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Comparison of friction performance of four anodised aluminium surfaces for use in a clutch actuator

Frida Riddar*, Åsa Kassman Rudolphi

Tribomaterials Group, The Ångström Laboratory, Uppsala University, Box 534, 751 21 Uppsala, Sweden

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ABSTRACT

Clutch actuators in the automotive industry are used to convert the force applied by the driver to the clutch. A typical pneumatic actuator consists of an anodised aluminium cylinder in which a piston, with a rubber lip seal and a PTFE guiding ring, slides. The system is silicone grease lubricated. The aluminium cylinder is most often cast, e.g. permanent mould, sand, or high pressure die cast. An interesting alternative is extrusion. After anodising the cylinders display different surface topography due to, amongst other things, the fabrication method. In this study, the friction behaviour of the anodised surfaces from the four mentioned methods are investigated in a reciprocating sliding test. Two test setups were used, one simulating the real contact situation, and one using a simpler sphere on flat geometry. The extruded surface oxide cracked during testing, resulting in very fluctuating friction behaviour. The high pressure die cast surface showed rather good results, but never the best. However, it is considered not suitable for the application due to its poor oxide properties. The permanent mould cast surface displayed the lowest friction coefficient, while the sand cast surface often showed the highest friction.

1. Introduction

Clutch actuators convert the force applied by the driver on the clutch pedal into a force acting on the release bearing of the clutch [1]. In a pneumatic actuator a piston moves inside a cylinder housing in an axial back and forward motion. Typically, an actuator uses anodised aluminium as cylinder material, and mounted on the piston are a rubber lip seal and a PTFE guiding ring. Thus, the lip seal and guiding ring slide against the inner surface of the cylinder housing. Before assembly the system is lubricated with silicone grease.

By anodising aluminium components, the corrosion protection and wear resistance can be significantly enhanced [2]. In this paper the friction performance of four anodised aluminium cylinders, produced by extrusion, permanent mould casting, sand casting and high pressure die casting, were investigated. The aluminium cylinders were produced for usage in pneumatic clutch actuators in trucks. The three casting methods are all employed today as manufacturing techniques for commercial clutch actuators. Extrusion, on the other hand, is a possible new way to produce cylinder housings for clutch actuators.

In an earlier study by the authors it was shown that the surface topography and the structure of the oxide are very different for the four methods [3]. It is possible that the difference in surfaces topography influences the lubrication and the friction performance, e.g. that depressions in an undulated surface could act as reservoirs for lubricants [4,5].

In this paper, the friction performance of four different anodised aluminium surfaces are studied, using a lab test setup that simulates the contact situation of a clutch actuator. The test method has been used in previous studies of permanent mould cast surfaces, by the present authors [6,7]. It has been shown that for lubricated conditions the friction behaviour is fluctuating, while it is very stable for unlubricated conditions. This could be an effect of the nature of the grease, e.g. how it is affected by shearing and temperature [8,9], as discussed in [7]. It could also be an effect of the complex contact geometry of this specific test setup. Due to the contact geometry there is a gap between the lip seal and the guiding ring, which may act as a lubricant storage.

In this study, to investigate the influence of contact geometry, tests where the lip seal and guiding ring are replaced by a ball were also performed. Balls of NBR rubber and PTFE were used. The results from the tests using balls are also of general interest for other tribological contacts between polymer materials and anodised aluminium in the clutch actuator system.

2. Experimental setup

2.1. Test setup

A reciprocating sliding test rig was used. To simulate the contact in a clutch actuator, parts of a lip seal and a guiding ring are mounted on a part of a piston, and slide against the inner

* Corresponding author. Tel.: +46 18 4717241; fax: +46 18 4713572.
E-mail address: frida.riddar@gmail.com (F. Riddar).

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surface of a part of an aluminium cylinder. A schematic of the setup is shown in Fig. 1, while the test equipment is more thoroughly described in [10]. This setup was also used in previous studies, where test parameters and procedures are presented in more detail [6,7]. In order to study a simpler contact situation, also tests with a ball against the aluminium cylinder were performed, i.e. a ball with a diameter of 10 mm replaced the piston with lip seal and guiding ring.

Reciprocating sliding tests were performed for 100,000 cycles at a frequency of 3 Hz, corresponding to a test duration of approximately 9 h 16 min. The peak-to-peak amplitude was about 7 mm.

Vibration tests were performed by vibrating the sample holder of the aluminium sample at 100 Hz frequency and about 100 μm peak-to-peak amplitude. Two different vibration tests were performed: continuous vibration and interrupted vibration. Both tests were performed during 10 h, corresponding to 3.6×10^6 vibration cycles. During the interrupted test, one 1 Hz sliding cycle of about 5 mm peak-to-peak amplitude was applied every 30 min, i.e. every 1.8×10^5 cycle.

In all tests simulating the contact in a clutch actuator the contact load was 15 N, and in the ball-on-aluminium surface test the contact load was 5 N. The contact load was applied by a spring, and the friction force was measured with strain gauges.

The tests were performed at an aluminium sample temperature of 80 °C, corresponding to the working temperature of a clutch actuator. This was achieved by heating the aluminium sample, using two thermo elements mounted inside the sample holder.

2.2. Anodised aluminium cylinder surfaces

The investigated aluminium cylinders (actual cylinder housings for pneumatic clutch actuators) were produced by permanent mould casting, sand casting, extrusion and high pressure die casting. Test samples (10 mm × 25 mm) were cut from the cylinders.

The aluminium foundry alloys used were: AlSi7Mg for sand casting and permanent mould casting, AlSi1Mg for extrusion, and AlSi9Cu3 for high pressure die casting. The alloys were selected since they are typical for respective production method. After fabrication the cylinders were machined and anodised. This resulted in the different surface structure and topography, more thoroughly described in [3], see Fig. 2.

The surface of the permanent mould cast cylinder still shows traces from the machining, but also a superimposed surface structure with lower and higher areas, see Fig. 2(a). The sand cast cylinder shows an undulated surface structure of smooth plateaus and lower areas, see Fig. 2(b). On top of the plateaus it is possible to detect faint traces from the machining. On the extruded surface traces from the machining are still visible. These are not only perpendicular to the sliding direction but also at an angle from it

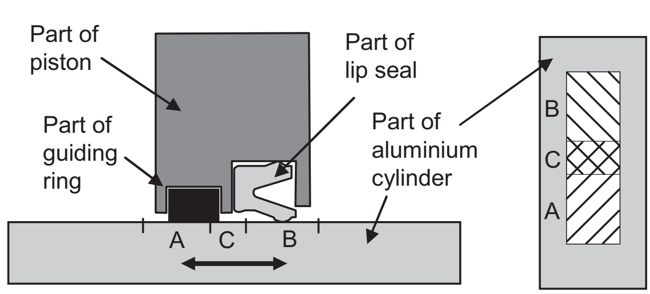

Fig. 1. Schematic of the test setup simulating the clutch actuator. When the peak-to-peak amplitude is larger than approximately 5 mm, the area A slides only against the guiding ring, B only against lip seal and C against both guiding ring and lip seal.

due to a different machining procedure of the extruded cylinder, see Fig. 2(c). The surface of the high pressure die cast cylinder appears randomly rough, see Fig. 2(d). The surfaces were measured by white light optical interference microscopy. The R_a values were: permanent mould cast, $R_a=0.5$ μm; sand cast, $R_a=0.9$ μm; extruded, $R_a=0.2$ μm; and high pressure die cast, $R_a=0.6$ μm.

2.3. Counter materials and lubrication

The tested lip seal, guiding ring, and silicone grease are typical for commercial clutch actuators. The lip seal is made of NBR rubber (Shore A hardness of 75) and the guiding ring of PTFE with 25% graphite. The balls, with diameter 10 mm, were of NBR rubber (Shore A hardness of 70) and PTFE (Shore A hardness of 60).

The lubricant was always evenly applied onto a set area, 15 mm × 10 mm, of the anodised aluminium sample. Three conditions of silicone grease lubrication were tested: no grease (unlubricated), high lubrication (10 ± 1 mg grease), and low lubrication (2 ± 1 mg grease).

2.4. Performed tests

The *test simulating the clutch actuator* was used for different types of tests:

- All four aluminium surfaces were tested in the reciprocating sliding tests (high lubrication, 3 Hz, 100,000 cycles, 15 N contact load, 2 parallel tests). (The results of the permanent mould cast surfaces were also presented in previous studies [6,7].)
- The sand cast and the permanent mould cast surfaces were vibration tested (high lubrication, 100 Hz, 1,000,000 cycles, 15 N contact load, 2 parallel tests of the interrupted vibration test, 1 continuous vibration test). (The results of the permanent mould cast surfaces were also presented in a previous study [7].)

The *ball-on-aluminium surface test* was used for the following different types of tests:

- All four aluminium surfaces were tested against both types of balls in the reciprocating sliding test (low lubrication, 3 Hz, 5 N contact load, 1 test of 100,000 cycles, 1 or 2 tests of 10,000 cycles).
- All four aluminium surfaces were tested against both types of balls in the continuous vibration test (100 Hz, 5 N contact load, 1 test at low lubrication for 1,000,000 cycles, 1 test unlubricated for 100,000 cycles).

3. Results

3.1. Test simulating the clutch actuator

The four different aluminium surfaces showed some differences in friction performance during the reciprocating sliding testing, see Fig. 3. With the extruded surface the friction was highly fluctuating (Fig. 3(c)). This can be explained by the development of cracks all over the surface during testing, as observed after the testing. Both the sand cast and the high pressure die cast surfaces showed increasing friction coefficients, reaching about 0.15–0.20 at the end of the tests (Fig. 3(b) and (d)). The permanent mould cast surface resulted in two different behaviours, in one test the friction coefficient remained low and stable throughout the test, while in the other test it increased to the same level as for the two previously mentioned surfaces (Fig. 3(a)).

When looking closer at the first 2000 cycles of the same tests, it is obvious that the friction coefficient started at different