Micro-injection molding (VE)

When Moldflow (or Moldex) is used to predict the flow pattern, the pressure, the weight, the shrinkage (the final dimensions) and warpage for very thin and small parts (micro-injection molding), discrepancies between predictions and actual measurements are expected, the main reasons being:

- **High shear rates** : the shear rates in micro-injection molding are much higher (> 1E6 1/s) than those typically measured. This makes the extrapolation of the viscosity curves questionable, especially since a Newtonian plateau and/or a shear thickening effect might theoretically occur at such high strain rates when all the molecules have disentangled (so-called infinite shear viscosity plateau). Additionally, the extensional /elongational flow (and all entrance effects) become(s) significant (directly affecting the pressure). For a fiber reinforced grade, we may expect significant fiber breakage as well.

- **Shear heating** : at extremely high injection speeds, shear heating, which is proportional to the square of the shear rate, can cause the actual melt temperature to differ significantly from the set or expected temperature.

- **Switch-over point variability** : with high speeds, the "switch-over point" (does it still make sense?) may vary, leading to inconsistent amounts of polymer entering the cavity during the filling phase. This can cause fluctuations in shot weight and affect shrinkage and warpage due to varying pressure levels and extreme cooling rates.

- **No-slip boundary assumption** : at high shear rates, the no-slip boundary assumption might be no longer valid (when exceeding a critical wall shear stress). It is mainly due to *flow-induced chain detachment/desorption* at the polymer/wall interface. This effect becomes more pronounced as the melt temperature increases and micro-channel size decreases, resulting in a greater apparent viscosity reduction not accounted for in commercial tools. This assumption is also questionable if a second Newtonian plateau is expected/observed since this would result in huge shear stresses (viscosity x shear rate) at the wall!

- **Surface tension** : surface tension, often neglected in macro molding, plays a role in filling micro structures but is not considered in current simulation tools.

- **Thermal gradients and cooling rates** : accurate prediction of thermal gradients and cooling rates is crucial in micro-injection molding. The rapid heat transfer and cooling in micro-scale parts are typically poorly predicted. A constant heat transfer coefficient (HTC) is usually assumed based on measurements from macroscopic injection molding parts, which may not be appropriate for micro-scale thermal exchange.

- **Semi-crystalline polymers** : for semi-crystalline polymers, high cooling rates can result in the polymer being partially or completely amorphous, directly affecting shrinkage and warpage.

- **Amorphous (unfilled) polymers** : high shear rates can lead to significant molecular orientation in amorphous unfilled polymers, potentially affecting shrinkage and warpage, which is not accounted for in simulations.

- **Jetting and inertia effects** : at very high injection speeds, jetting may occur at the sprue level and in the cavity. Inertia forces dominate over viscous forces (Reynolds number >1), so inertia effects should be included in the calculations (this is possible with Moldflow).

- **Non-return valve** : ensuring that the non-return valve (check ring) prevents any backflow is crucial due to the speed and high molding pressure.

- **Injection profile** : it is recommended to apply a "ram speed versus ram position" injection profile instead of a constant injection speed in calculations for more accurate pressure predictions. Using the piston/screw position data also allows for the inclusion of the total volume of polymer melt in the injection chamber in compression calculations.

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So clearly, the predictions with the current tools are challenging and it is important to keep in mind the above-mentioned points. Some "quick trials" (definitely not an exhaustive study) were performed in 2020 (ADL, CTD) at IKV (Aachen, Germany). A summary is presented **here** .