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DETERMINATION OF THE COEFFICIENT OF FRICTION BETWEEN ALUMINIUM PROFILES AND OTHER MATERIALS

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Abstract: In the 21st century, various components are available to users for modern machine construction. One such component is the machine-building aluminium profile, which is an extruded product with a complex cross-section. Different aluminium profiles can be connected to each other by creating detachable connections, one option being to create a tension joint using grooves, screws, and connecting elements. The strength of the joint is determined by the torque with which the screws are tightened. Consequently, the coefficient of friction determines whether the elements will slide on each other or not. During the assembly of aluminium profiles, we conducted experiments on material combinations that come into contact with each other, from which we determined the coefficient of friction values for each material pair.

Keywords: *Bosch, aluminium, profile, friction, dynamometer*

1. INTRODUCTION

In tribology, wear and friction are closely related concepts. Friction determines the extent of wear, which is why friction cannot be ignored in many wear tests. Examples of such tests include the pin-on-disc and ball-on-disc tests, which are among the most common tribological tests. In these tests, the experiments are conducted under various conditions, such as high temperatures, different lubrication conditions, etc. Thus, the coefficient of friction and the wear rate between the tested material pairs are determined under controlled and recorded parameters.

Previous studies have already addressed the measurement of the coefficient of friction between aluminium and other materials, such as steel (e.g., (Javadi & Tajdari, 2006) and (Wang, Cai, Zhou, & Duszczyk, 2009)).

In study (Javadi & Tajdari, 2006), a twist-compression test was performed between aluminium and steel. At the beginning of the test, the value of μ was 0.2, then increased to 0.8, and subsequently stabilized at a value of 0.6. The conclusion drawn from the test was that the coefficient of friction varies with deformation, i.e., it is not constant.

In study (Wang, Cai, Zhou, & Duszczyk, 2009), a ball-on-disc test was conducted at high temperatures, in the range of 350-500°C, also between steel and aluminium. The test results showed that μ is strongly dependent on temperature and sliding distance.

The experiments we conducted focus primarily on determining the coefficient of friction between the anodized layer on the surface of extruded Bosch aluminium profiles and other materials. The results of these experiments provide important information for installations using aluminium profiles.

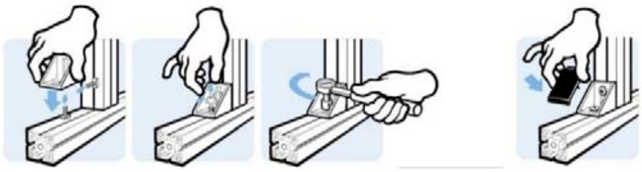

Figure 1. *Drill-free connection of profiles (Javadi & Tajdari, 2006)*

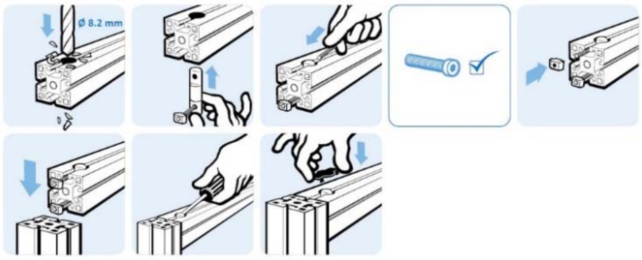

Figure 2. *Connecting profiles with a drilled connector (Javadi & Tajdari, 2006)*

Drill-free connectors are generally used as supports, but they can also be used to create tensioned joints. The most popular connector of this type is the corner piece. A corner piece can be used to connect two aluminium profiles at a 90° angle. A groove nut can be placed in each groove of the aluminium profiles. Screws can be inserted into the groove nuts from above through the corner elements. Here, the corner element acts as a washer. After this, a cover element can be attached to the corner element, which covers the screws and ensures an aesthetic appearance.

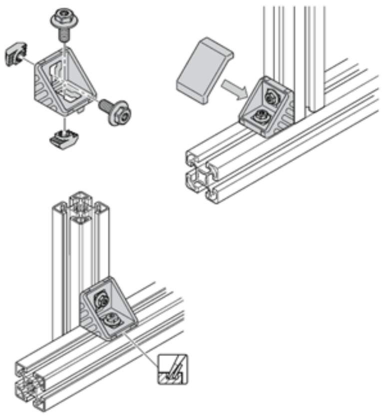

***Figure 3.** Installation of corner element*

***Figure 4.** 45x45 Bosch aluminium profiles connected with corner elements*

Type	F_{max}	M_{max}	M_{max}	M_{max}
40x40	3000 N	55 Nm	145 Nm	35 Nm

***Figure 5.** Load capacity of connections created with 40x40 corner elements*

Figure 3 and Figure 5 can be found in the Bosch Rexroth product catalogue (Rexroth Bosch Group: Aluminium Structural Framing System, Version 9).

The load-bearing capacity of the joint created in this way is determined by the tightening torque of the screws. The greater the force with which the corner element is pressed against the surface of the aluminium profile, the greater the load-bearing capacity of this connection. The friction coefficient between the elements pressed together and the compressive force can be used to determine the frictional force. The question is, how high is this friction coefficient?

Aluminium oxidizes quickly when exposed to air, which is why products made from this material always have a protective layer of aluminium oxide on their surface. The surface of aluminium profiles used in machine construction is covered with a so-called anodized layer.

The name comes from anodic oxidation, which is an abbreviation of the English term "ELOXAL - ELectrolytic OXidation of ALuminium". Products treated with anodization become wear- and corrosion-resistant, as well as aesthetically pleasing.

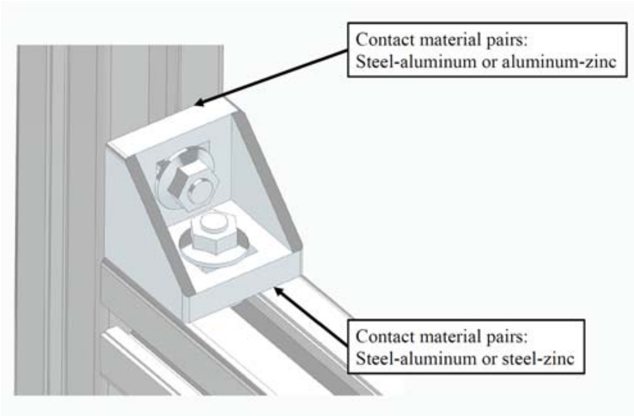

Figure 6. *Contact material pairs*

2. METHODOLOGY

The friction coefficient was measured specifically between the surface anodized layer of aluminium profiles and other materials, so in the rest of this article, we will refer to the protective anodized layer under the aluminium surface.

During the investigations, we examined several connections:

- We determined the coefficient of friction between the inner groove of the profile and the steel-aluminium material of the groove.
- We also determined the coefficient of friction between the surface of the aluminium profile and the corner element made of cast aluminium or zinc.

Of the two factors, the smaller one will determine the maximum load capacity. The coefficient of friction between different materials was measured using a measuring system designed specifically for this purpose.

We attached an aluminium profile or steel plate to the carriage moving in two directions. We placed a test sample made of another material (e.g., a zinc corner piece) in contact with the surface of the fixed elements, for which we created a gripping device using a 3D printer (Figure 9). One end of the holder is secured with a rope, while the other end is connected to a force gauge sensor.

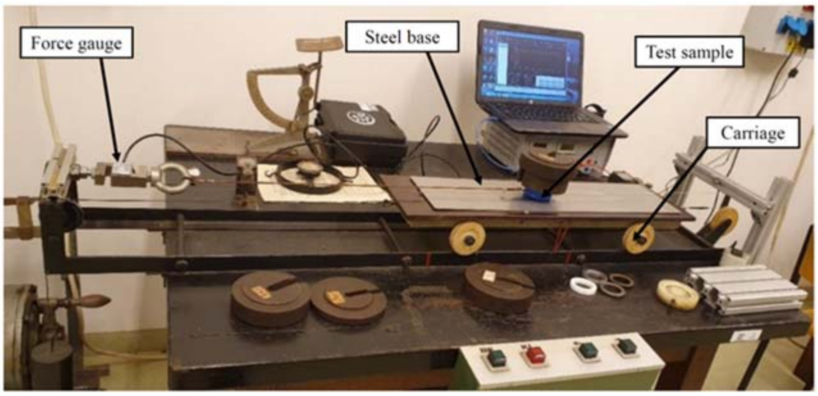

Figure 7. *Measuring system for measuring friction coefficient*

The receiving device had to be made for two reasons:

- on the one hand, it should be easy to grip,
- on the other hand, it should have a large enough surface area to allow various weights to be placed on top of it.

If we place different weights on the blue socket and start moving the bottom plate across the cart, the weights will press the corner element against the surface of the plate. This causes friction between the two elements (Besenyei & Bihari, 2024).

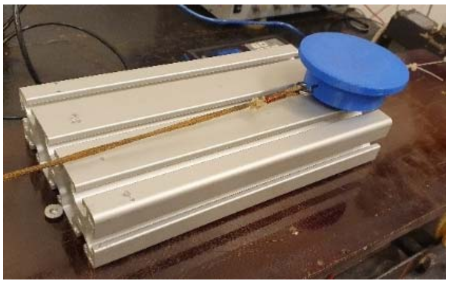

Figure 8. *Measurement on aluminium profile*

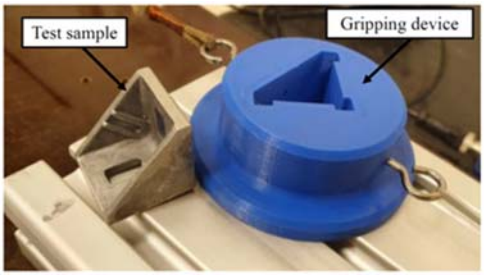

Figure 9. *Corner element and matching socket*

Figure 10. *Force gauge in installed condition*

Table 1
Data of the force gauge
(Besenyei, Bihari, & Mikó, 2024)

Dimensions:	(L x W x H) 97 x 42 x 200 mm
Mass:	540 g
Force reading range:	0 - 5000 N
Display:	Digital
Basic accuracy:	0,1 %
Resolution (force):	1 N
Product type:	Dynamometer

The force gauge data was recorded in accordance with the data specified in the product catalogue (PCE Instruments: Dynamometer PCE-DFG N 5K). Since the bottom plate was pulled at a constant speed, the force gauge will show a value other than zero, similar to a conventional spring force gauge (Némethné Nándori, 2025).
The test was conducted on a 500 mm long aluminium profile. The test distance corresponds to 400 mm, and since each measurement was taken over a period of 10 seconds, the speed can be estimated at 0.04 m/s. This speed remained constant throughout the tests.

3. DETERMINATION OF THE COEFFICIENT OF FRICTION

We performed tests lasting approximately 10 seconds using the force gauge. We recorded the average friction forces indicated by the stamp, then calculated the friction coefficient values for each material combination.
Since we pulled the bottom plate at a constant speed, the force gauge stamp will show a value other than zero, similar to a conventional spring force gauge (Némethné Nándori, 2025). Table 2 below shows different measurement results

Table 2
Force pairs of different measurement results

	steel-steel		**steel-aluminium**		**steel-zinc**		**aluminium-zinc**	
	F_f	**F_n**	**F_f**	**F_n**	**F_f**	**F_n**	**F_f**	**F_n**
1	0.8	11.5	1	11	3	10.5	0	9.8
2	2	21.3	3	20.8	4	20.3	0.9	19.6
3	4	31.1	5.1	30.6	5	30.1	1.5	29.4
4	5.1	40.9	7.4	40.5	6.8	39.9	2.9	39.2
5	6.9	50.7	9.8	50.3	7.5	49.7	3.4	49.1
6	8.3	60.5	12.6	60.1	9.5	59.6	4.4	58.9
7	11	70.3	13.2	69.9	10.9	69.4	5.6	68.7
8	11.7	80.1	15.2	79.7	11.7	79.2	6.3	78.5
9	13.9	89.9	17.1	89.5	13	89	7.2	88.3
10	15.3	99.7	19.2	99.3	14.4	98.8	10.6	98.1

The ratio of friction force to compressive force gives the value of the coefficient of friction (Besenyei, Bihari, & Mikó, 2024).

$$\mu = \frac{F_s}{F_n} \tag{1}$$

Pairs of forces that belong together can be represented in the form of a scatter plot. In this case, a trend line starting from the origin can be fitted to the points, whose R2 value indicates how well the line approximates the points.

$$R^2 = \frac{\sum_{t=1}^{T}(\hat{Y}_t - \bar{Y})^2}{\sum_{t=1}^{T}(Y_t - \bar{Y})^2} \tag{2}$$

R2, also known as the coefficient of determination, can take values between 0 and 1. The closer the value is to 1, the more reliable the results are and the closer the trend line is to the points on the graph (Wang, Cai, Zhou, & Duszczyk, 2009). The "Y" placeholders in the formula are used to substitute the current values into the calculation model. It is customary to express the R2 value as a percentage. For the relationships examined, we obtain the results according to Table 3 for the different material combinations.

Table 3

Results of the different material combinations

	steel-steel	steel-aluminium	steel-zinc	aluminium-zinc
R2	0.9938	0.997	0.9947	0.9682
μ	0.15	0.19	0.15	0.08

Experience shows that if the values obtained for R2 show at least 94 % reliability, this means that the results obtained from the measurements are considered acceptable.

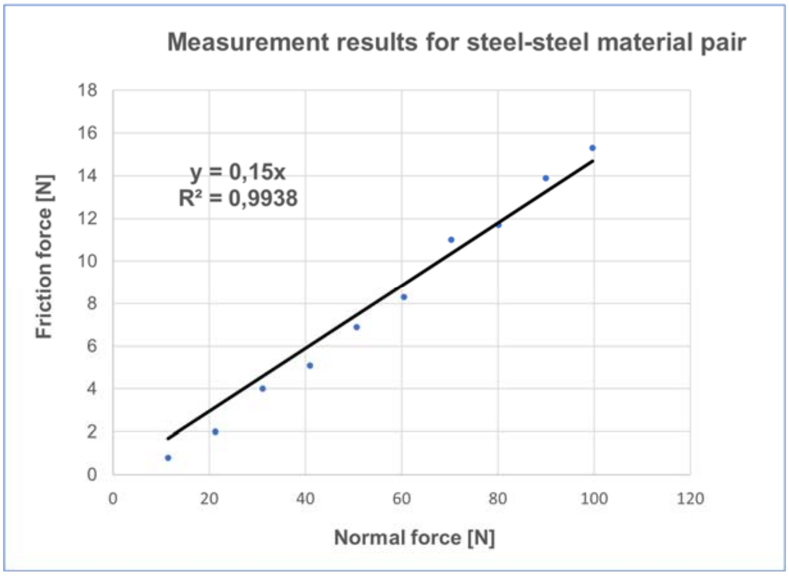

Figure 11. *Measurement results for steel-steel material pair*

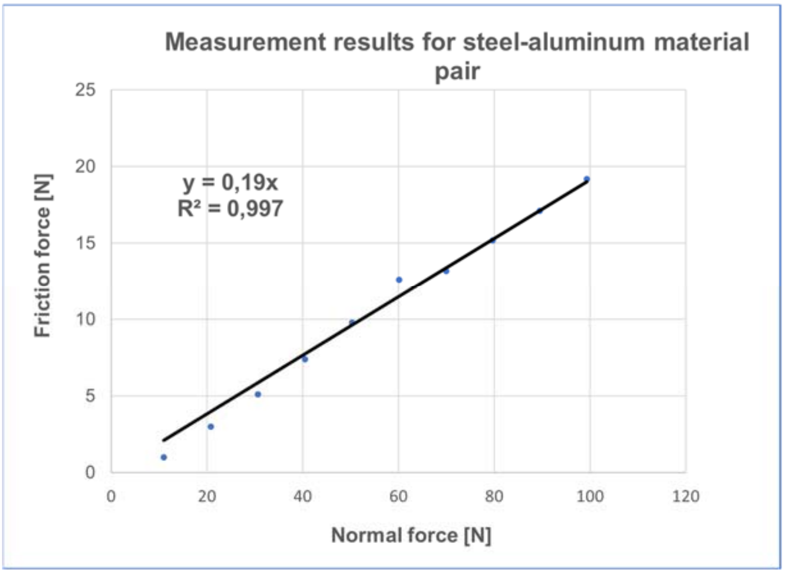

Figure 12. *Measurement results for steel-aluminium material pair*

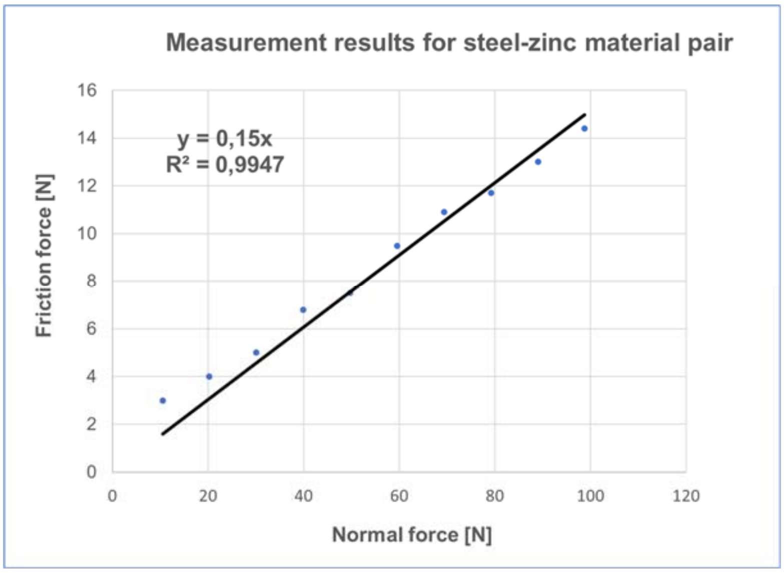

Figure 13. *Measurement results for steel-zinc material pair*

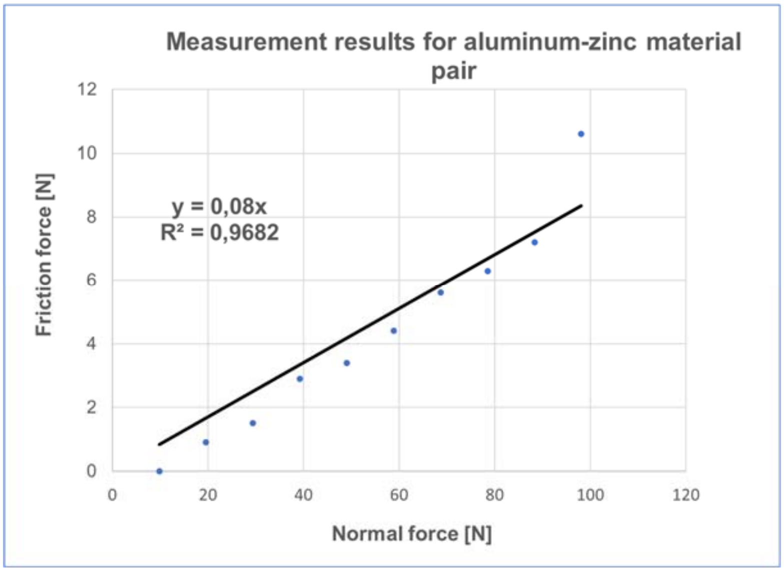

Figure 14. *Measurement results for aluminium-zinc material pair*

The points on the diagram represent the values of the different force pairs. The straight lines are trend lines created by regression, which use a function to best approximate the aforementioned points.

The diagrams clearly show that if we take the ratio of the x and y values, we obtain the value of the coefficient of friction. In this case, this corresponds to the ratio of the frictional force and the normal force. In the trend line equation, this value is the tangent of the function like in case of equation (3) as an example.

$$\mu_{steel-aluminum} = \frac{F_f}{F_n} = \frac{y}{x} = 0{,}19 \qquad (3)$$

4. Summary

In practice, there are cases where profiles are fastened to each other in such a way that their position relative to each other is not fixed but can be changed. This can be achieved by loosening the connection with the screw connection, so that the corner element does not connect the two profiles meeting at right angles, allowing the profile to be slid relative to the other along the groove together with the corner element. Then, by tightening the screws again, a tensioned connection is formed.

Of course, in terms of load bearing, this fastening method has a much lower load capacity and is also worse in terms of accident prevention than using drilled connectors, but it does not require profile machining, so when designing a structure with this connection, it is worth taking into account the coefficient of friction between the different materials.

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