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WEAR OF NON-METAL SLIDES UNDER VERY HIGH LOAD

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Abstract

The tests described in the article are related to the project of a high-altitude scientific rocket, which is expected to be built in the Institute of Aviation. The unguided rocket will be launched from a platform with a relatively long start beam and will be supported by slides at the start. Because of the relatively high rocket mass and nearly horizontal start needed for initial rocket tests, its slides will be under extremely high load defined as a combination of pressure and sliding velocity. In addition to the mechanical load, the slides will be also loaded thermally because of the friction in a pair: slide-guide rail (made of hard-anodized aluminium alloy). This leads to rapid wear of the slides.

The aim of the tests was to establish what the friction coefficient between the slide and the guide rail is (as function of mechanical load) and how big slide-wear in a single work cycle (simulation of a single rocket launch) is. The tests were performed for few material samples: two modern plastics used in so-called "linear systems" (offered by a firm, which is one of the leaders on this market), samples made of well-known and widely used materials like cotton-phenolic textolite and well-known samples of material called Teflon (PTFE – polytetrafluoroethylene) with 15% addition of graphite. Results show that the temperature resistant plastic used in general linear systems at our condition are on the verge of wear according to our model. Textolite and Teflon with graphite addition have better characteristics of wear. They can be safely used as material of slides.

***Keywords**: high load slides, high load linear bearings*

1. Introduction

While designing mobile launcher for unguided scientific rocket, the Institute of Aviation conducted tests of slide materials for leading carriages. The purpose of the tests was to select appropriate slide material. Firstly T-shape guide rail made of hard anodised aluminium alloy of 8 m length (drylin T, TS-01-20, Igus) was selected. The launcher's start beam should be able to set angle in the range of 30°-100° in relation to the horizon. The sliding carriages can be mounted only on rear part of the rocket (due to construction reasons) in relative long distance from rocket centre of gravity. Considering the rocket mass, location of slide carriages on the rocket relative to its C.G., nearly horizontal launch, rocket velocity at the end of launch beam (at least 20 m/s) and thermal load caused by friction – the sliding elements for about half a second will be under extremely high load, defined as a combination of pressure and sliding velocity.

There were selected four sliding materials. Temporary load expected during launch is outside of the score of the characteristics from catalogues (for all selected material in constant operation) [5, 6]. There is no material data for such high dynamic loads in short time. In order to perform wear tests of slide materials a stand for dynamic tests of friction materials for brakes was adapted.

The tests show the wear of sliding elements and friction coefficient between slide and guide rail under maximum load, which can appear during start of the rocket. Tests should give information how thick sliding material in carriage and what is the friction coefficient between slides and guiding rail should be. After tests it turned out that same of tested materials have wear more than acceptable in our application what could cause unacceptable contact metal – metal (rail – carriage body).

2. Tested materials

For known rocket parameters and initially assumed carriage dimensions, following requirements for sliding material were defined: pressure – 7 MPa, sliding velocity – 20 m/s, maximal wear for single rocket launch – 1 mm.

The following materials were selected for the tests:

- Iglidur J (Fig. 1a) – the material used originally in linear system ”Drylin T” produced by “Igus” company This material was designed for the lowest coefficients of friction, but not for high pressure and temperature (max. pressure 35 MPa, max. temp. 120°C),
- Iglidur X (Fig. 1b) – one of the best sliding materials produced by “Igus”, but normally not used in pair with selected T-shape guiding rail (normally used in cylindrical bearings). This material is designed for high pressure and high temperature (max. pressure 150 MPa, max. temp. 315°C),
- Textolite – dry and soaked with oil (Fig. 1c) – cotton-phenolic composite well known and widely used for bearings, gears, etc., used for high pressure and moderate temperature (max. pressure 140 MPa, max. temp. 180°C),
- PTFE + 15 % graphite (Fig. 1d) – polytetrafluoroethylene with 15% addition of graphite. It has good slide properties and resistance to abrasion. Used for low pressure and high temperature (max. pressure 12 MPa, max. temp. 260°C).

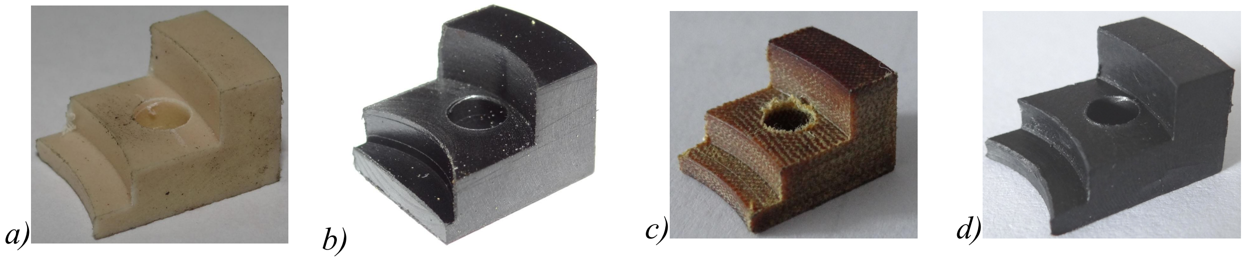

Fig. 1. Probe of sliding material: a) Iglidur J, b) Iglidur X, c) Textolite, d) PTFE + 15 % graphite

Presented above (for considered material) maximum pressure values correspond with low sliding velocities (for high velocities they are significantly lower) [1]. Operating speed limit for materials produced by “Igus” is 10 m/s. The load corresponding with that velocity is lower than 1MPa [5]. These materials are not normally used for such high velocities in combination with high pressure.

There were two types Textolite probes: dry and soaked with oil. Oiled Textolite was subjected to soaking in engine oil with a temperature of 80°C for over 30 hours. Probes of sliding materials while tested on the test stand cooperated with a collar (rail imitator) made of hard anodized aluminium alloy – the same material as original guide rail.

3. Test stand

All tests were performed using IL-68 test stand (Fig. 2). IL-68 [2] is the inertial dynamometer type test stand, designed for friction materials testing, mainly brake materials (technical parameters – Tab. 1). Principle of operation of the stand uses known (changeable) inertia energy of a flywheel, which is driven by electric motor. After reaching the desired RPM, the engine is disconnected from flywheel by clutch. The test begins when hydraulic cylinder presses the stationary test head onto the rotating test head with set clamping force. The tested material is attached to the stationary test head. The second material of the tested pair is attached to the rotating test head driven by a flywheel (Fig. 3).

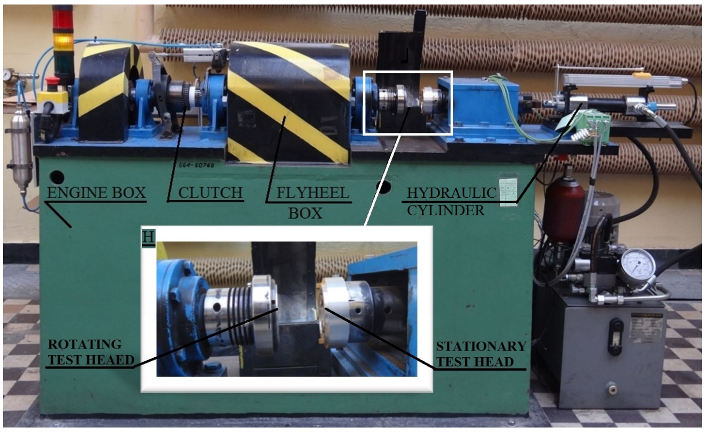

Fig. 2. IL-68 test stand side view

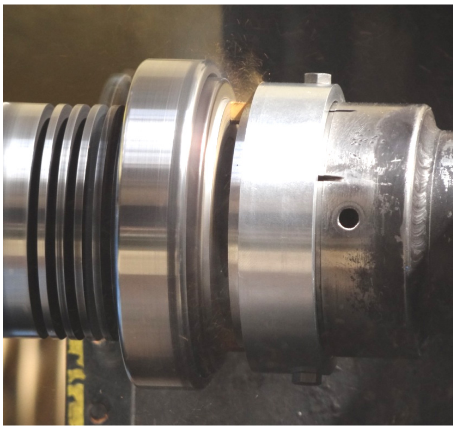

Fig. 3. Friction test of Textolite probes

Tab. 1. Selected technical parameters of IL-68 test stand [2]

No.	Name	Value/Description
1	Max. shaft rotational speed	9000 rpm (150 rps)
2	Flywheel moment of inertia	0.154 – 1.54 kgm^2
3	Max. clamping force	5.88 kN

The IL-68 test stand allows to measure and to acquire measurement data such as braking torque, braking force, braking time, friction coefficient, wear, temperature and rotational speed of rotor. These parameters are used not only as test data but also as internal control signals for IL-68 test stand. All of acquired data is stored in digital format for further analysis. This paper presents tests with friction engagement limited to specified time. The stand does not allow setting a precise contact time of a friction pair. Usually contact time on IL-68 last until complete stop of the rotating head (there is no reason for precisely set the contact time of test heads for testing brake materials).

4. Test method

The samples (Fig. . 1) were made from the listed materials (paragraph. 2) and mounted in pairs on stationary test head (Fig. 5). On the rotating test head (Fig. 4) collar made from hard-anodised aluminium alloy (rail imitator) was mounted. The collar's material was taken from original guider rail of the same producer as T-shaped rail used to build launcher.

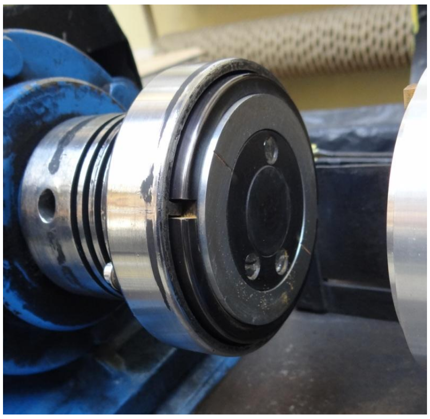

Fig. 4. Aluminium collar mounted on rotating test head on the IL-68 stand – rail imitator

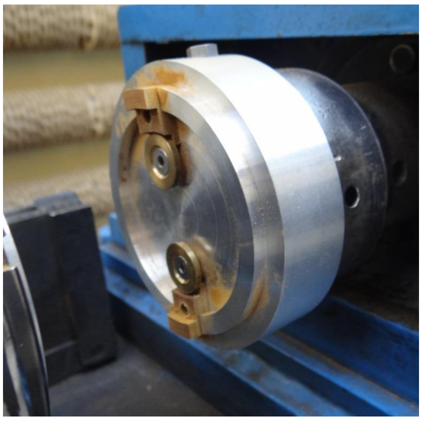

Fig. 5. Textolite samples mounted on stationary test head on the IL-68 stand (after test)

The rotating speed of the test head reaches 6000 rpm, what combined with mean radius of probes mounting (68 mm) gives linear velocity about 21 m/s which is close to launch velocity.

Two values of clamping forces were used: 40 daN and 80 daN. The force 80 daN is equivalent to maximum expected pressure (7 MPa) on slide material during the rocket launch. After about 2 seconds, the operator removes clamping force and the stationary test head is retracted. Once rotating head stopped, the probes were disassembled to measure the wear of sliding material by calliper.

In order to define static friction coefficient the stationary test head was pressed onto steady head with rail imitator with set clamping force. Then the movable head was turned a few times manually by the operator. During the test all data was recorded by acquisition system (Fig. 6 and 7).

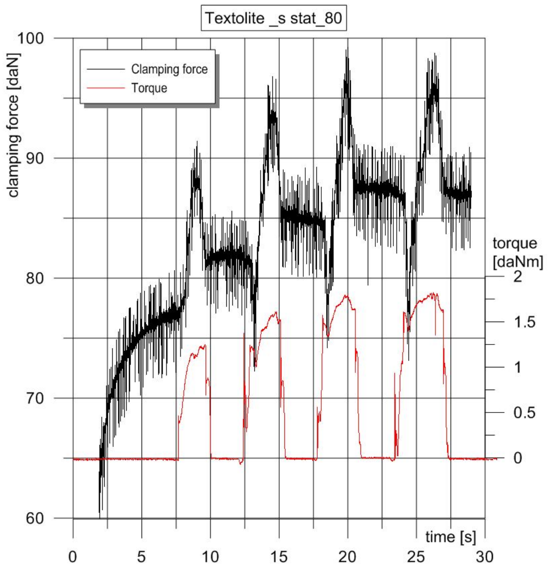

Fig. 6. Static test result example

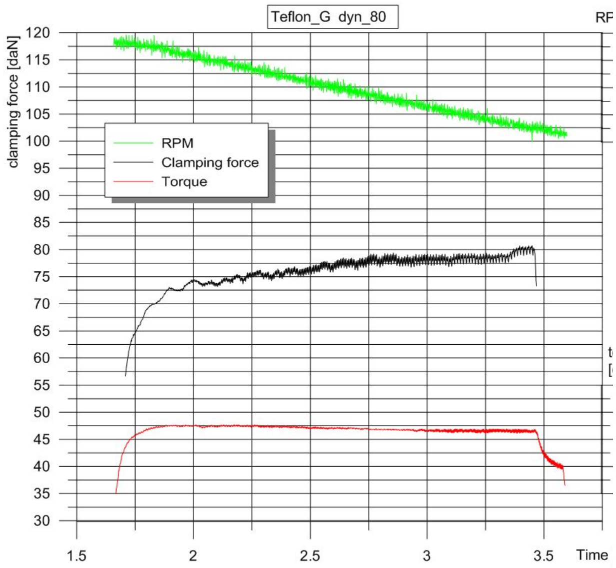

Fig. 7. Dynamic test result example

Data acquisition system recorded three parameters: torque, rotational speed and clamping force. For data processing, a simple moving average filter was used (15 samples). In order to define the coefficient of static friction, maximum torque values and corresponding clamping force values were taken to calculate an average (Fig. 6). A dynamic friction coefficient was calculated as an average of 4 selected (in equal distances) time points.

The IL-68 stand was not able to set precise contact time. The contact time was set manually (about 2 sec.) by the operator. The exact contact time was obtained from the recorded data. The test stand was also equipped with a regulator of clamping force, which during our experiments worked out of its normal range. It caused considerable fluctuation of clamping force (Fig. 6).

5. Results

Firstly, the test is resulted in establishing values for static and dynamic friction coefficients (μ_s and μ_d). Tested materials are for two clamping forces in pair with rail imitator. Secondly, it resulted in establishing wear values of tested materials (Tab. 2). Due to the fact the test times varied (1.2 s – 3.3 s), wear should be referred to the contact time.

The coefficients of friction were calculated from elementary equation:

$$\mu = \frac{2 \cdot M}{F \cdot D}, \tag{1}$$

where:
μ – friction coefficient,
M – torque measured during a test,
F – clamping force,
D – diameter of probes position.

Tab. 2. Obtained values of friction coefficients and wear velocity of the sliding materials

MATERIALS	μ_d [–]		μ_s [–]		$\Delta x/\Delta t$ [mm/s]	
	F_N =40 daN	F_N =80 daN	F_N = 40 daN	F_N = 80 daN	F_N = 40daN	F_N = 80 daN
Textolite (dry)	0.26	0.17	0.16	0.16	0.37	1.03
Textolite (oil)	0.27	0.19	0.14	0.14	0.50	0.96
Iglidur X	0.29	0.20	0.12	0.11	0.68	1.51
Iglidur J	0.18	0.12	0.12	0.11	1.78	2.38
PTFE+graphite (15%)	0.20	0.19	0.13	0.12	0.06	0.61

where μ_d , μ_s – dynamic and static friction coefficients, $\Delta x/\Delta t$ – average wear velocity, F_N – clamping force (planed values – exact value was read from recorded data).

6. Discussion

Obtained static coefficients of friction are very close to those given by manufacturers in technical data [5, 6]. For all tested materials the static friction coefficient practically does not depend on clamping force, what is compatible with classic mechanics. However, differently from classic mechanics, the dynamic coefficient of friction decreases as clapping force increases. Only PTFE samples keep almost constant μ_d for both clamping forces. The dynamic coefficient of friction is always significantly higher than the static coefficient of friction and it depends on clamping force (F_N). That behaviour of friction coefficient [$\mu_d > \mu_s$ and $\mu_d(F_N)$] is incompatible with classic mechanics but common for polymer material according to [3, 4]. It may be caused by increasing amount of abrasion products between friction surfaces and by exceeding the temperature limits [8].

There were observed a few process that caused wear of tested materials:

- abrasion – mainly for Textolite (Fig. 8),
- adhesion wear – trail on rotating aluminium collar mainly for Textolite and PTFE (Fig. 9),
- creep – observed for PTFE + 15% graphite (Fig. 10),
- smelting – mainly Iglidur J and Iglidur X (Fig. 11).

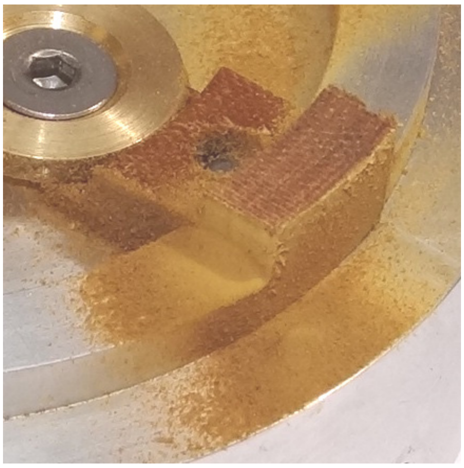

Fig. 8. Textolite probe after test – attrition

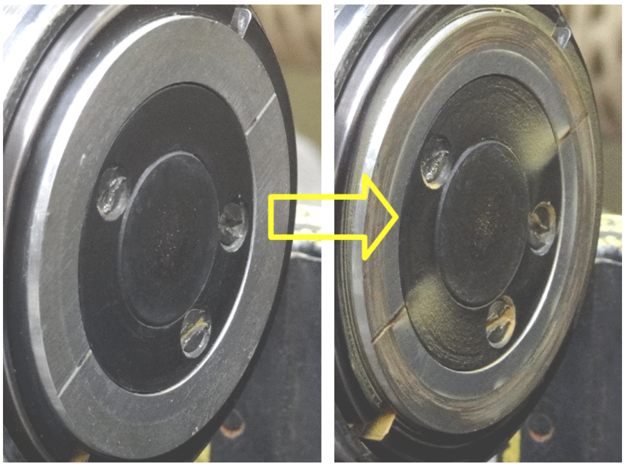

Fig. 9. Rotating aluminium collar before and after Textolite test – adhesion wear

In performed tests, wear was defined as dimension change (Δx) of sample towards axis of clamping force regardless of what processes are involved. The tests aim was to estimate the wear of slides during a single rocket launch. Based on the achieved results, assuming a constant load, and acceleration, the following hypothesis was established: wear velocity of sliding material depends on friction power (2):

$$\text{Wear velocity} \sim \frac{Power\_of\_friction}{contact\_area} = \frac{p \cdot v \cdot S}{S} = p \cdot v . \tag{2}$$

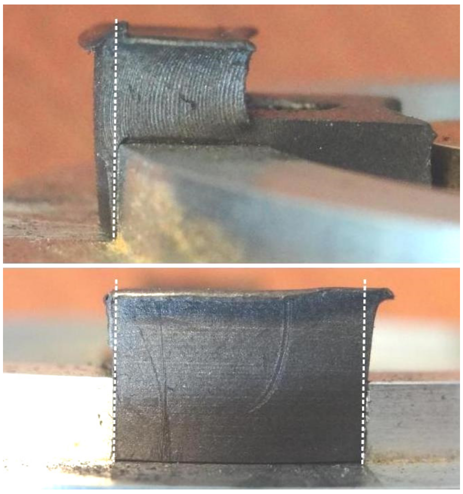

Fig. 10. PTFE + graphite(15%) probe after test – creep

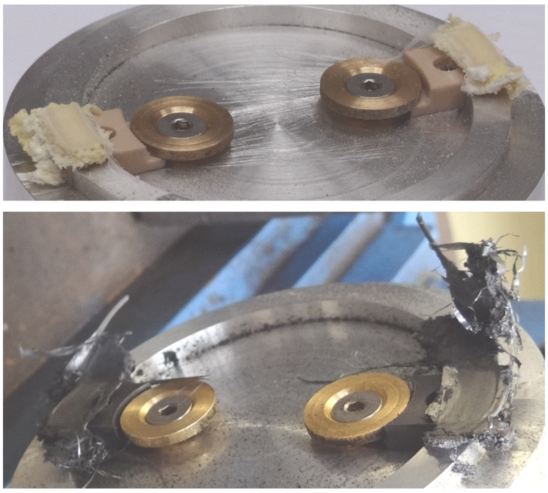

Fig. 11. Iglidur J (white) and Iglidur X (black) probe after test – smelting

From hypothesis (2) following equation was obtained:

$$\frac{dx}{dt} = A \cdot p \cdot v \rightarrow \Delta x = A \cdot p \cdot v \cdot dt, \tag{3}$$

$$\Delta x = A \cdot p \cdot \int_0^t v \cdot dt = A \cdot p \cdot L, \tag{4}$$

where:

p – pressure [MPa],
S – contact area [m^2],
v – sliding speed [m/s],
A – constant coefficient,
t – time [s],
L – length of sliding way [m].

The wear velocity of tested materials was nonlinear in references to power of friction. However, wear velocity of Textolite probes (dry and soaked with oil) was nearly linear. In order to designate coefficient A in equation (4) approximate lines were drown which were equivalent to the maximum wear velocity (Fig. 12). Textolite soaked with oil had almost the same wear as dry Textolite, so one approximate line was used for both types of Textolite probes. Using obtained A values, known maximal pressure p and length of sliding way L wear of tested materials were calculated (Tab. 3).

There is no doubt that PTFE with graphite addition has the lowest wear from all tested materials in the considered range. The highest wear velocity has Iglidur J, designed for much lower velocity. Iglidur X has the same wear velocity as Textolite for 40daN, but for 80daN it is significantly higher.

Tab. 3. Estimated wear of the sliding materials for single rocket launch

Slide material	Δx [mm]
PTFE + graphite (15%)	0.225
Textolite	0.354
Iglidur X	0.579
Iglidur J	1.113

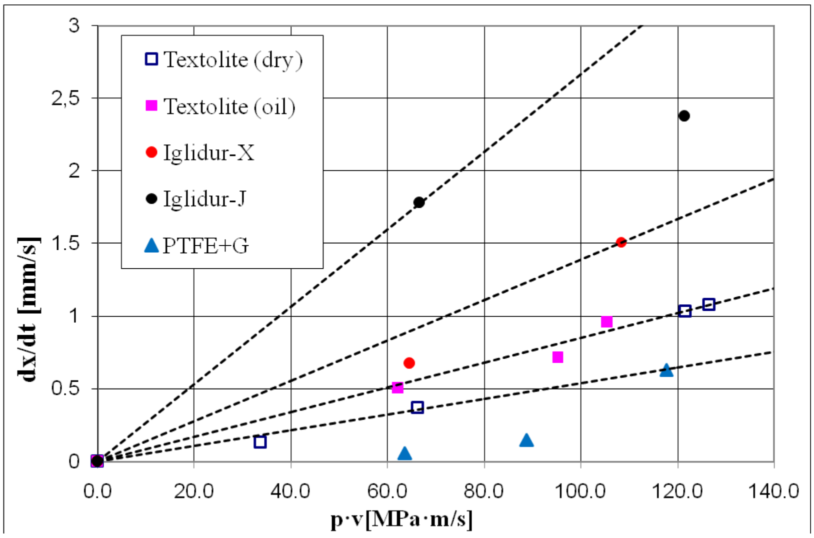

Fig. 12. Wear velocity of tested materials in reference to power of friction

Due to construction restraints, the wear shall not exceed 1 mm during a single rocket launch. Just to be on the safe side we took maximum value of wear velocities and assumed safety factor 2.

7. Conclusions

While performing tests of sliding materials their load (p·v) exceeded the one permitted by manufactures, what causes theirs rapid wear. Performed tests allowed evaluating wear of the slide during a single rocket launch. PTFE with 15% graphite addition had the lowest wear velocity and its friction coefficient was lower than Textolite. Considering the power hypothesis and the safety factor, it was apparent that PTFE had the best sliding characteristics for our application from all tested material. Wear of PTFE probes was caused mainly by creep. Graphite particulars penetrated to micro cracks of anodized surface of rail imitator, but it did not worsen sliding properties.

Textolite was the most popular and easy accessible from the tested materials, but its sliding properties in our application was slightly worse than PTFE. Soaking Textolite with oil (by applied simple method) had no influence on sliding parameters. Wear of Textolite probes was mainly by attrition. Textolite probes left a trail on the surface of the rail imitator (the trail could have been be easily removed by a wet cloth).

Materials made by “Igus” have the highest wear from tested sliding materials. Their wear was mainly by smelting. There is a significant difference between “Iglidur J” (basic material) and amplified “Iglidur X”. “Iglidur X” for clamping force 40 daN has similar wear to Textolite, but for 80 daN its wear is higher. Tests parameters exceeded acceptable speed and load limits by “Igus” catalog data.

No destruction processes were observed on surface of rail imitator. Trails after Textolite and PTFE probes were removed after each test.

The contact time of friction pairs can have a crucial impact on wear of sliding materials and coefficient of friction [7]. In order to build better hypothesis of wear process of plastics, the test stand should have a possibility of setting exact contact time and better maintaining of clamping force. Another important parameter is temperature on contact surface. Measuring temperature would allow building a better wear model.

Acknowledgements

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