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To know how it works

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TO KNOW HOW IT WORKS

VISCOSITY MEASUREMENT IN THE INJECTION MOLDING PROCESS. The know-how about the flow behaviour of the plastic melt is crucial in plastic manufacturing and processing as well as in recycling: raw material characteristics can be illustrated and property changes of the plastics caused by degradation or cross linking can be detected. This knowledge is also needed for rheological calculations, quality assurance and the control of the manufacturing process. To obtain this knowledge during injection molding, the Swiss manufacturer Sulzer Werfo uses online monitoring.

Sulzer Werfo deals with development und manufacturing of plastics parts for discharge and application systems of 2 component materials for applications in the dental or industrial sector such as casting compounds, cements or bleaching products. Thereby mainly two liquid substances are mixed or discharged in static or dynamic mixers. The high quality requirements for the mixture cause complex mixer geometries with particular expensive mold technology. To guarantee a safe production of the mixer elements with always the same part quality, an ongoing monitoring of the melt viscosity is necessary.

Characterize flow behaviour

To date the flow behaviour of plastic melt is characterized by various methods: The viscosity is measured with rheometers and displayed in flow curves. These flow curves show the viscosity as a function of shear rate and temperature whereas always isothermal conditions are assumed. The behaviour can also be demonstrated with more simplified methods such as the determination of the melt flow rate (MFR) or the melt volume rate (MVR), the flow spiral test or the determination of the solution viscosity. These methods however give only indirect information on the melt flowability during production and do not allow a continuous quality monitoring.

Know-how about the melt viscosity in the mold cavity as a function of temperature and shear rate is essential for process optimization in injection molding. Hence mechanical characteristics of the part as well as requested machine capacity or the flow path / wall thickness ratio can be evaluated.

By continuously further development of the processes, the mold technology and the complexity of the final product, a constant and a tightly tolerated flowability must be guaranteed. But the common examination of the viscosity differs considerably from the requirements of the injection molding process.

Prerequisite for a significant monitoring and detection of the viscosity is the inclusion of parameters with the biggest influence: the melt flow velocity and the cavity pressure.

Determination of viscosity by the injection molding machine

Injection molding machines have already been used in the past to detect viscosities by measuring capillaries which have been placed in front of the nozzle. This method is due to the different geometry of the nozzles, expensive and not very practical. Flow figures such as injection work or injection integral give also indirect information about the actual viscosity but without including the effective conditions in the mold or the cavity. For all these processes a pressure measurement in the hydraulic or in the nozzle of the machine is necessary. The advantage of indirect characteristics is that the measurement and the calculation occur online and thus give information about the general flow behaviour during the process. However this information is rather focused on the machine and not on the flow behaviour in the mold cavities.

Assuming that these indirect characteristics give enough information on the melt flow a limited reproducibility is to be expected due to possible machine variations such as peak pressure, metering time and melt cushion variations.

To detect viscosities on the injection molding machine first of all, analog to capillary rheometry, the shear stress and the (apparent) shear rate have to be measured and calculated: To detect the shear stress, a pressure loss along

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Online process monitoring

Sulzer Werfo is using the process monitoring unit Pass Controller to monitor the viscosity online. Thus characteristics of the molded part such as the maximum cavity pressure or the cavity temperature are being used to control and monitor the process. The melt viscosity is gradually detected online and monitored within limits.

the flow path has to be measured during the injection phase. A measurement is possible with two cavity pressure sensors which are placed in the cavity: As soon as the melt reaches each sensor, the time of the pressure rise is automatically calculated. By using the distance between the two sensors and the time the melt needs to flow through this distance, the corresponding shear rate can be detected automatically and relative exactly. The disadvantages of this method are the high costs for both pressure sensors and the missing information on the temperature. The determined values can not be allocated and documented to a reference temperature.

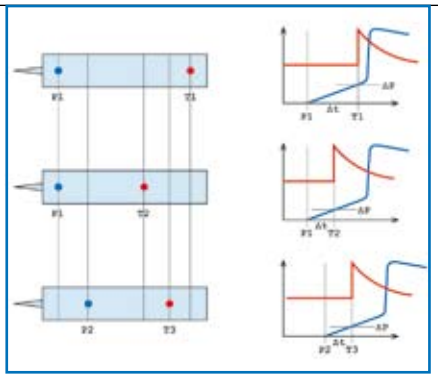
An optimised and simplified method is the combination of a cavity pressure sensor and a cavity temperature sensor. Prerequisite: the cavity pressure sensor should be placed close to the gate and the cavity temperature sensor should be placed within or at the end of the flow path.

This method which has been developed by Priamus System Technologies allows determining easily viscosities in the injection mold. The principle of this process is similar to the capillary rheometry and is generated by a measured pressure difference at which the distance between pressure and temperature sensor is used as basis. The calculation basis of the apparent viscosity consists of the volumetric flow rate and the pressure loss over a certain flow path whereby the melt behavior is taken as a basis in a slit nozzle.

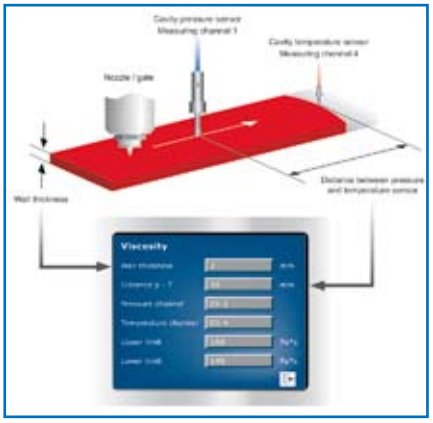
This simplified method based on cavity pressure and cavity temperature is integrated in the process monitoring unit Pass Controller. To evaluate the viscosity only the wall thickness of the molded part and the distance between the pressure and the temperature sensor have to be entered.
During the injection molding cycle the rise of both, the cavity pressure signal and of the cavity temperature are detected. The flow time between the two sensors which is needed to evaluate the shear rate, is automatically measured and analysed. The pressure drop which is required for the shear stress is also automatically evaluated by detecting the cavity pressure at the time of the temperature rise.

Proved and tested

To verify the process test series have been carried through with a lineal shaped test part. The viscosities have been evaluated from two semi-crystalline polyacetal copolymers (Hostaform C9021 and C52021 from Ticona) and an amorphous styrol / butadiene / styrol block copolymer (SBS). Since the manufacturers MVR information varied considerably, different results were to be expected. The melt viscosities were determined at three melt temperatures over five typical volumetric flows and injection speeds and by three material specific cavity temperatures. A constant injection speed ensured a constant volumetric flow in the cavity. For statistical evidence the engineers documented up to 50 succeeding cycles for each setup. The melt temperature was hereby tested by a pyrometer. Thus similar to test series of a capillary viscometer a viscosity value could be determined for each injection speed and melt temperature setting. For a more accurate evaluation comparative measurements with the test material have been carried through by the capillary viscometer.



The sensors can be placed in the cavity at any position. Prerequisite: Pressure comes before temperature. To evaluate the viscosity, the pressure drop (Δ p) and the flow time difference (Δ t) is automatically detected as soon as the melt reaches the temperature sensor.

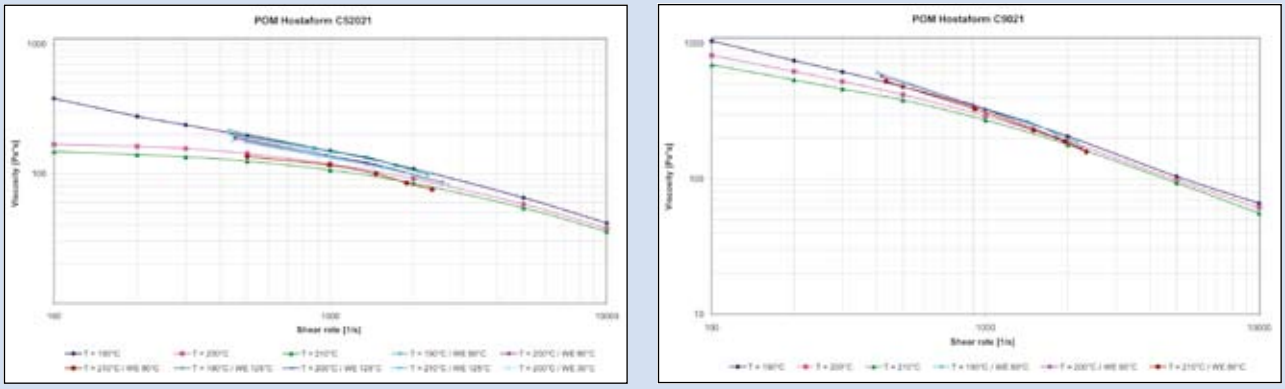


Only the wall thickness of the molded part as well as the distance between the pressure and the temperature sensor have to be entered to evaluate the viscosity.

The process monitoring unit Pass Controller controls continuously the detected viscosity.

Detect batch variations immediately

With viscosity measurement the condition of the plastic melt during processing can be displayed and documented. This method shows what is not visible when the rheometer is used for measurement: For example the influence of different mold temperatures at consistent process conditions or viscosity differences due to metering time variations.
The crucial criterion to measure viscosity in the mold is the online monitoring: batch variations of granulates can be detected



The flow curve shows the viscosity as a function of the shear rate and the temperature. The pictures show the comparison between the viscosity values of the semi-crystalline polyacetal copolymers detected on the machine and by the rheometer.

immediately. Thus raw material can be tested far better if it complies with the requested tolerances.

By continuous viscosity measurement at Sulzer Werfo already marginal changes of raw material characteristics can be detected, documented and included in the process control. With the implementation of the viscosity monitoring the process safety can be enhanced, the reject rates reduced and expensive material analysis and test procedures minimized.

The results were acquired within the master thesis “New ways to detect viscosity with cavity temperature and cavity pressure measurement”. The author thanks the University of Applied Sciences Northwestern Switzerland in Brugg-Windisch/Switzerland, the Plastics Training and Technology Center (KATZ) in Aarau/Switzerland, Omya (Switzerland) and Ticona.

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