

# Evaluation of coefficient of friction in similar conditions to ejection of molding parts

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**ABSTRACT:** The injection molding is the technique most used for processing polymers. Nowadays, due to economic demands the ejection of the parts occur as soon as possible to lead to a short cycle times. The ejection stage is the most critical phase during the injection molding processing. During this stage, especially in deep core molding, it is possible the development high friction forces making difficult the ejection of the moldings without marks or other defects. The aim of this work is to assess the coefficient of friction between the part and the mould walls in conditions similar that occurs during the ejection in the injection molding process. The assessment of the coefficient of friction was carried out with the help of one apparatus that possibility this type of measurement. This equipment provides that measure under controlled conditions as test temperature, replication temperature, material of the mould, and superficial roughness. The obtained results with several polymeric materials (semicrystalline and amorphous) show that the tribological conditions have great influence on the coefficient of friction in static conditions.

## 1 INTRODUCTION

The technique most used to process parts with polymers is the injection molding. In these days, due to economic demands the ejection phase occurs as soon as possible to lead to a short cycle times. This stage is the most critical during the injection molding (Pouzada et al. 2006; Correia et al. 2011; Ferreira et al. 2002) especially in molds with deep cores (Pontes et al. 2005; Pouzada et al. 2006).

In order to understand what happens during the ejection of the parts in the injection molding is necessary to understand the tribological behavior of the materials. Tribology study the contact between two solid surfaces in movement. That movement produces effects such as friction, wear rate, adhesion, among others (Sinha & Briscoe 2009; Blau 2009). Friction is known as the opposition to the motion between two bodies in contact. For the determination of the coefficient of friction is necessary measure the normal force. This force is proportional to the friction force (Sinha & Briscoe 2009; Blau 2009). The coefficient of friction ( $\mu$ ) allow the characterization the movement resistance between two contact surfaces. This variable neither is a material property nor a physical constant (Blau 2009). It depends on some variables, namely sliding velocity, temperature, con-

tact pressure, properties of the materials in contact, superficial finishing, among others (Blau 2009). Another important variable that have influence in the coefficient of friction is the draft angle in the case of deep parts (Pouzada et al. 2006; Ferreira et al. 2002; Correia et al. 2011).

Important variables that have influence in the coefficient of friction and are covered in this paper are the type of mold, the part material, the roughness and the coatings of the molding surfaces.

Correia (Correia et al. 2011) carried out a study to understand the contributions and the mechanisms involved in the friction during the ejection in the injection molding process. It was studied the relevance of temperature, contact pressure and roughness in the coefficient of friction. During the work was concluded that friction force increases with the surface roughness and the contact pressure and reduces with the increasing temperature.

Pontes (Pontes et al. 2004) have studied the effect of the superficial roughness and the temperature on the static coefficient of friction of the pair ABS/steel. It was concluded that two variables are important in the control of the friction between two surfaces. There is an optimal surface roughness that corresponds to the minimum of the static coefficient of friction, when the ejection force is lower. It was

also concluded that the optimal surface roughness varies with the testing temperature.

Boey (Boey et al. 2005) studied the coating of the molds surfaces with DLC coatings and the use of techniques that implement ions in the nitrated steel. He concluded that the last one has much better properties than the simple nitrated steel. However he also concluded that DLC coatings showed the best performance and have a great potential in the industry.

## 2 EXPERIMENTAL

### 2.1 Materials

Five materials were studied in this work. The polymeric materials were PP ( Domolen 1100 L by Domo Chemicals), reinforced PP with 30 % of glass fibers (Domolen P1-01-V10-N by Domo Chemicals), PC (Lexan 123 R By Sabic), PS (Polystyrene 145 D by BASF), PMMA (Plexiglas 8N by Evonik Röhm GmbH).

The tested parts were produced in the Ferromatik-Milacron K85 injection molding machine with 85 ton of clamping force.

### 2.2 Equipment

The study consisted in measuring the coefficient of friction to evaluate the influence of various types of steel and coatings in the mold surface in the injection molding process. For this propose it was used a prototype equipment (Figure 1) described by Pouzada et al. (2006). This prototype was developed at Minho University to measure the coefficient of friction in ejection conditions and works assemble in a universal testing machine, Instron 4505, which records the data from the force to determine the coefficient of friction.



Figure 1. Testing apparatus for coefficient of friction measure.

The friction tests were performed at room temperature. The test time is about 15-20 min and includes the heating of the mould surface up to the

replication test, stabilization of the temperature, application of contact pressure, cooling down to the testing temperature and the realization of the friction test.

### 2.3 Stamps and coatings

The dimension of the stamps (Figure 2) used for this propose are  $55 \times 19 \times 8$  mm, with two types of different 1.2083 steel and a stamp processed with 1.2711 steel.

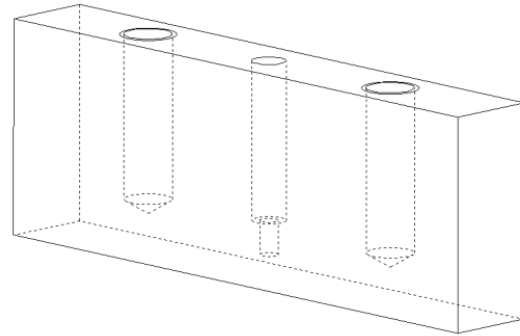


Figure 2. Technical design of the stamp.

To manufacture the stamps they were used EDM machining and EBM finishing in the test surface. The machined stamps were used to measure the coefficient of friction, then were coated with near frictionless coatings, PTFE and  $WS_2+C$ . The coating of the stamps was realized to understand the influence of the coating in the coefficient of friction.

## 3 RESULTS AND DISCUSSION

To promote a better way to organize the obtained data the stamps have the following nomenclature (Table I).

Table I. Stamps nomenclature

Nomenclature	Stamp
A	1.2083 coated with PTFE
B	1.2083 after re-processing
C	1.2083 Supra
D	1.2083 coated with $WS_2+C$
E	1.2083 coated with PTEF gradient
F	1.2711

### 3.1 Reproducibility of test

For all stamps and polymeric materials they were performed five tests under the same test conditions. In Figure 3 it is presented a typical graph obtained by the universal testing machine. This graph repre-

sents the measured force, frictional force, afterwards used to calculate the coefficient of friction between the stamps and the polymeric material.

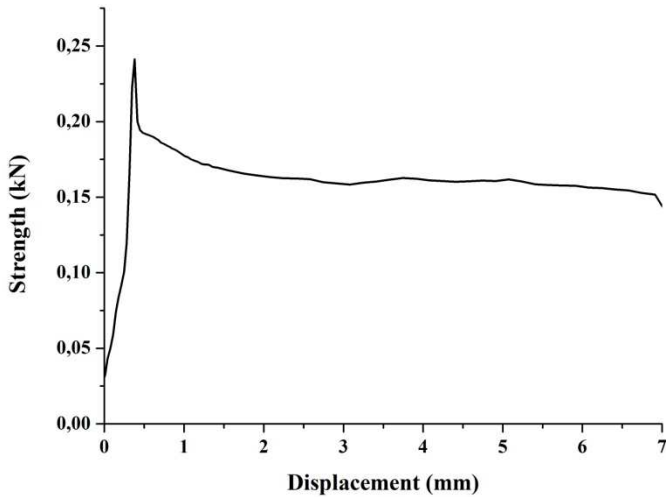


Figure 3. Graph from the coefficient of friction tests.

The maximum value obtained in the graphs (similar to Figure 3) is used for the determination of the coefficient of friction, since this is the most critical moment of the ejection stage in the injection molding process. This force represents the friction force.

### 3.2 Type of steel

In the Figure 4 it is shown the influence of the steel on the coefficient of friction.

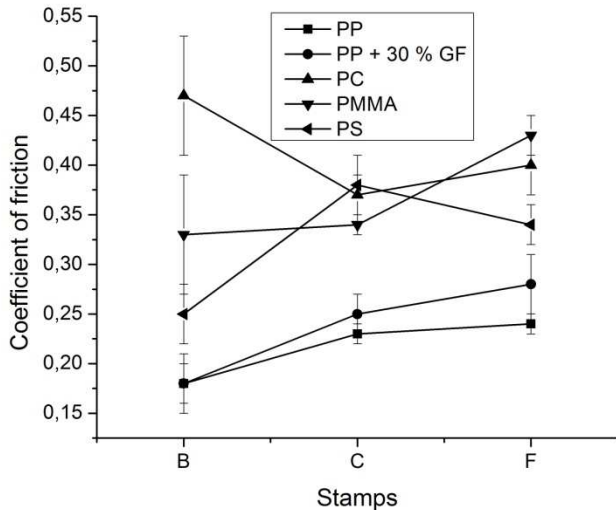


Figure 4. The effect of Steel of the stamp on the coefficient of friction.

In the Figure 4 it is possible to verify that the tested materials have different coefficients of friction. It was possible to observe that PP, reinforced PP had a behaviour similar to each other and that PS led to the higher values. The coefficient of friction of PMMA is almost constant with the stamp B and the stamp C. Among the stamps C and F it was verified an increase of about 0.10 on the coefficient of friction. In the case of PC the coefficient of friction

decreased when changing from stamp B to stamp C and increased in the case of the stamps C and F.

### 3.3 Coating effect

The results of the tests carried out with the stamps manufactured with different types of steel are presented in Figure 5 and Figure 6.

In the case of the 1.2083 steel coated with PTFE (A) and PTFE gradient (E) the results are shown in the Figure 5. In Figure 5 it is possible to observe that the stamp manufactured with the 1.2083 supra steel without coating is the one that promotes smaller coefficients of friction for PP and reinforced PP.

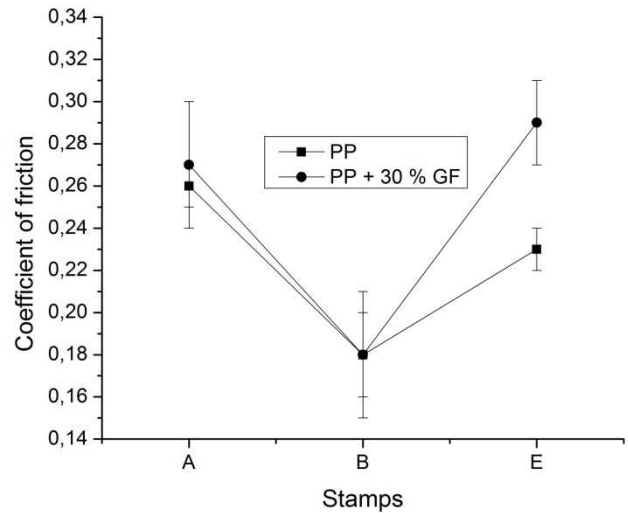


Figure 5. Influence of PTFE coating in the 1.2083 steel.

For the 1.2083 steel (Figure 6) it was observed that for all materials the stamp without the coating promotes less coefficient of friction than the stamp coated with  $WS_2+C$ .

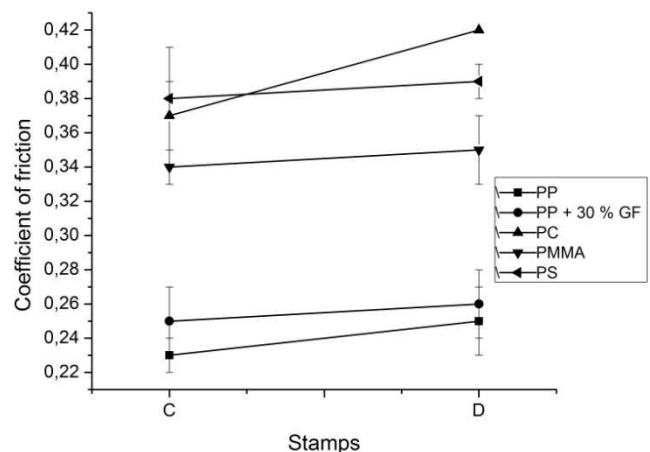


Figure 6. Influence of the  $WS_2+C$  coating in the 1.2083 supra steel.

### 3.4 Polymer material effect

The type of polymer materials also has influence on the coefficient of friction. Figure 7 shows the effect of the type material, PP (semicrystalline polymer)

and PS (amorphous polymer), with the two stamps that led to a smaller coefficients of friction.

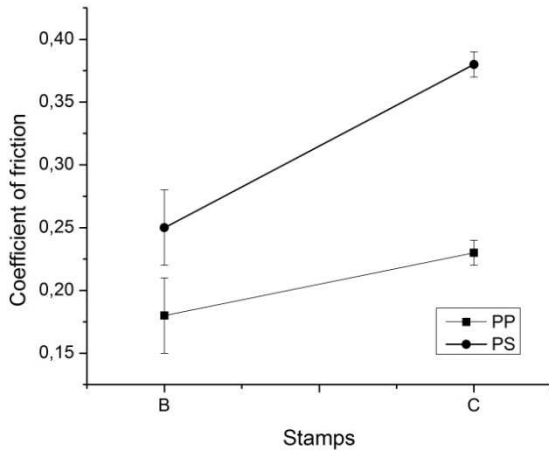


Figure 7. Effect of the type of polymer material.

It is possible to observe that the two polymer materials behave differently. For the two stamps PP has a coefficient of friction lower than the PS.

### 3.5 Stamp coatings vs different polymer materials

Different polymer materials had different behaviors during the molding process with different types of coatings in the mold. As it was discussed before it is possible to observe in Figure 8 that the coating of the stamp led to a larger coefficient of friction. In any case the coefficient of friction on demoulding PP is lower than in the case of PS.

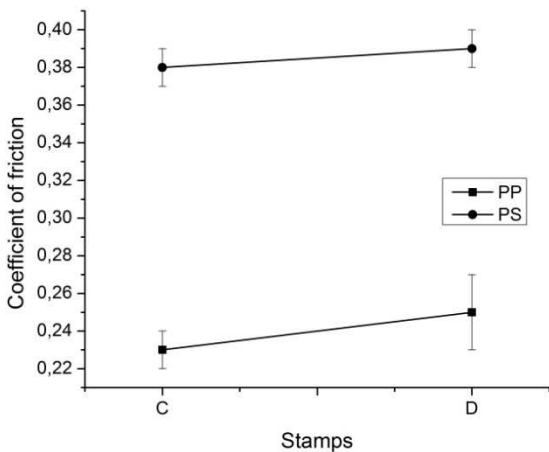


Figure 8. Type of polymer and stamp with and without coating of WS<sub>2</sub>+C.

The effect of the different types of coatings for PP and PC is shown in Figure 9. The WS<sub>2</sub>+C coating promotes higher coefficient of friction than the stamps coated with the gradient of PTFE.

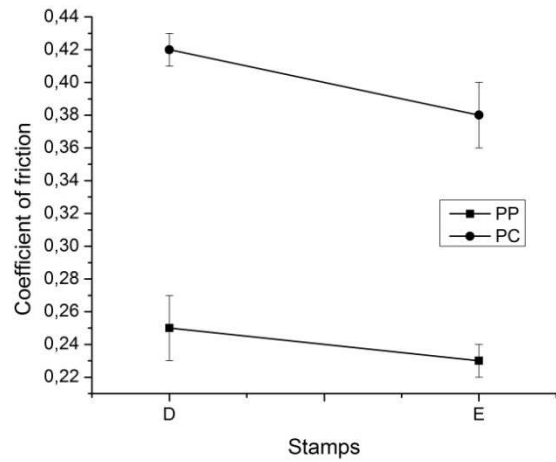


Figure 9. Effect of different type of coatings.

## CONCLUSIONS

Analyzing the tests performed to assess the coefficient of friction it is possible to observe that the different types of steel and polymer materials had different types of responses.

The steel 1.2083 leads to lower coefficient of friction than the 1.2083 supra steel in the case of PP and PS.

Stamps with test surfaces without coating promote less coefficient of friction when compared with the same steel covered with the studied coatings.

Semicrystalline polymers, such as PP, in contact with the steel during the ejection stage had less coefficient of friction than amorphous polymers, as PS.

With respect to the coatings, the coefficient of friction is lower with gradient of PTFE coatings than with WS<sub>2</sub>+C coatings.

## ACKNOWLEDGEMENTS

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