Correlation between the anisotropy of an AA2021-T351 aluminium rolled thick plate and the occurrence of the stick-slip phenomenon

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Abstract: *The stick-slip phenomenon is a dynamic instability that appears at the contact interface of two sliding surfaces. Its occurrence is influenced by the relative sliding speed, the contact pressure, and the system rigidity, but also by the state of contact between the two sliding surfaces. The present paper aims to study the influence of the anisotropy of an aluminium AA2021-T351 plate on the stick-slip phenomenon. For this, using the CETR UMT II tribometer, linear sliding tests have been performed on the aluminium alloy thick plate surface using a cylindrical pin made of ultra-high-molecular-weight polyethylene (UHMWPE) along three directions: a longitudinal one, corresponding to the rolling direction of the sample (0°), a transverse one, perpendicular to the rolling direction (90°), and a median direction (45°). Varying the sliding speed, the contact pressure, and the system rigidity, it was possible to observe the influence of the material anisotropy on the specific parameters of the stick-slip phenomenon.*

Key Words: *friction, stick-slip, anisotropy, aluminium alloy, plastic materials*

1. INTRODUCTION

Friction appears wherever there is movement, hence friction has a very important role in many industrial processes. A particular friction phenomenon is the stick-slip movement, which is a dynamic instability that appears at the contact interface of two sliding bodies. The stick-slip movement, in most cases, is an unwanted phenomenon, so engineers try to eliminate it. Thus, it is very important to know the conditions in which it appears ant to study the parameters that influence its occurrence, such as the relative sliding speed, the contact pressure, the system rigidity or the state of contact between the two sliding surfaces.

The stick-slip phenomenon can be described as an intermittent movement, caused by the differences between the values of the kinetic friction coefficient (μ_k) and those of the static friction coefficient (μ_s).

It usually appears when the values of the static friction coefficient are higher than those of the kinetic friction coefficient [1]–[4].

In case of the stick-slip phenomenon, the variation of the friction coefficient (μ) can be represented function of time or displacement (d), as shown in Fig. 1, where μ_{smax} – maximum static friction coefficient, μ_s – static friction coefficient, μ_k – kinetic friction coefficient, μ_m – mean value of the friction coefficient and μ_v – friction coefficient amplitude (stick-slip amplitude).

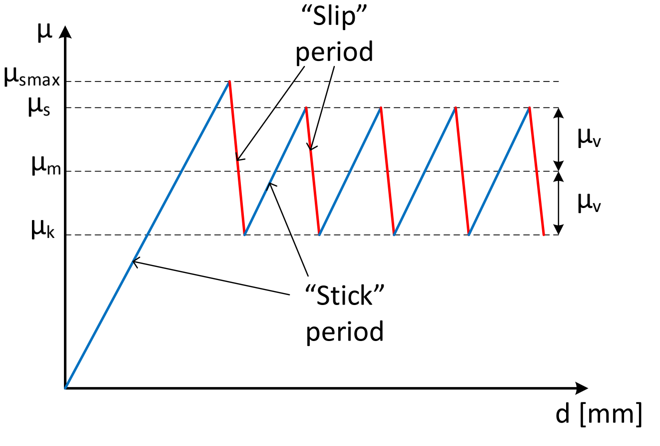

Fig. 1 – Variation of the friction coefficient versus displacement

The parameters that influence the amplitude and frequency of the stick-slip phenomenon are the relative sliding speed, the contact pressure, the system rigidity and the state of contact between the two sliding surfaces [5]–[8].

In order to have better friction performances, engineers choose materials that form friction pairs that have specific friction properties, such as reduced friction coefficient. One of these pairs is aluminium alloys with plastic materials (Fig. 2).

Fig. 2 – Aluminium-plastic sliding system [9]

Because of their excellent mechanical properties, high mechanical strength and low density and weight, aluminium alloys are frequently used in numerous industry fields, such as aeronautics, naval and automotive domains. Plastic materials are used in dry friction pairs because they have very good self-lubricating properties.

The most common plastics found in industrial products are polyethylene, phenol, teflon (PTFE) and nylon [10].

The friction pair chosen for the current study is composed of an AA2021-T351 aluminium alloy rolled thick plate and an ultra-high-molecular-weight polyethylene (UHMWPE) pin. The main mechanical properties of the two materials are presented in Table 1.

Table 1 – Mechanical properties of AA2021-T351 and UHMWPE [11]

	AA2021-T351	**UHMWPE**
Ultimate tensile strength	420 MPa	38.6 MPa ÷ 48.3 MPa
Yield strength	250 ÷ 301 MPa	21.4 MPa ÷ 27.6 MPa
Young's modulus E	72653 MPa	894 MPa ÷ 963 MPa
Poisson's coefficient $\boldsymbol{\nu}$	0.33	0.46

The rolled aluminium plate is considered anisotropic because its properties vary as a function of the rolling direction.

It has an orthotropic plastic anisotropy considering three specific material orientations: x – rolling (longitudinal) direction LD (0°), y – transverse direction TD (90°) perpendicular to the rolling direction and z – thickness direction [11].

For the surface anisotropy an extra direction is investigated, the median direction MD, which is the direction at 45° from the rolling direction, as shown in Fig. 3.

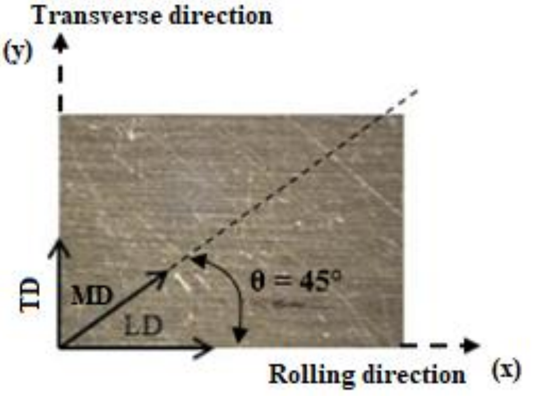

Fig. 3 – Surface anisotropy

The present paper aims to study the influence of the surface anisotropy of the AA2021-T351 aluminium alloy plate on the stick-slip phenomenon.

2. TESTING PROCEDURE

Using the CETR UMT II tribometer (Fig. 4), linear sliding tests have been performed on the aluminium alloy thick plate surface using a cylindrical UHMWPE pin that slides on the AA2021-T351 plate along the three directions: LD (0°), TD (90°), and MD (45°).

Varying the sliding speed, the contact pressure, and modifying the system rigidity, it was possible to observe the influence of the material anisotropy on the specific parameters of the stick-slip phenomenon.

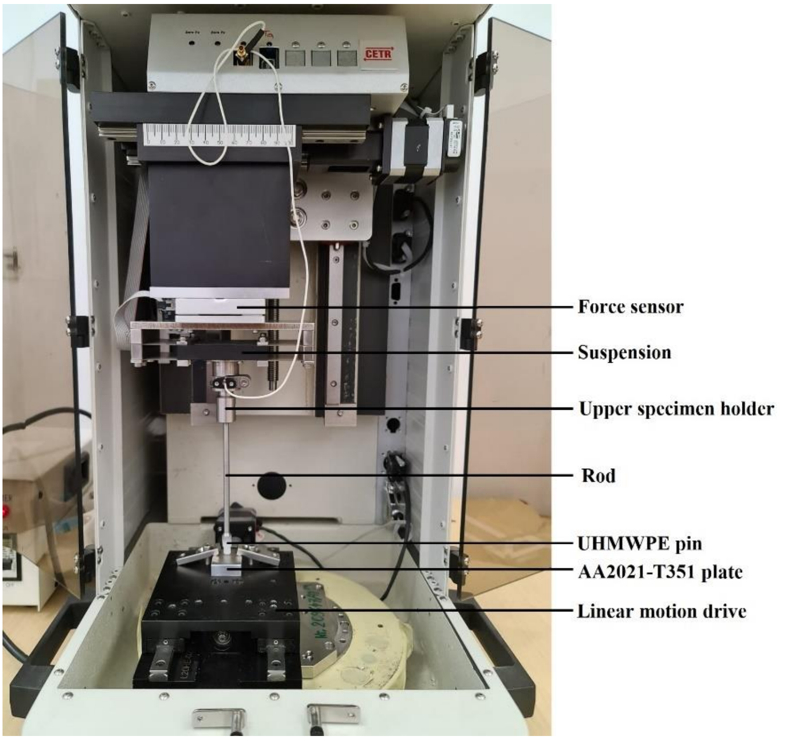

Fig. 4 – The UMT II tribometer set-up

The tribometer is equipped with a model DFH-20 two-dimensional force sensor (maximum load – 200 N) used to measure the sliding and breakaway friction force between the UHMWPE pin and AA2021-T351 plate, as well as measuring and controlling the loading force. The suspension between the force sensor assembly and the upper specimen holder is necessary to maintain a constant load by compensating for variations in the distance between the force sensor and the surface of the aluminium plate when it is in motion.

The UHMWPE cylindrical pin has a 6 mm diameter and is mounted in the holder with the help of a connecting steel rod that has a 5 mm diameter and a length of 113.6 mm.

The rod is used to reduce the system rigidity (7.159 N/mm) so that it is possible to observe the stick-slip phenomenon.

The aluminium plate is a 30×25×10 mm parallelepiped and is connected to a model L20HE reciprocating linear motion drive.

The tests have been performed at four different relative sliding speeds (0.01 mm/s, 0.05 mm/s, 0.1 mm/s and 0.5 mm/s), and one normal loading force of 150 N. Considering the geometry of the UHMWPE pin, the resulting contact pressure is 5.3 MPa.

3. RESULTS AND DISCUSSIONS

For a better correlation with the surface of the AA2021-T351 plate, the variation of the friction coefficient is represented as a function of the displacement.

Fig. 5 presents the variation of the friction coefficient for the 0.01 mm/s relative sliding speed. As it can be seen, the stick-slip phenomenon appears for all three directions, but there are noticeable differences for the values of the friction coefficient and for the amplitude and frequency of the stick-slip.

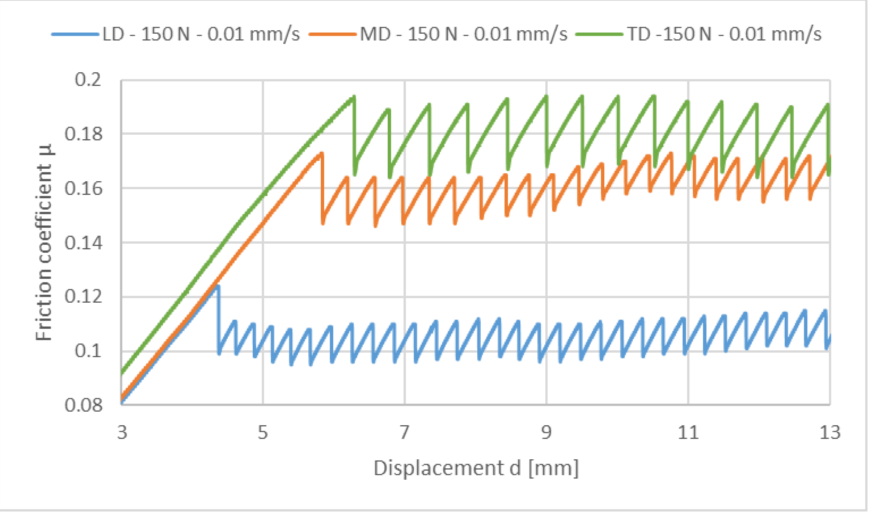

Fig. 5 – The variation of the friction coefficient vs. displacement for 0.01 mm/s relative sliding speed

The variation of the friction coefficient for the 0.05 mm/s relative sliding speed is represented in Fig. 6. Here we can see that for the transverse direction (TD - 90°) and median direction (MD - 45°) the stick-slip phenomenon still occurs, but in the case of the rolling longitudinal direction (LD - 0°) the stick-slip disappears and we have smooth sliding. It is mentioned that at the beginning of the smooth sliding there is an area of approximately 1 mm where there is a variation of the friction coefficient in the form of damped oscillations.

Therefore, in the case of the current testing set-up that has a rigidity of 7.159 N/mm and a contact pressure of 5.3 MPa, for the rolling direction the speed limit for the occurrence of the stick-slip is between 0.01 mm/s and 0.05 mm/s.

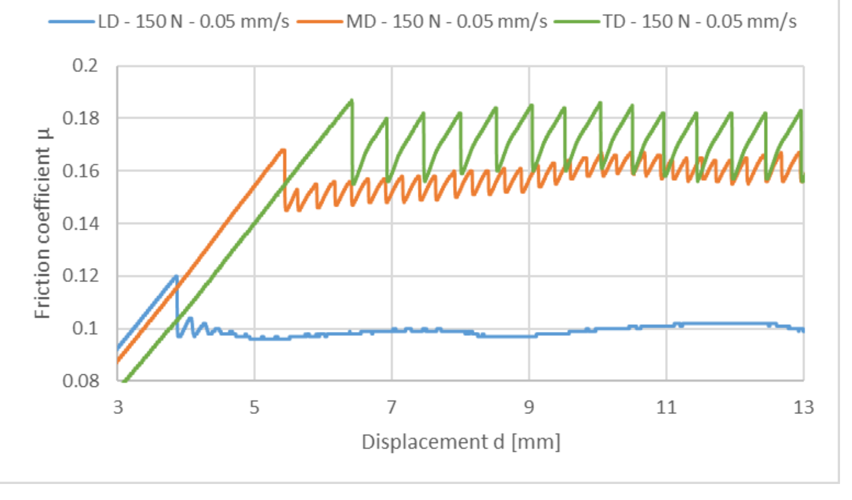

Fig. 6 – The variation of the friction coefficient vs. displacement for 0.05 mm/s relative sliding speed

Fig. 7 presents the variation of the friction coefficient for the 0.1 mm/s relative sliding speed. A 2-fold increase in speed does not affect the occurrence of the stick-slip phenomenon. For the transverse direction (TD - 90°) and median direction (MD - 45°) the stick-slip movement is still present, while for the rolling direction (LD - 0°) there is smooth sliding during the whole test.

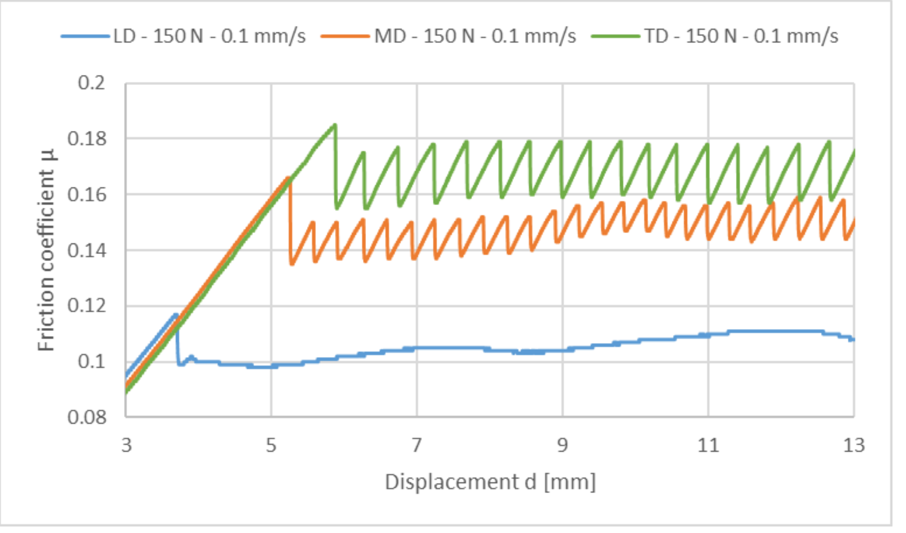

Fig. 7 – The variation of the friction coefficient vs. displacement for 0.1 mm/s relative sliding speed

The variation of the friction coefficient for the 0.5 mm/s relative sliding speed is presented in Fig. 8. This is the highest testing speed used for the current tests because, as it can be seen from the graphs, at this speed there is no more stick-slip movement for any of the three directions.

Hence, for the transverse direction (TD - 90°) and median direction (MD - 45°), the speed limit for the occurrence of the stick-slip is between 0.1 mm/s and 0.5 mm/s, five time greater than that for the rolling longitudinal direction (LD - 0°).

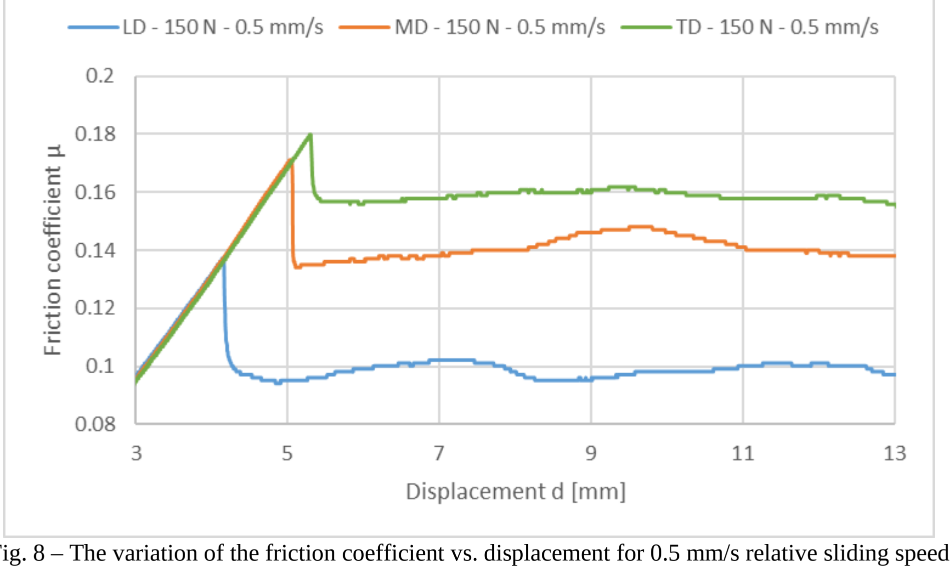

Fig. 8 – The variation of the friction coefficient vs. displacement for 0.5 mm/s relative sliding speed

For each test, the values of the characteristic parameters of the stick-slip phenomenon (maximum static friction coefficient – μ_{smax}, static friction coefficient – μ_s, kinetic friction coefficient – μ_k, mean value of the friction coefficient – μ_m and stick-slip amplitude – μ_v) have been calculated and are presented in Table 2.

Table 2 – The values of the characteristic parameters of the stick-slip

LD (0°)	Relative sliding speed [mm/s]			
	0.01	0.05	0.1	0.5
μ_{smax}	0.124	0.12	0.117	0.137
μ_s	0.098	-	-	-
μ_k	0.111	-	-	-
μ_m	0.105	0.096	0.103	0.096
μ_v	0.007	0	0	0
MD (45°)	Relative sliding speed [mm/s]			
	0.01	0.05	0.1	0.5
μ_{smax}	0.173	0.168	0.166	0.171
μ_s	0.152	0.153	0.141	-
μ_k	0.168	0.162	0.154	-
μ_m	0.16	0.157	0.148	0.14
μ_v	0.008	0.005	0.007	0
TD (90°)	Relative sliding speed [mm/s]			
	0.01	0.05	0.1	0.5
μ_{smax}	0.194	0.187	0.185	0.18
μ_s	0.166	0.158	0.158	-
μ_k	0.192	0.183	0.178	-
μ_m	0.179	0.171	0.168	0.158
μ_v	0.013	0.013	0.01	0

As can be seen in Figs. 9 and 10, the surface anisotropy of the AA2021-T351 aluminium alloy rolled thick plate has a significant influence on the characteristic values of the friction coefficient and on the stick-slip amplitude.

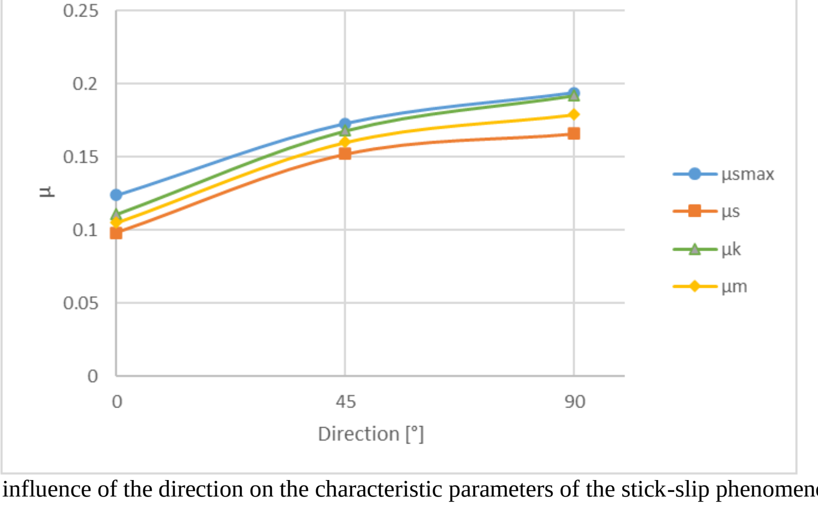

Fig. 9 – The influence of the direction on the characteristic parameters of the stick-slip phenomenon (sliding speed 0.01mm/s)

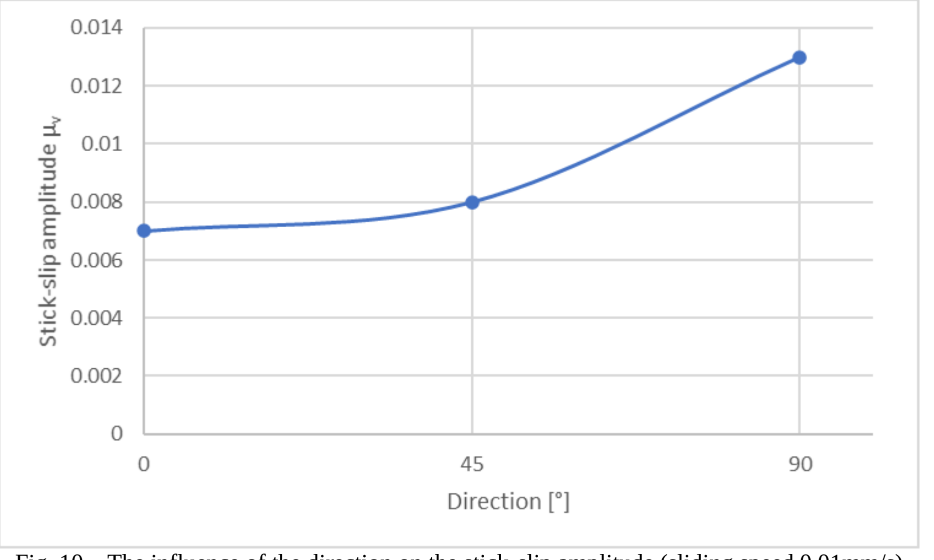

Fig. 10 – The influence of the direction on the stick-slip amplitude (sliding speed 0.01mm/s)

4. CONCLUSIONS

The results of the conducted tests demonstrate that the surface anisotropy of the AA2021-T351 aluminium alloy rolled thick plate influences the occurrence of the stick-slip phenomenon.

At the lowest relative sliding speed (0.01 mm/s) the stick-slip movement is present for all three directions (rolling longitudinal direction LD (0°), median direction MD (45°) and transverse direction TD (90°)). While increasing the sliding speed, the stick-slip movement gradually disappears. In the case of the current testing set-up, for the rolling direction the speed limit for the occurrence of the stick-slip is between 0.01 mm/s and 0.05 mm/s, while for the other two directions is approximately 10 times larger, between 0.1 mm/s and 0.5 mm/s.

The anisotropy of the AA2021-T351 aluminium alloy rolled thick plate has a significant influence on the characteristic values of the friction coefficient (maximum static friction coefficient – μ_{smax}, static friction coefficient – μ_s, kinetic friction coefficient – μ_k, mean value of the friction coefficient – μ_m) and on the stick-slip amplitude (μ_v).

The rolling direction has the lowest values of the friction coefficient and the lowest stick-slip amplitude. On the other hand, the transverse direction has the highest values and the highest stick-slip amplitude, while the median direction has values between the other two, as it would have been expected.

Therefore, it is recommended that the sliding should be on the rolling direction.

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