Influence of Rheology on Part Dimensions and Production in Injection Molding
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Abstract
The present work was conducted to assess the influence of polymer viscosity variation from batch to batch on the part dimensions and production interruptions. The results show however that parameters such as mold temperature, barrel temperature profile and holding pressure have much more influence on these two production quality indicators than the polymer viscosity.

Introduction
Industrial use of polymers is confronted with the batch to batch variation of the base material. Despite the fact that they are synthetic materials, the fabrication process of polymer produce large variation of characteristics that might impact the parts with which they will be produced. In this paper we review the influence of batch to batch variation of the MVR (Melt Volume Rate) from a PA 6T/66 50 %GF (Grivory HT2V-5H Natural | PA6T/66-GF50) on the part dimensions and process stability. The investigations were conducted using DOE’s (Design of Experiment) to assess the influence of the plastic variation on the injections parameters and the produced parts. Injection simulation using the Moldflow® software were also used to control shear stress value and process parameters to keep them in the boundaries of the manufacturer values. Other properties variations of the polymer were not considered at first, besides its water content, as they were not readily available from the producer. Moreover, the MVR value was considered as the most influential parameter as far as injection process is concerned.

Materials & Methods
The PA material was obtained in 4 different batches with MVR (measured at 330°C with 10 kg) varying from 64 ml/10 min up to 123 ml/10 min (ISO 1133).

MVR and Viscosity
The typical industry standard to indicate “ease of flow at a specific temperature” is MVR. The given MVR values by the manufacturer are measured according to the ISO 1133:2005 norm. The issue with MVR measurement is that they are measured at very low shear rate (10 s⁻¹ – 500 s⁻¹) whereas in the injection process the polymer is deformed with very high shear rate (typically between 10'000 s⁻¹ and 50’000 s⁻¹)[1]. For most thermoplastics, the effective viscosity differences between the batches is much lower than it appears from the values given by the MVR measurement method. To more clearly assess how rheology affect the processing conditions we measured the viscosity of our four batches by capillary rheometer with programmable shear rates up to 20'000 s⁻¹. By applying the Bagley and the Rabinowitch [2] corrections we were able to determine the true wall-shear rate viscosity values in near injection shear rate conditions. It should be noted that only apparent viscosity values may be calculated from MVR values with the implicit assumption of a homogeneous laminar shear flow. However the MVR values could be quite useful as they can be linked to the viscosity curves [3].

Test Part Design
To determine the effect of viscosity variations on the part dimensions, we designed a part (figure 1) enabling to ease both the flow simulation work and the part processing and performance analysis.

The overall injection molding process parameters were kept constant to ensure that the viscosity effects could be determined. Subsequently processing parameters were modified following a DOE approach as described below. All the injection processes were conducted with the same mold on the same injection machine an Arburg™ 270s 500/250.

The parts were measure with a highly reproducible protocol. A holder was designed to ensure each part was always placed exactly in the same position to record and assess potential part dimension variations.

![Figure 1. Test Part design and Dimension References](image)

**Design of Experiment (DOE)**
In order to determine the most influential variables that trigger the production problem, (size variations and/or production cycle disruption) two DOE procedures have been used. The large number of variables in an injection
process requires a systematic approach to decide whether the injection machine setup or the viscosity change of the PA material has more weight in the observable part dimensions and performance. DOE procedures are well suited for this purpose. However the splitting of the experiment in two separate DOE’s is a common feature to simplify the work load [4]. The key variables chosen for the DOE for dimensional changes setup were

- A: Batch viscosity
- B: Mold temperature
- C: Temperature profile in the barrel
- D: Holding pressure

A second DOE with a slightly different set of variables was used to assess the observed production disruption by machine nozzle obstruction they were

- Batch viscosity
- Mold temperature
- Nozzle Temperature

Evidently the holding pressure is irrelevant for that investigation.

**Results**

**Viscosity**

The true wall shear rate viscosity measurements results on three of the four batches presented a discrepancy in relation to the MVR values as well the reference ranges found either in Moldflow® database [4] or in the CES program from Granta Design® [5] (Figure 2).

These results suggested that the PA’s residual water content was an issue. Despite the fact that the PA’s were dried according to manufacturer prescription: 80°C for 8 hours, they showed much higher water content than recommended. EMS Chemie AG® sets a water content limit @ 0.1% to guarantee consistent molding process. Figure 3 shows the water content of the different batches after 8h drying time, the one with the MVR of 123 after 24h, 48h, 72h and 96 h of drying. The batch with a MVR 64 has been measured from a new bag showing the original moisture content.

These results show that the drying period of rather old products could be much longer than recommended. Subsequently it raises the question of the possible effects of long(er) drying procedures on the mechanical properties of the PA’s final application.

The true wall shear rate viscosity measured after the moisture content has been brought under the threshold are shown in figure 4 for the extreme batches. They match with the predicted values from both Moldflow® and CES from Granta Design.

![Figure 3. Moisture content after drying for 3 old batches of EMS® Grivory HT2V-5H Natural | PA6T/66-GF50 with different MVR and one new batch with MVR 64.](image)

![Figure 4. Comparison between Viscosity vs Shear Rate and MVR Values](image)
Part Dimension Variations

With the first DOE, we investigated the part dimension variations in relation with the first set of the defined variables.
The results are shown in figure 5. The most influential variables are the temperature profile in the barrel and the holding pressure. It becomes obvious that the viscosity variation of the different PA’s doesn’t have a significant effect on the part dimensions. It can be observed that the higher the barrel temperature and/or the holding pressure, the lower the shrinkage.

![Figure 5. Results of the DOE on part dimensions influence of variables A: Viscosity B: Mold Temperature C: Barrel Temperature Profile D: Holding Pressure Level](image)

Production Disruption

The results of the second DOE are shown in figure 6. They assess the influence of the batch viscosity on the machine nozzle obstruction risk leading to production stops. This situation is observed in the industrial use of these materials as well as in the production of our test parts [4]. Likewise to the first DOE, it appears that the batch viscosity is not the most important variable for preventing production stops. It is equally important to work with a high barrel temperature profile but foremost with a mold temperature as high as possible.

![Figure 6. Results of the DOE on Nozzle Obstruction Risk A: Viscosity B: Mold Temperature C: Barrel Temperature Profile](image)

Discussion

The results of the present work show that the batch to batch viscosity may not be a major factor in the process stability of the injection molding. All the PA manufacturers are known to deliver material within a wide viscosity range. We could show that, although it has some effect on the processing stability, it is manageable in an industrial production environment. The key processing condition settings are far more important to the parts dimensional consistency and the production disruption requiring a process stop and time consuming cleaning effort. Setting the barrel temperature and the mold temperature at the high end of the recommended temperature by the manufacturer of the provided PA the best production performance overall.

![Graph showing shrinkage difference](image)

Conclusions

The influence of PA batch to batch rheology variation on the part dimensions and production stops is a factor manageable in continuous industrial injection molding operations. More importantly this work shows that variables such as mold temperature, barrel temperature profile and holding pressure have much stronger impact. A further finding was that long open batches of the Grivory® PA will not be dried correctly by following the manufacturer’s recommendation. The final residual water content will significantly change the PA viscosity to a larger extend than the original batch to batch variation.

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References


