A Novel Measuring Technique to Evaluate Frictional Characteristics of Roll-Slip Contacts in Polymer-Metal Pairs

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Abstract: Tribology research is aimed for desirable frictional characteristic; especially in rolling/sliding of polymer-metal contacts which helps smooth operations and energy savings. Conventional roll-slip tests for few million cycles have significant deposit of polymer transfer layer on counterface, thus having a polymer-polymer contact instead of polymer-metal contact. Besides, backtransfer affecting the friction force was never explored. Studying these phenomenon individually and characterizing frictional property without the presence of transfer layer helps for a better understanding of the combined system. A new procedure for measuring friction torque at 20% slip ratio is adapted for varying speeds from 10 to 500 rpm. The observed friction-force increases rapidly at low-speeds and becomes linear at high-speeds. The micrographs of the contact surface prove no trace of transfer layer was found in the newly developed measuring process. Also specimen surface temperature never reached the effective level to affect friction properties.

Keywords: Roll-slip, measuring technique, polymer-metal pairs

1.0 INTRODUCTION

The Polymer-meal pairs are best used for their frictional properties and the self lubricating properties through transfer layers. Engineering plastics commonly used in gears, rollers and pump parts are Polyamide (PA6), polyacetal (POM) and Polyethylene terephthalate (PET) which are tested for the frictional behavior under rolling-sliding configuration [1-5]. In the existing researches on roll-slip phenomenon test cycles from few hundred thousand to million cycles were used. Such conditions lead to thermal expansion which in turn produces unsteady frictional characteristics due to the visco elastic property of the polymers [6]. In a regular configuration like pin-on-disc, block-on-ring, flat-on-flat frictional heat is unavoidable. Continuous contact in these configurations leads to have an increased temperature however, in rolling/sliding contacts the contact points has an advantage of cooling period after the contact. The deposition of transfer material on the counter face is critical which relies on the parameters like load and velocity activated by thermal effects. It is evident that transfer layer are formed [6] which in turn changes the polymer -metal contact to polymer-polymer contact. In real situation it is not clear that if this transfer layer does exists on the counter material all through-out the application. Earlier research with Bijwe et al has reported the back transfer of polymer resin in composite material to the counterface material [7]. In most of the cases the transfer layers are very well present and in few cases the transfer layer cannon be seen due to backtransfer of polymer as a consequence of adhesion. Thus a clear distinction is required between the effects of friction between polymer-metal and polymer-polymer contacts. The transfer plays a significant role in deciding the friction characteristic of the system [8].

Speed and temperature are interrelated and changing the temperature indirectly influences the fictional character by the viscoelastic behavior as a reaction to the increased temperature [8]. Moreover, earlier researches on roll-slip phenomenon has be conducted with a constant velocity however the influence on studying a varying frequency has not been explored Thus it is interesting to investigate the effect of friction force at varying speeds. Optimizing speed can provide situation for which the transfer layer formation is avoided.

Apart from the transfer layer, consistencies of the measured parameters from the equipment are rather important in scientific investigation. In the existing techniques the tangential force was recorded as a measure of friction force in roll-slip contacts. However, measuring the friction torque from the contact seems to be rather appropriate. While using both the systems the frictional properties of the test equipment itself contribute to the inaccuracies. Such inaccuracies should be compensated to obtain the absolute frictional properties. The current research aims at investigating the influence of a specific speed on friction force in a polymer-metal contact without transfer layers. Identifying the individual influence of polymer-metal and polymer-polymer contact contributes for a better understanding of the tribological properties. A continuous varying speed seems to be closer to the applications where different sequences producing same friction force might conclude the negligible effect of varying speed. To compare the new measuring technique incorporation of additional material as a reference to compare the trend might validate the process itself. Thus new test method can be adapted on saving time and energy.

2.0 MATERIALS AND METHODS

2.1. Test materials

Commercially available polyamide rods from Quattroplast Kft. (Hungary) were used as a polymer test material. Moreover, in place of composites test material polyester (UP) resin with woven fabric and Polytetrafluoroethylene (PTFE) was used. For both the test materials, structural steel (S355J2) was employed as the counterface material. Initially, PA6 rods and the steel discs were machined for producing the required slip ratio. However, the composite material was tested in the as given condition. The material properties of the test materials and the counterface materials are tabulated below in Table 1. The dimensions of both the polymer and steel disc are Ø89.9 and Ø 74.95mm respectively; the dimensional specifications of the discs are selected to match the slip ratio of 20%. The composite specimen had completely finished surface with a roughness within the range of 2 to 3 μm. The polymer specimen and the steel counterface had a surface roughness of 2.5 and 1.4μm respectively. At every cycle, the test materials and the counter materials were cleaned. A separate cleaning procedure was used for polymer and steel. All the samples were conditioned at 23 C and 50% RH for 48 hours before testing.

Table 1: Properties of the used material

Properties	Steel	Polymer	3D Composite
	S355J2	**NaPA6**	**Orkot®**
Yield strength [MPa]	355	80	55
Elongation at break [%]	16 - 18	>40	-
Young’s modulus [GPa]	510 - 680	3.3	80
Hardness	160 HB	83 Shore D	100 Rockwell M
Moisture absorption at 23°C and 50 ReH [%]	-	2.5	-
Thermal conductivity (20˚C) [W/(m·K)]	60	0.23	0.169
Maximum allowable service temp. [˚C]	-	110	130

2.2. Instrumentation

All tests were carried out in a modified FZG (Forschungsstelle fur Zahnrader und Getriebebau) setup. Fig. 1 shows the schematics of the test rig where individual shafts for polymer and steel disc from the same drive is used. The flexible bearing of the specimen shaft is loaded by means of deadweight using a pivoted connection. Thus the specimen shaft is always engaged to the countermaterial even when the polymer is worn. The shaft carrying steel disc is fixed with a torque sensor (Lorenz Messtechnik DR-20-type) to measure the exhibited torque from friction. A contactless infra-red sensor was placed 50 mm perpendicularly away from the contact surface to measure the online temperature of the test material. All data are logged online using a PCI 6229 National Instrument data acquisition.

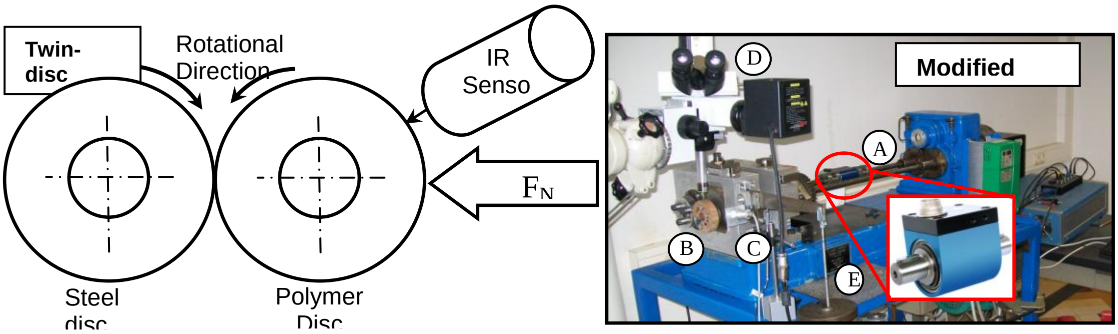


Figure 1. Schematics of the twin disc instrumentation and the Modified FZG set-up (A) Torque sensor (B) Test specimen and counterface material (C) IR Sensor (D) Optical Microscope (E) Load.

2.2. Instrumentation

A twin disc setup is the appropriate tool to investigate the friction behavior for roll-slip mechanism. For formulating a testing sequence the commonly used engineering polymer is tested against structural steel. Moreover, to identify the feasibility of the developed method an additional material (composite) was used with the similar sequence. The slip ratio is expressed using eq (1) where d1 is the diameter of the steel disc and d2 is the diameter of the polymer disc. And the friction force is calculated from the measured friction torque as given in eq (2):

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

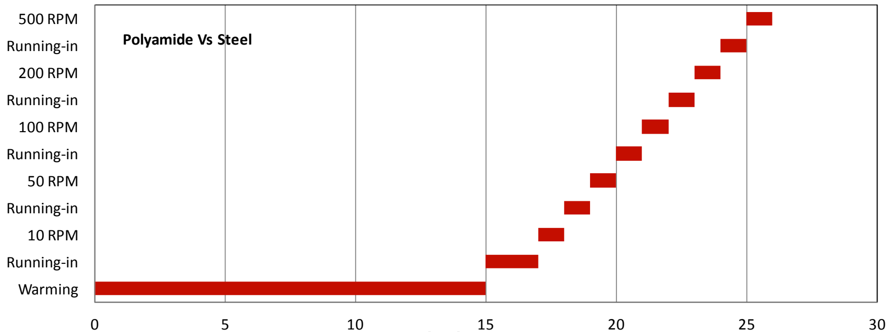
$$\text{Friction force }(N) = \frac{T(Nm)}{r(m)} \qquad (2)$$

where

T = Measured friction torque (During contacts) – friction torque of the equipment (without load),

r = Radius of the polymer specimen.

The tests parameters were carefully chosen to investigate the effect of roll-slip on different velocity A load of 210 N was used since the contact pressure depends upon the material intrinsic property they vary inevitably between the polymer and the composite. Five different speeds were used starting from 10 rpm followed by 50, 100, 200 and 500 rpm. Before starting the specimen the machine was run for 15 minutes without loading in order to heat up the system. A running-in was included where the peaks from the countermaterial to be aligned with the polymer surface to serve the sole purpose of having a conformal contact. Automation of the test program was implemented using Labview program. The followed cycles from both the test materials are given in Fig 2. Each program was repeated for six times to understand the repeatability. After every cycle the specimen was measured for its roughness and the image of the specimen was captured. A total cycle of 25 minutes with different speeds was used for PA6 against steel, likewise the same test duration is followed for Orkot. Except for speed, Orkot used a varying speed of 10, 100, 200, 450 and 700rpm. At the end of every cycle the images were captured using a 10 bit QICAM color CCD camera and an Olympus SZX optical microscope. The micrograph was made before and after every loading steps were specimen was removed from the test-setup and furthermore the corresponding roughness was measured in the HOMMEL tester with the standard DIN 1548 using a cut-off value of 0.8 and a traverse distance of 4 mm..



	Warming	Running-in	10 RPM	Running-in	50 RPM	Running-in	100 RPM	Running-in	200 RPM	Running-in	500 RPM
Cycle	0	15	17	18	19	20	21	22	23	24	25
🟥 Duration / speed	15	2	1	1	1	1	1	1	1	1	1

Figure 2 Test sequences and the speed used (a) PA6 VS Steel

2.3 Steps involved in the newly developed experimental procedure:

Step 1: The polymer and the steel discs are machined to the required surface finish; same cutting tool was used to have similar surface parameters and texture. Step 2: The specimen was conditioned at (23°C, 50 RH) for a period of 48 hours. Step 3: Warming of the machine is done for 15 minutes before testing. Step 4: The base torque of the machine was measured from free running for different speeds. Step 5: Specimen and the counter material was loaded, both the specimen were cleaned with Loctite 7061 cleaner. Prior to t Loctite 7061, the counter material was cleaned with acetone. Step 6: The mentioned cycles in Fig 2 was followed. Step 7: The specimen was removed from the test rig to measure the roughness and to acquire the micrograph. Following from step 4 the experiment was repeated for 6 times

3.0 Results

Developing an experimental procedure for optimal testing and to identify the influence of individual parameters is important to validate the tribological system. An attempt has been made to see the significant difference in the variation of results when the speed is changed. The measured friction torque of the machine (no load condition) at designated speeds is compensated from the friction torque in the loading cycles. The same post-processing has been done for all the tests. Results from six repetition has been reported in Fig 3 where all the six different sampling following the same test sequences with continuous varying speeds from 10 rpm following up till 500rpm. The results show a similar friction force at the corresponding speed in each sample. Comparing the six samples a good confidence has been proved considering the repeatability of the testing process.

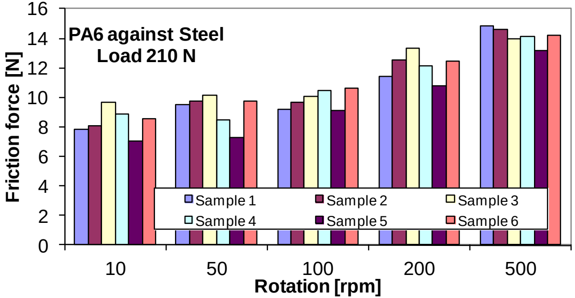


Figure 3. Number of samples and the corresponding friction force for the five different speeds seems similar in all five samples.

For the six samples in both low-speeds to high speed and vice versa a scatter was made with friction force as a function of speed. For the scatter in Fig. 4 (a) and (b) the deviation stayed within 25% which is normal in a tribological investigation. It also seen that results are similar for both the sequences from 10 to 500 rpm and vice versa showing a similar trend in the frictional force. In both the sequence no trace of polymer was found in the steel counter face.

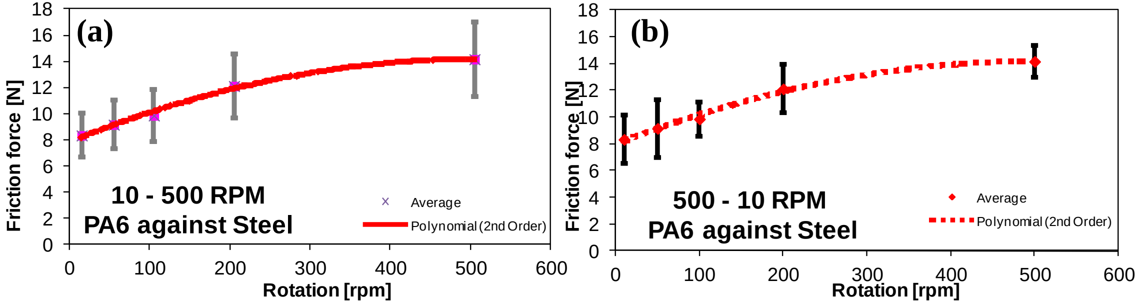


Figure 4 Friction force at a load of 210N in (a) sequence 10 to 500 rpm (b) sequence 500 to 50 rpm

The same test method on polymer composite resulted in producing similar trend in friction force with a rapid rate of increase in friction force at low speed followed by a linear increase at high speed. In this study, on using polymer composite a similar pattern of sequence were followed with the speed ranging from 10 to 700 rpm varied at100, 200 and 450 rpm in-between. The temperature plot shown in Fig. 5 illustrates the negligible influence of temperature (less than 2°C) for increasing speed thus avoiding the circumstances of thermal expansion leading to change in friction force due to the deformation of polymer. Observations from the micrograph reports that there is no significant change on the surface topography considering all the six samples tested with the new methodology. Arrow marks on the images indicate the rolling direction.

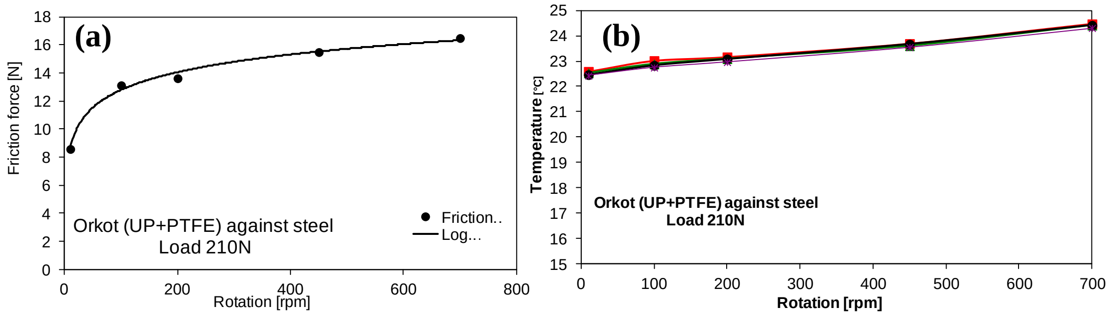


Figure. 5 Temperature and the friction force against the varying speeds for polyester composite.

From Fig. 6 (a) (b) & (c) it is clear that the modification in surface morphology is negligible with just an increase in width of the white line across the image. Preliminary tests conducted at 1000 rpm has proven considerable amount of transfer layer visible to the naked eye (Fig 7 (c). Moreover, Fig 7 (b) shows the micrograph of the steel surface from Fig. 7(c) where the presence of transfer layer is distinguished by the wrapping effect of the light scattered region from the cusp curves. However, these regions are clearly seen in with proper scattering of light in the specimen surface tested with the new methodology. This transfer layer was also observed on having prolonged test duration. It can also be seen from the micrograph that there were no deposit of polymers on the counter material in Fig 7 (a) which was acquired after the new testing process.

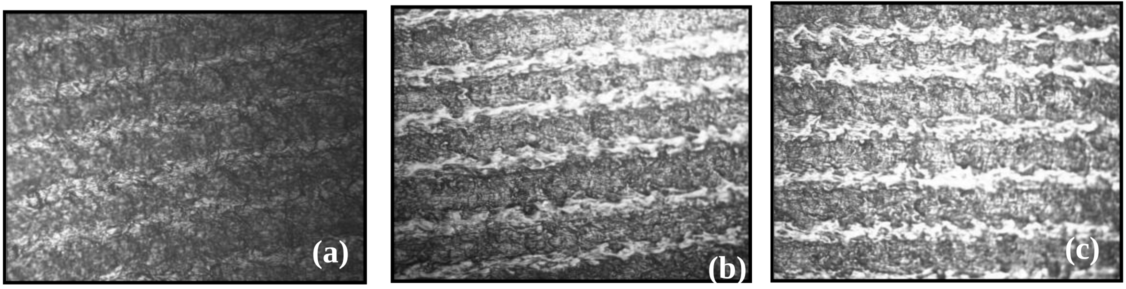


Figure 6 Micrographs of the polymer specimen in the initial test and after five samples of test in the same material.

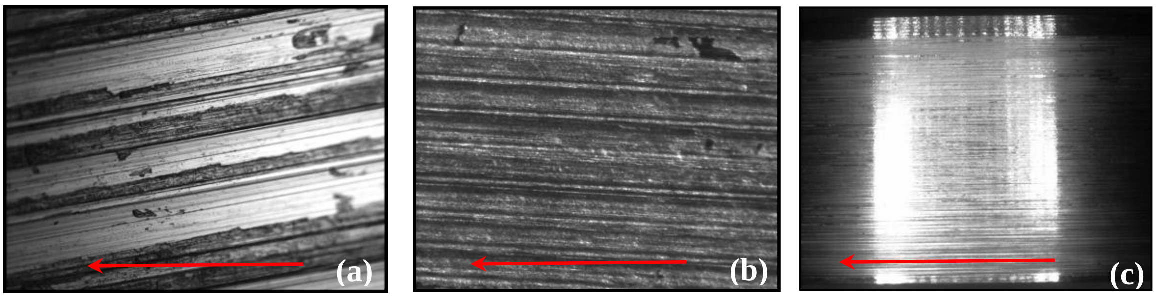


Figure 7 Micrograph of steel surface from (a) new measuring technique (b) Conventional measuring process with deposit of transfer layers (c) Photographic image of the transfer layer.

4.0 DISCUSSION

Thus characterizing the polymer-steel contact adds value on identifying the influence of transfer material. The current methodology developed for testing roll-slip phenomenon can act as a foundation in characterizing the frictional properties of polymer-metal contacts. Testing for frictional characteristic of polymer metal contacts is critical and complex due to the intrinsic property of the material. Polymer predominantly influenced by the viscoelasticty behaviour changes its frictional characteristic with the influence of heat and the transfer layer formed on the counter material. Besides, in rolling-sliding contacts it is further more difficult to understand the friction process from the fundamental level where two components such as tangential traction and sliding aids to a combined friction force. As mentioned in the literature a system for roll-slip was adopted with different diameters to obtain the rolling to sliding phenomenon [9]. In a tribological system it is obvious that the friction changes inevitably due to the change in speed. However, monitoring such a case in rolling-sliding situation is vital to see the influence of varying speed and the consistency of corresponding friction behaviour. Moreover in real system the change in speed is rather spontaneous and continuous. Nevertheless, tests are performed on never performed on varying speed. Thus a continuous monitoring system with varying speeds was adapted for investigations. The observed trend of the friction force has a rapid increase at the initial stage and then gradually becomes linear which is also true from the time dependant strain behaviour of polymers. Comparing the friction force between two test sequences from low-speed to high speed and vice-versa, the influence of temperature can be identified. On analysing Fig 4(a) & (b) trends in both the sequences were similar. On the other hand it is expected that the sequence starting with the high speed must have produced different friction force comparing the sequence starting with low speed due to the effect of velocity increasing the temperature for having dissimilar frictional value. But, the above two sequence proves that there is no influence of temperature in the used methodology. Moreover, it is also evident that varying speed does not have any influence on the frictional characteristics. It is also clear from the micrograph that there is no substantial wear. However, the roughness peaks from the machining process present in the polymer surface has been reduced during the contact. Thus increasing the area of contact and reducing the contact pressure. The observed trend for friction characteristics has been compared with other materials (Composite) to study the feasibility of such a test methodology for composites. It is also proved in-case of polymer composites furthermore the temperature plots as seen from in Fig. 5(a) doesn't not show a significant change. Thus the test methodology proves to be efficient in polymers and polymer composites. From Fig. 5 it is clear, that the trend observed in the polymer composite also follows a similar pattern thus in good correlation with the test sequence from polymers shown in Fig. 4. In both the cases the friction force increases rapidly at low speeds and after reaching saturation level the friction force increases in a constant pace. The developed method can be effectively used for fictional characterisation of polymer-metal contacts. However, in addition to the current investigation future work on characterizing the back transfer of transfer layer could provide a better understanding on the tribological properties of the whole system.

5.0 CONCLUSION:

A new methodology for testing roll-slip phenomenon of polymer and polymer composites against steel counterface was validated. The identified method produces similar results for polymers and composites considering the trend on friction behaviour of the material at varying speeds. The method is effective to inspect polymer-metal contacts by avoiding the transfer layer formation in counterface materials. The observed trend has a rapid increase at the initial stage and then followed a linear raise on friction force. Both testing sequence from high speed to low speed and vice-versa showed similar results explaining that no significant effects from the continuous varying speeds. The current method can be used to study the frictional characteristics of polymer-metal contacts with a reduced testing time.

6.0 REFERENCES

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