THE EFFECT OF TEMPERATURE AND SURFACE ROUGHNESS ON COEFFICIENT OF FRICTION BETWEEN THERMOPLASTICS AND MOLDING SURFACES.

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Abstract - Key issues in the design of injection moulds are the design of the impression and the gating system. Other functional systems require particular attention in precision moulds, namely cooling, guidance and ejection.
In the ejection phase of injection molding process the molding parts are mechanically forced to separate from the molding surfaces, this aspect being more relevant when deep cores are involved. The performance of the ejection system depends on factors that must be considered in the design stage of the tool, namely, the draft angles, the surface finish, and the properties of the molding material at the ejection temperature and the dimensioning of actuation devices (e.g. hydraulic or pneumatic cylinders). Furthermore, the knowledge of the friction properties of the mating pair: mould surface (typically steel) and part (plastics), is important to optimize the ejection system solution. The coefficient of friction between plastic/steel at the ejection stage depends on variables, namely the surface texture of the core and the temperature at ejection.
This paper assesses the results of static coefficient of friction of three thermoplastics. The results were obtained with a prototype apparatus that reproduces the conditions occurring during the ejection phase. Focus is made on the effect of the roughness and the temperature at ejection.

Introduction

Injection moulding is one of the major processes in the production of plastics parts. Consequently, the exigency degree on the conception and production of injection moulds increases, in accordance with the required product quality.
During injection moulding, the material is exposed to a thermomechanical cycle. The material, initially on the solid stage, is heated up to its melting point – plasticization – and injected to fill completely the mould impression – injection. Subsequently, the part is cooled and extracted - ejection.
For the correct ejection system design, it is important to know the forces occurring involved in the ejection phase. One the major issues on the prediction of the ejection is the assessment of the coefficient of friction on similar conditions that occur during ejection.
The coefficient of friction between polymer and mould surface depends on factors, such as the physical and chemical interactions on the surface of the contacting materials. On the other hand, these interactions depend on temperature, pressure and material.
Malloy et al. [1,2] show that the coefficient of friction between the part and the mould core does have a significant influence on the ejection process. Sasaki et al. [3] studied the effect of the core roughness and injection pressure on the ejection force, to clarify the factors that cause it to increase. Pontes et al. [4] reported the existence of an optimal surface roughness when the ejection force is lower, using a special mould that produces a lateral gated tube.
Recent prototype equipment was developed that enables the assessment of the coefficient of friction in conditions similar to that occurs during the ejection of injection moulding parts [5,6]. Furthermore this equipment enables the study of the effect of parameters on the coefficient of friction on ejection, namely: the replication of the surface finish, the testing temperature, the contact force, and the test speed.
In this work the effect of surface roughness and temperature on the coefficient of friction in conditions similar occurring during ejection of a injection moulding part is analyzed.

Experimental

Three thermoplastic were used (two amorphous, ABS and PMMA, and one semi-crystalline, HDPE) to produce 2 mm thick injection-moulded square testing specimens ($6{,}25\times6{,}25$ mm^2). The testing specimens, half of the mouldings, were cut from these mouldings.
The normal contact force applied by the pneumatic cylinder was set to *ca.* 390 N.
The material of the moulding surface in contact with the polymer specimen was a standard tool steel (DIN Ck 45).
The testing routine for the determination of the coefficient of friction is described elsewhere [5].

The replication temperature shown in table 1 for each material was applied after some preliminary tests to find the adequate temperature that enables a suitable surface replication.
In order to analyze the effect of temperature and surface finish on the coefficient of friction, different testing temperatures (Table 1) and four steel specimens with different height roughness (0,5; 1,6; 3,0; 9,0) was tested. For each condition five specimens were tested. The roughness was measured in the testing direction.

Results and Discussion
The effect of surface roughness and testing temperature on the coefficient of friction is shown in figure 1 to 3, for ABS, HDPE and PMMA, respectively.
The results indicate that the selected parameters in the range of study do result in significant effects over the coefficient of static friction. Moreover, the higher testing temperature leads to the increment of the value of the coefficient of static friction. The results also show the existence of an optimal surface roughness when the coefficient of static friction is lower.

Table 1 – Testing and replication temperatures

Material	Replication Temperature (ºC)	Testing Temperature (ºC)
ABS	110	30, 60, 90
HDPE	130	30, 50
PMMA	110	30, 60

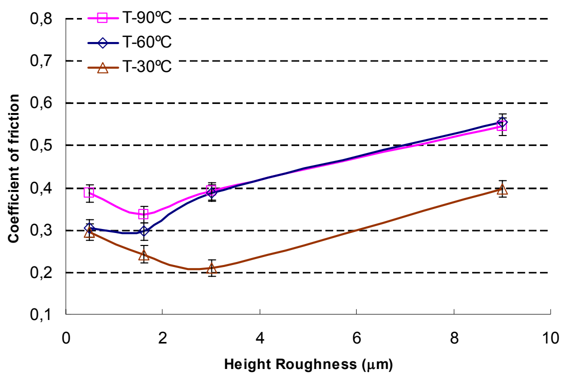

Figure 1 – Evolution of the coefficient of friction - ABS

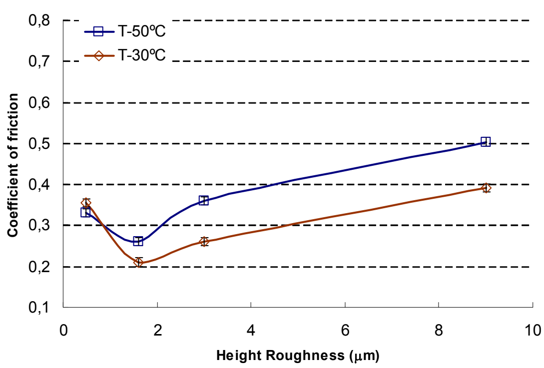

Figure 2 – Variation of the coefficient of friction - HDPE

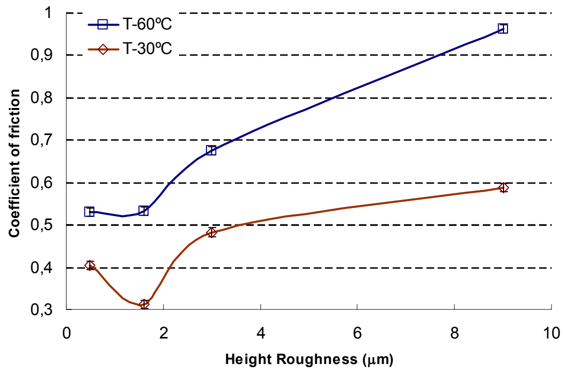

Figure 3 – Evolution of the coefficient of friction - PMMA

Conclusion
The results confirm that the testing temperature and the surface roughness are important in the characteristics of friction behaviour.
Preliminary results on the ejection forces [4] showing an optimal surface roughness when the ejection force is lower, were confirmed in this work. This optimal surface roughness corresponds to the minimum of the coefficient of static friction.
It is also concluded that the increase of testing temperature leads to a higher coefficient of friction and that the optimal surface roughness depends on the testing temperature.

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