The values of the estimated standard deviation in case of CuSn14 have been distributed within the narrower range, which can be seen in Fig. 8. The results show a monotonous decline in the value of the estimated standard deviation with the increase in rotational speed. The average value of the estimated standard deviation in the speed range from 610 to 1620 1/min is 0,00190 which is a somewhat higher value than in case of thermoset composites, although the average values are very close. The test specimens were used to test the roughness before and after testing and it was found that the surfaces on the test specimens were smoother. For thermoset composite it was found that the surface roughness ranged in the area from Ra = 1,13 μm to Ra = 1,32 μm, whereas in case of bronze there was improvement of the surface quality within the range from Ra = 0,21 μm to Ra = 0,57 μm. The average reduction of surface roughness Ra in case of bronze is 0,27 μm, and in case of composite samples it is 0,23 μm, which is a very small difference.

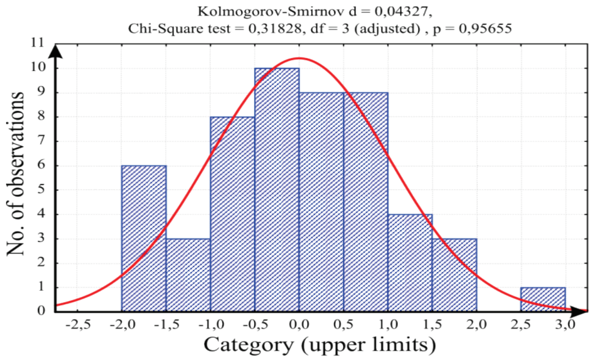

Figure 6 Kolmogorov-Smirnov test and checking the residue of normality variance

Table 4 Analysis of variance

Source	Sum of squares	df	Mean square	F-value	p-value $Prob > F$
Model	$2,028\times10^{-3}$	21	$9,659\times10^{-5}$	13,02	< 0,0001
A- Rotational speed	$1,003\times10^{-3}$	2	$5,015\times10^{-4}$	67,59	< 0,0001
C-C	9146×10^{-4}	17	$5,380\times10^{-5}$	7,25	< 0,0001
D-Material	0,000	0			
AD	$4,921\times10^{-5}$	2	$2,461\times10^{-5}$	3,32	0,0495
Residual	$2,300\times10^{-4}$	31	$7,420\times10^{-6}$		

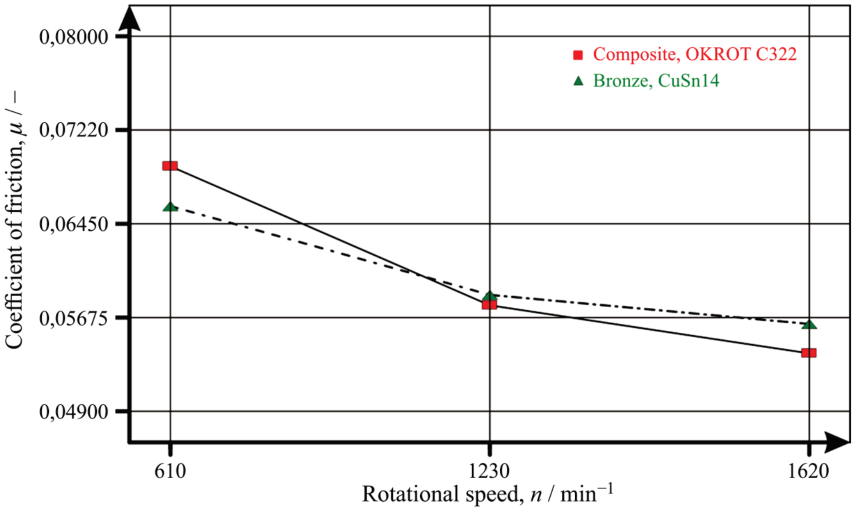

Figure 7 Change of friction coefficient according to velocity for thermoset composite and CuSn14

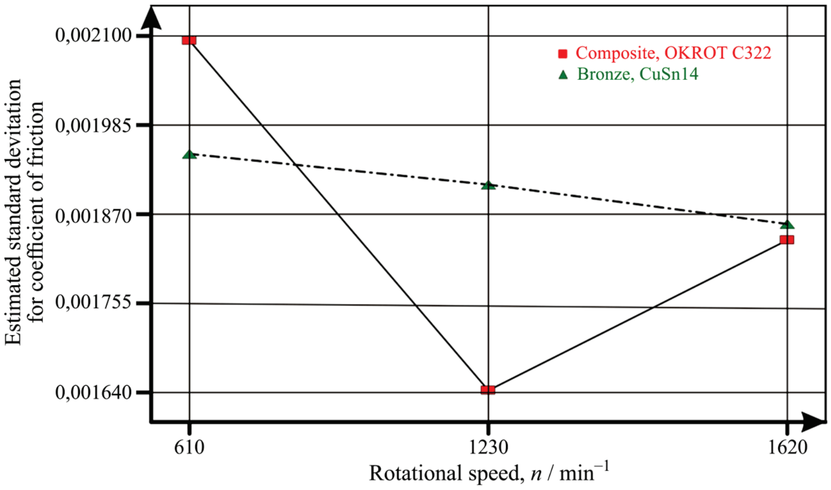

Figure 8 Estimated standard deviation of material for the range of velocities

5 Conclusion

By testing bronze CuSn12 and Orkot C322 it has been found that the load on the test specimen does not significantly affect the friction coefficient but that it is rather most affected by the rotational speed and the material of the test specimen. The results of the experiment show that the increase in the rotational speed results in the decrease of the friction coefficient for both test materials. The influence of velocity on the change of the friction coefficient has proven to be a very influential parameter in case of samples of thermoset composites. In the range of rotation velocities from 610 1/min (1,41 m/s) to 1230 1/min (2,89 m/s) there comes to greater decrease in the friction coefficient whereas further increase in the rotational speed up to 1620 1/min (3,81 m/s) there is a fall in the friction coefficient which has better influence on the resistance to material wear. In case of bronze it may be seen that there is also a falling tendency of the friction coefficient with the increase in velocity, but in a somewhat smaller amount. Generally, it may be claimed that at lower velocities the friction coefficient is more favourable in case of bronze in the range from 610 1/min to 1230 1/min whereas in the range of velocities from 1230 1/min to 1620 1/min the friction coefficient is more favourable than in case of composite samples.

The reduction of the friction coefficient in the application of slide bearing in the presented range of velocities can be manifested on several advantages such as the lower loss in the bearing, reduced energy consumption, lower temperature during operation and smaller quantity of fluid required for lubrication. The effect of hydrocracked and synthetic lubricants for polymer composites can be of significant influence on the resistance at wear. Also, lubrication by lubricants has great impact on the resistance to wear and in bronze-based alloys [20]. The test composite contains MoS_2 which affects the improvement of lubricity and reduces the friction coefficient.

The presented results of the coefficients of friction depending on the rotational speed follow the change according to the Stribeck curve for combined friction (Fig. 7).

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Cathy Mackenzie, Conference Secretary

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INTRODUCTORY COURSE

There is also an introductory course on noise on Monday 20 April, which has proven to be very popular in previous years.

PROVISIONAL INTERNATIONAL ORGANISING COMMITTEE

Dick Bowdler Chairman	UK
Jean Tourret President INCE/Europe	France
Geoff Leventhall Director INCE/Europe	UK
Norm Broner	Australia
Cristophe Delaire	Australia
Renzo Tonin	Australia
Brian Howe	Canada
David Michaud	Canada
Bo Søndergaard	Denmark
René Gamba	France
Arno Trautsch	Germany
Hideki Tachibana	Japan
Frits van den Berg	Netherlands
Karl Bolin	Sweden
Sylvia Broneske	UK
Matthew Cand	UK
Malcolm Hayes	UK
Mark Bastasch	USA
Patricia Davies	USA

Provisional List of Topics

Source noise mechanisms and propagation

- Noise generation mechanisms and reduction at source
- Amplitude Modulation – mechanism and solution
- Propagation models and their accuracy

Health issues related to turbines

- Sleep disturbance and annoyance
- Non-acoustic factors in attitudes to wind turbine noise.
- Infrasound and Amplitude Modulation effects

Measurement and testing experience

- Specific instrumentation for WTN measurements
- IEC 61400-11 ed.3
- Baseline background noise
- Post completion compliance testing

And:

- Offshore wind farm construction
- Small wind turbines – specific problems.
- Standards and regulations