

Friction torque, temperature and roughness in roll-slip phenomenon for polymer–steel contacts

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Abstract

The current study gives an insight of the roll-slip phenomenon of polymer-metal pair where priority is given to measurement techniques, test duration and the behavior of the polymer. A systematic tribological measurement was used to identify the friction torque from polymer–metal pairs where the friction torque from contact is obtained by subtracting the base torque of the test rig to exploit the absolute results. Base torque of the machine is almost constant, the changing can describe with linear trend line which is less than 0,5% per ten minutes. Measurements made for 3 hours shows that the friction force between the polyamide 6 (NaPA6) and structural steel (S33J2) has a polynomial of degree two with a function ($F_f = -1.5549 \cdot T^2 + 9.4031 \cdot T + 13,126$). Micrographs from the contact surface revealed the damage of roughness peaks during the course of testing. The involved wear mechanisms was investigated with roughness measurements and microscopy. The roughness plots also correlates with the micrograph where the rate of decrease in Ra in the initial stage is higher followed by a linear increase in the later stage. This can describe using polynomial function of degree as ($Ra = 0.029 \cdot T^2 + 0.3695 \cdot T + 2.4967$).

Keywords

Roll/slip, compensation friction torque, roughness.

1. Introduction

In polymer tribology the commonly investigated phenomenon is sliding, and a significant amount of research has also been conducted for rolling [1-5]. However a limited research was done for the phenomenon with a rolling to sliding ratio [6-8]. Roll-slip phenomenon still needs a lot more investigation from the measurements perspective for polymer metal pairs. Roll-slip is the

commonly occurring mechanisms in the engineering components like gears cams rollers etc. This phenomenon exhibits in small scale applications like gears in fax machines to the large scale levels like bearings for roller mills and in agricultural engineering applications. Earlier researches on rolling resistance have been interpreted from the view point of traction where both the specimen and the counter material deform [5]. Nevertheless, in those models both the specimen and the counter material deforms. But in the case of polymer metal pair the mating material is rigid to undergo a deformation. Thus the mechanisms involved in the contact surface are vital to dictate the friction behaviour.

Inaccuracies behind every scientific research might have the appropriate reasoning from experiments perspective. Careful consideration of the whole system can avoid the errors. A developed connection between the mechanism and the system can serve as a starting point for updating and corrections. These inaccuracies can be attributed to specific sector tribology: where 92 % mean deviation confirms to the corrections of the result. Most of the researches performed calculates the combine friction force/friction torque of the system and the contact [6-8]. In polymers metal contacts where the friction is relatively low this combined value might affect the precision of the measurement. Thus friction torque from the machine itself is an important factor on maintaining the accuracy and the repeatability of the experiments. Attempts have been made by researchers to by using a elastic contacts for identifying the friction force in rolling /sliding contacts [5] where the validation might be more realistic on subtracting the friction of the stem from the contact. Reserch using PA 46 on twin-disc with the slip ratio of 2% has been performed earlier where the rate of change of coefficient of friction during the test period was 0.25 to 0.35 [6]. Images and roughness acquired from time to time could also serve as an vital evidence on identifyin the involved wear mechanisms. Xiao et al in his study on roll-slip phenomenon of steel on steel pairs has found high friction coefficient increases with increasing roughness [9], nevertheless, more data are required for the polymer metal roll-slip . Polymer which has greater importance due to its embedding ability and the visco elastic behaviour can be correlated with the change in surface topography. The changes in roughness during in the course of wear like damage of peaks and valleys also dictate the course of wear. Besides the roughness of the counter material influences the tribological properties and the correlation between the roughness of the polymer and the friction is mostly governed by the modulus of elasticity of the polymer.

2. Materials and methods

In order to investigate the roll-slip and its relation to the friction force a twin-disc setup was used. The slip ratio used in the testing is defined as the rolling to sliding ration and given in equation (1) where d_1 is the diameter of the steel disc and d_2 is the diameter of the polymer disc.

$$s = \frac{d_2 - d_1}{d_1} \quad (1)$$

Test Materials

The examined materials were from Quattroplast Kft. (Hungary). The used thermoplastic polymer was Sodium catalyzed cast polyamide 6 – NaPA6 and commercially available structural steel (S355J2) was used as the counter material. The material properties of the test materials are tabulated below in Table 1.

Properties	S355J2	NaPA6
Yield strength [MPa]	355	80
Elongation at break [%]	16 - 18	>40
Young's modulus [GPa]	510 - 680	3.3
Hardness	160 HB	83 Shore D
Moisture absorption at 23°C and 50 ReH [%]	–	2.5
Thermal conductivity (20°C) [W/(m·K)]	60	0.23
Maximum allowable service temp. [°C]	–	110

Test setup

The equipment used for testing roll-slip is the modified FZG (Forschungsstelle für Zahnrad und Getriebebau) setup. This equipment was used to model a rolling to sliding contact with a specific slip ratio. Since both the soft carrying counter material and test specimen rotate at the same rpm, the required slip ratio is obtained by the difference in diameter of the specimen.

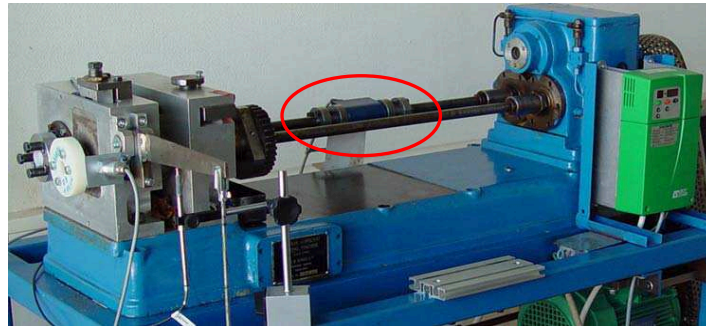


Figure 1. Modified FZG where the twin-disc tests were conducted.

A torque meter (Lorenz Messtechnik DR-20-type) is used to record the exhibited torque. Fig. 1. shows the used twin-disc setup with the circle mark on the torque meter which was connected to the shaft of the counter material disc.

The temperature of the contact surface is measured on the polymer material using a contactless infra-red sensor. The temperature sensor is placed 50 mm perpendicularly away from the contact surface. The load is given through the pivoted arm engaged to the movable shaft where the polymer disc is fixed. All the measurements are recorded online using a data acquisition system. The roughness was measured at regular intervals using a cut-off value of 0.8 and a traverse distance of 4 mm was used.

Test Parameters

Roll-slip testing tends to have complex measurements where the results have to be corrected to find the absolute value. The test parameters were carefully chosen to investigate the three different purposes. Initially the torque from the machine (base torque) is identified by running the machine at no load condition without contact for 30 minutes at a speed of 250rpm. The initial measurement was done in order to validate the base. Furthermore, a test with duration of 3 hours is conducted to identify the rate of change in friction force as a function of time. The second test was conducted at a speed of 200 rpm with a normal force of 130N. Before and after the test the base torque of the machine was measured on no load condition for a period of 15 minutes. The dimensions of both the polymer and steel disc are Ø89.9 and Ø 74.95 respectively; the dimensional specifications of the discs are selected to match the slip ratio of 20% which is considered to be close to the practical application.

The final test is to identify the change in microstructure of the specimen. The test was repeated with stop-over for measuring the influence of roughness of the specimen at an interval of 15 minutes for 225 minutes. After every 15 minutes the test was stopped and the image of the specimen was acquired using an optical microscope connected to a 10 bit CCD, simultaneously the roughness at that instant was also measured using a Hommel tester.

3. Results

In scientific investigation it is important to know the consistency of the measured parameters from the equipment. Precise measurements adds value to the whole research especially in place of tribological measurements it could lead to energy saving and indirectly help on material selection. In normal flat on flat testing the friction measurements are directly obtained from the load cell however in testing roll-slip the measurements made from the torque sensor serves as a reference to calculate the co-efficient of the friction. In such places the torque sensor measures the combined friction torque from the contact and the machine. Thus the components of the test rig also aids to the inaccuracies (e.g. seals and bearing resistance).

Base torque

The first measurement aims to identify the resistance of the test-rig. Fig. 2. show the plot for the base torque as a function of time.

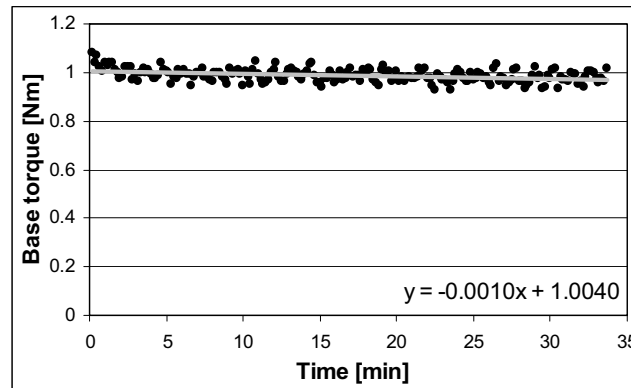


Figure 2. 30 minutes base torque measurement.

As clearly seen on the Fig 2. the base torque is almost constant along the time. At the first 5 minutes there is a decrease in base torque which probably belongs to lubrication effect. After 5 minutes the oil fill all the places (bearings) and follows without any change and hence the curve is linear. The base torque relatively having small rate of change where the variation every 10 minutes is less than 1%. But on using the second part of the measurement (15-30 minutes) the variation is 0,5% per 10 minutes. Base on this phenomenon in further investigation it will be appropriate to measure the base torque before and after the test, and correcting the nominal torque with a linear base torque function.

3 hours friction measurement

For a specific condition (20 % slip, 200 rpm, 130 N normal force) the friction force between sodium catalyzed PA6 and S355J2 structural steel was measured. The plot with the friction force as a function of rolling-sliding time is shown in Fig. 3.

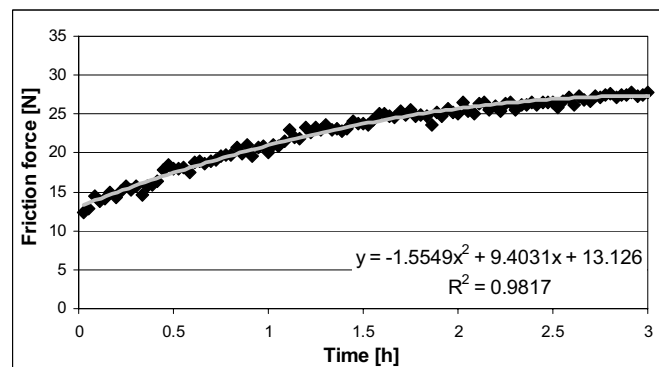


Figure 3. The friction force as a function of time with the fitted curve.

The tendency of the friction force can be described with a polynomial function of degree 2. The equation for the calculated curve is given in (2), which is valid from 0-180 minutes.

$$F_f = -1.5549 \cdot T^2 + 9.4031 \cdot T + 13,126, R^2=0.9817 \quad (2)$$

This tendency refers that the half of the changes occurs in the first 30% time of testing. Moreover, to study the effects of temperature a curve was plotted with temperature as a function of rolling-sliding time (Fig. 4.).

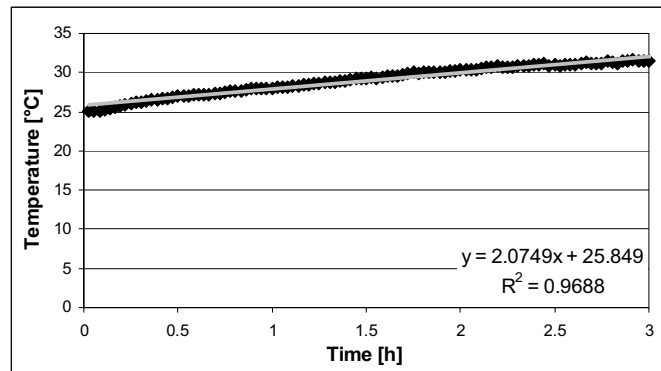


Figure 4. The temperature as a function of time with the fitted curve.

It is clearly seen on the fig. 4 that the change in temperature almost linear. The equation for the calculated curve is (3), which is valid from 0-180 minutes.

$$t = 2.0749 \cdot T + 25.849, R^2=0.9688 \quad (3)$$

The change in temperature after 3 hours testing is less than 7°C. This value is relatively low, which does not change significantly the mechanical and tribological properties.

Microstructure changing

All the images were acquired using a 20X objective which has a calculated total magnification of 335 times, the field of view is about 1,4×1 mm polymer surface (Fig. 5.). The measured roughnesses are also shown in the micrograph where it is evident that the roughness decreases as a function of time. Considering the image as a function of time the damage of the peaks from the machining is very much visible leading to the change in the roughness value. Moreover, the peaks after considerable running time have been worn down to the level of the valley and are connected by the valley. The difference of 1µm was observed for the initial and the final value of the Ra (Fig. 6.).

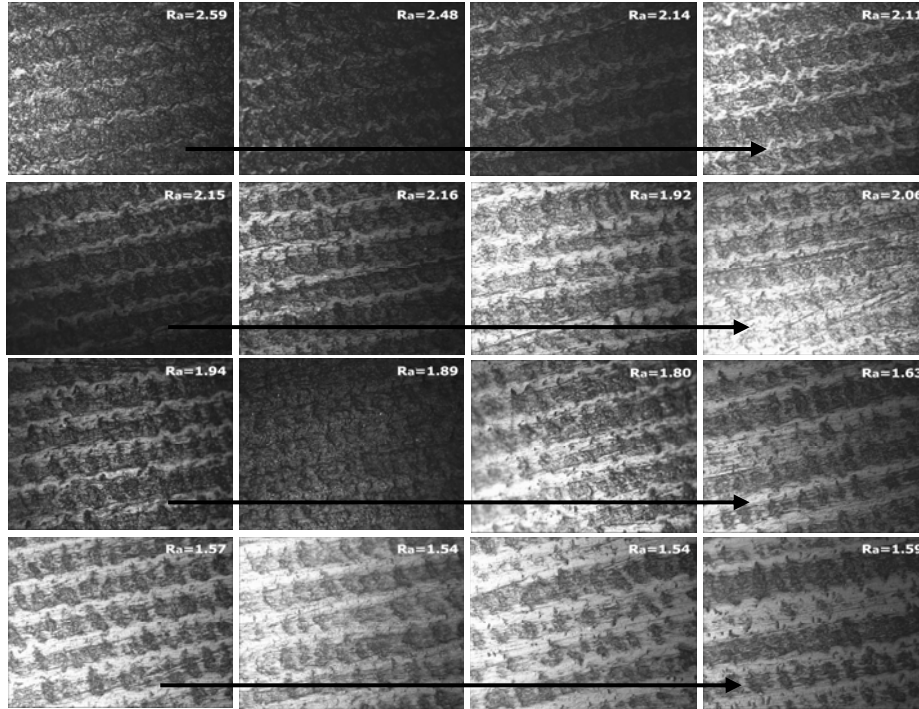


Figure 5. The micrograph of the worn surface and the corresponding roughness values taken at regular intervals.

Abrasion of soft polymer by the structural steel is seen from the lines running over the contact surface. The change in Ra for the speculated test period is 38 % and considered to be significant in case of tribological testing.

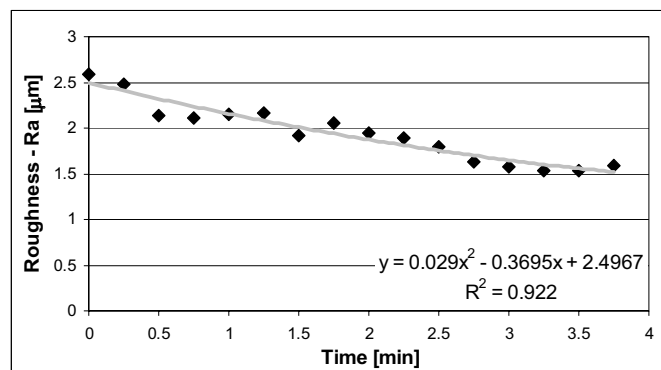


Figure 6. Roughness changing at every 15 minutes.

The trend for the change in roughness is illustrated by polynomial function similar to the friction force. The equation for the calculated curve is (4), which valid from 0-225 minutes.

$$Ra = 0.029 \cdot T^2 + 0.3695 \cdot T + 2.4967, R^2=0.9220 \quad (4)$$

4. Discussion

Standards for measuring system can provide a systematic approach to acquire error free data. Acceptable range for the errors in the obtained results depend upon the sector, however considering tribology field limitations exists. Measuring friction torque using standard procedures for roll-slip phenomenon aids precise results. Isolation of complex phenomenon provides a chance to analyze the influence of individual parameters. Considering the base torque in fig 2 it can be seen from the plot it is almost constant which is due to the lubrication effect from the bearing are moreover the oil temperature is constant. The obtained base torque from the machine is removed as compensation from friction torque due to the contact. The 3 hours test shows a trend with polynomial of degree 2 where the friction force which can be attributed theoretically to the change in surface and temperature. From the temperature plot it is evident that the change is less than 7°C where the curve as seen from the plot has a linear increase. This might be due to the cooling effect between every contact where the contact surface is exposed to the ambience temperature (25°). Moreover, there is enough time to conduct the heat via the metal counterpart and the shafts. Based on the temperature measurement the change in surface has a vital effect of the friction force but not to the temperature.

The rate of change of roughness is high which is seen from the micrograph. It is evident from the curves that the change in roughness is also polynomial, because the at the initial stage the roughness peaks are worn much faster. This influence can be attributed from the topographical change of the surface: Initially the surface changes fast, because the real contact area is much smaller at this stage where the contact is mostly from the tip of the roughness peaks. For which the contact pressure is relatively high for the individual peaks. After a specific period of testing the peaks are damaged and the real contact surface increases. The bigger area leads smaller contact pressure but help to the adhesion phenomenon. This effect has a vital influence to change the friction force.

5. Conclusions

Structured roll-slip tribological measurement was identified where careful consideration was taken for the compensation of the friction torque from the machine itself. It was also found the base torque is almost constant along the testing which aids to obtain the real values from the measurement. Following the

systematic approach, the long term measurement (3 hours) shows that, the friction force between the NaPA6/S33J2 can be described using a polynomial function with degree 2. Micrograph was used as evidence to compare the change in roughness. It was clearly seen that, the peaks are destroyed at the beginning of testing. In the initial stage the rate of change in roughness is much higher and further it becomes linear. The polynomial function in both the cases for roughness and the friction force illustrates the relationship between each other, although the relations are reverse. By using the results high precision online tribological measurements can be recorded. Further attempts to acquire the images online can aid to reveal the actual mechanisms involved in the course of testing.

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