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Effects of different mold surface coatings on the ejection force in micro injection molding

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Abstract
The effects of different mold coatings on the ejection force in micro injection molding was experimentally investigated for a selection of thermoplastic polymers, at different molding conditions. Two diamond like carbon (DLC) and chromium titanium niobium nitride (CrTiNbN) coatings were selected in accordance with their potential affinity with the considered injected polymers. A specific mold cavity was designed, manufactured by micro milling and characterized (both topography and geometry) in order to isolate the effect of polymer adhesion on the ejection force. The obtained results were then correlated with the adhesion work for all the combinations of injected polymers and surface coatings. The results indicated how an optimum mold coating, which minimizes the ejection force for a specific polymer, should be selected considering its wettability properties.

Micro-injection molding, coatings, wettability, ejection force

1. Introduction

The quality of micro injection molded parts can be negatively affected by the friction force developed during the demolding phase [1]. Ejector pins can apply high local stresses to the part, causing possible distortion, stress marks and fractures. The successful manufacturing of plastic micro parts, characterized by high precision and good tolerances, requires to consider how the demolding force can be reduced [2,3]. In this sense, many studies in the literature focused on the optimization of mold surface properties, aiming at improving their interaction with the polymer during processing. Several strategies have been introduced in the literature aiming at the reduction of both the friction and adhesion between the tool and the polymer [4,5]. In particular, mold surface coatings have proven to be a viable solution to improve the tribological conditions at the part-tool interface for both the filling and the ejection phases [6,7].

In this work, the effects on the demolding force of three different mold coatings (viz. diamond like carbon coatings and chromium titanium niobium nitride) were experimentally investigated. The µIM experiments were carried out using different polymers (PS, POM and PA6) in order to evaluate the effects of the different chemical interactions at the interface. The tribological conditions during the ejection phase were monitored by acquiring the online demolding force signal. Moreover, the wetting properties of the three polymers over the different coatings were evaluated measuring the contact angle of the melt polymers over the coated surfaces.

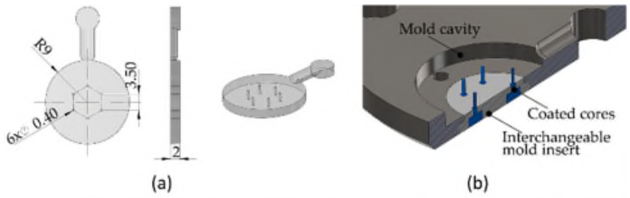

Figure 1. (a) Design of the study part – all dimensions are expressed in millimeters; (b) design of mold cavity and interchangeable insert.

2. Experimental

2.1. Mold design and manufacture

The part considered in this study is a cylinder with a diameter of 18 mm and a thickness of 2 mm characterized by six through micro holes (Fig. 1(a)). The design exhibits the typical features (i.e. through holes) of a multi – layer microfluidic device and allows the isolation of the effect of mold cores surface properties on the demolding force (Fig. 1(b)). In order to produce the diversely coated mold inserts, five identical sets of mold cores were machined combining micro electrical discharge machining (µEDM – Sarix, SX200) and micro milling (µM – Kugler, Micromaster 5X). Three different surface coatings technologies were selected for the experiments: (i – ii) diamond like carbon (DLC), and (iii) physical vapor deposition (PVD) of CrTiNbN.

2.2. Mold characterization

The surface texture of the cores was characterized using a 3D optical profiler (Sensofar, Plu Neox) operating in confocal mode with a 20X objective. Several roughness parameters were evaluated according to ISO 4287:1996 and ISO 13565-2:1996. Moreover, the wettability of the three polymers used for the µIM experiments (PS, POM, PA6) was evaluated by monitoring the contact angle of the melt polymer over the different coatings [8].

2.3. Micro injection molding experiments

Three polymers were selected for the µIM experiments: polystyrene (Total, PS Crystal 1540), polyoxymethylene (Basf, POM, Ultraform H2320) and polyamide 6 (BASF, PA6, Ultramid A4H). The force variations during the ejection stage were monitored using a Kistler 9223A piezoelectric force transducer positioned in contact with the three ejector rods.The effects of the selected mold surface coating on the demolding force were investigated for the three polymers by conducting some µIM experiments. A constant selection of µIM process parameters was adopted with exceptions for the melt and mold temperatures, which were set to proper values for each polymer. The demolding force peak F_{peak}, which represents the maximum load stressing the molded part during the demolding phase, was selected as the response variable for the analysis.

3. Results and discussion

3.1. Mold surface analysis results

The results of the mold surface characterization (Table 1) show how coatings affect both the presence of protruding peaks in the surface (*Sz*) and the overall roughness of the mold surface (*Sa*). The Abbott-Firestone curves were also evaluated, allowing the determination of the functional parameters *Sk*, *Spk* and *Svk*. In fact, the curve provides information about the material protruding and the voids characterizing the surface, thus being important to study the potential replication behavior of the µIM process [9]. The values of these parameters are comparable for all the coated inserts, while they are significantly different for the uncoated. The results of the wettability analysis conducted for the selected polymers and the coatings indicate that PA6 has a higher contact angle with all the coatings. The wetting behavior is more marked (i.e. higher interaction with the coated surface) for POM and even more PS, which had the smallest average contact angle.

3.2. Micro injection molding results

Considering the effects on the ejection force peak of polymer selection it was observed that the demolding friction is minimized when molding POM. In particular, when molding it instead of PA6 and PS the demolding force decrease by 26% and 41%, respectively.

The wetting behavior of each polymer over the differently coated surfaces was observed to be different, thus explaining the effects of polymer selection. When molding PS, the demolding force is maximized by the low value of the contact angle, which is responsible for the high interface interaction. In general, the tribological conditions at the part-tool interface are affected by the chemical adhesion at the interface but also by the rheological properties of the polymer melt. In fact, the viscosity represents the ability of the polymer to replicate the mold surface topography during the pressurized filling phase. When filling the cavity, the polymer melt can replicate the texture of the mold and, therefore, produce interlocking between the two surfaces, causing an increase of the force required to initiate the sliding of the solidified polymer. Moreover, the results indicate that for each polymer selection, the demolding force peak is also affected by the different surface treatments. For each one of the selected polymers, the effect of the mold coating on the demolding force was different, thus providing further evidence about the importance of the chemical adhesion at the interface.

Table 1 Average values and standard deviations of surface roughness parameters evaluated according to ISO 4287 and ISO 13565-2.

Coatings		***Sa*** **[µm]**	***Sz*** **[µm]**	***Sk*** **[µm]**	***Spk*** **[µm]**	***Svk*** **[µm]**
Uncoated	Avg.	0.08	2.57	0.19	0.11	0.16
	SD	0.02	0.47	0.04	0.04	0.05
DLC1	Avg.	0.13	3.24	0.34	0.17	0.20
	SD	0.03	0.39	0.05	0.05	0.06
DLC2	Avg.	0.12	3.54	0.30	0.16	0.19
	SD	0.02	0.23	0.04	0.04	0.05
CrTiNbN	Avg.	0.13	3.77	0.31	0.19	0.21
	SD	0.02	0.25	0.06	0.05	0.06

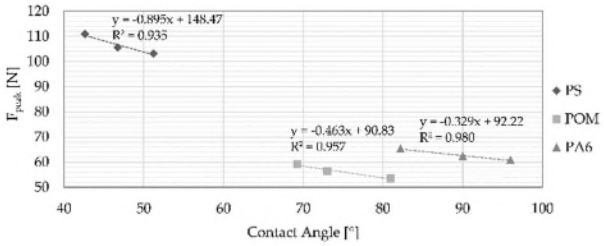

Figure 2. Correlation between contact angle and ejection force;.

Fig. 2 shows the interaction between the measured contact angles (CA) and the ejection force for the different polymers and coatings, indicating that higher values of the contact angle correspond to a lower demolding force. In fact, two materials showing high interfacial tension are easier to separate14. Moreover, a good linear regression (R^2~1) between the value of the contact angle and the demolding force peak was reported.

4. Conclusions

The main objective of this study was the investigation of the impact of different mold surface coatings on the demolding force in micro injection molding. The results of the µIM online acquisitions showed that the demolding force peak is affected by both polymer and coating selection. For each one of the selected polymers, the coatings yield different ejection force. Hence, indicating the effect of the chemical adhesion occurring, during the process, at the interface when the melt polymer wets the surface of the mold. This was supported by the results of the wettability analysis, which showed different contact angles over the different coatings. Specifically, a good linear regression (R2~1) was observed between the value of the contact angle and the demolding force peak, supporting the hypothesis that two materials showing high interfacial tension are easier to separate.

The maximum forces were observed when molding PS that is characterized by the smallest contact angle. Conversely, they were minimized when molding POM. However, compared to PA6, POM shows higher chemical adhesion (i.e. smaller contact angle), but its demolding force was higher. This is explained by the higher viscosity of POM that leads to a lower replication of mold topography and to a consequently weaker mechanical interlocking at the interface. Indeed, the understanding of the interface phenomena affecting demolding must also consider the interacting effects of polymer rheological properties and mold roughness (i.e. higher presence of void volumes).

References

[1] Heckele M and Schomburg WK, 2013, *J Micromech Microeng* **14**(3):R1
[2] Marson S, Attia UM, Lucchetta G, Wilson A, Alcock JR, Allen DM, 2011, *J Micromech Microeng* **21**(11), 115024.
[3] Masato D, Sorgato M, Parenti P, Annoni M, Lucchetta G, 2017, *J. Mat. Proc. Tech.*, **246**, 211-223.
[4] Dearnley PA, 1999, *Wear* **225**, 1109-1113.
[5] Stormonth-Darling JM, Pedersen RH, How C, Gadegaard N, 2014, *J Micromech Microeng* **24**(7), 075019.
[6] Lucchetta G, Masato D, Sorgato M, Crema L, Savio E, 2016, *CIRP Ann-Manuf Techn* **65**(1), 537-540.
[7] Griffiths CA, Dimov SS, Brousseau EB, Chouquet C, Gavillet J, Bigot S, 2010, *Int J Adv Manuf Tech* **47**(1-4), 99-110.
[8] Sorgato M, Masato D, Lucchetta G, 2017, *Microsystem Tech.*, **23**(7), 2543-2552.
[9] Sorgato M, Masato D, Lucchetta G., 2017, Prec. Eng. 50, 440-448.