Cooling Time as Variable

Quality Improvement. What would happen if, in injection moulding, instead of the demoulding point being determined by a pre-defined cooling time, the end of the cooling time were to be defined by the part temperature detected while the process is running? The benefits are constant part properties and gains in cycle time. This report explains the principles and how it is carried out in practice.

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Tighter cost pressures in the injection moulding industry caused by efforts to migrate production to low-wage countries are forcing processors to implement cost-reducing measures as rapidly as possible, for example, new production processes, greater integration and logistical changes. Current production also offers considerable scope for saving. One approach is the cycle time, which may be up to 40 % above the shortest possible value. The reasons for this lie in poor thermal design of the mould and excess residual cooling times, which are usually preset subjectively based on an estimate. The machine operator often also adds a safety margin to compensate for process and mould tolerances, e. g. temperature and control fluctuations, and to put production into a stable state. But this is often at the cost of non-optimum cycle times, and is therefore costly.

Cooling Time Calculated According to the Mould Temperature

The cooling is not only directly expressed in the process costs, but also has a considerable influence on the quality, which in turn influences the production efficiency. The residual cooling time, which is currently entered as a fixed value, cannot compensate for the disturbances that occur sporadically during production, for example fluctuations in the process, the machine control and the material. The consequences are changes in warpage, dimensional accuracy, surface quality and other part properties during the production of a batch.

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To solve these problems, the Technical University of South-Westphalia (plastics processing lab 1) in Iserlohn/Germany, Kistler Instrumente AG and well-known processors, in a joint research project, developed a system in which the demoulding point does not depend on a fixed predetermined cycle time, but on when the part has reached a defined thermal state. This procedure no longer keeps the cooling time constant but the thermal properties of the mould. The thermal state of the part is determined in the process, cycle for cycle, by measuring the part surface temperature and the cavity pressure. The residual cooling time is calculated automatically and transferred directly to the machine control.

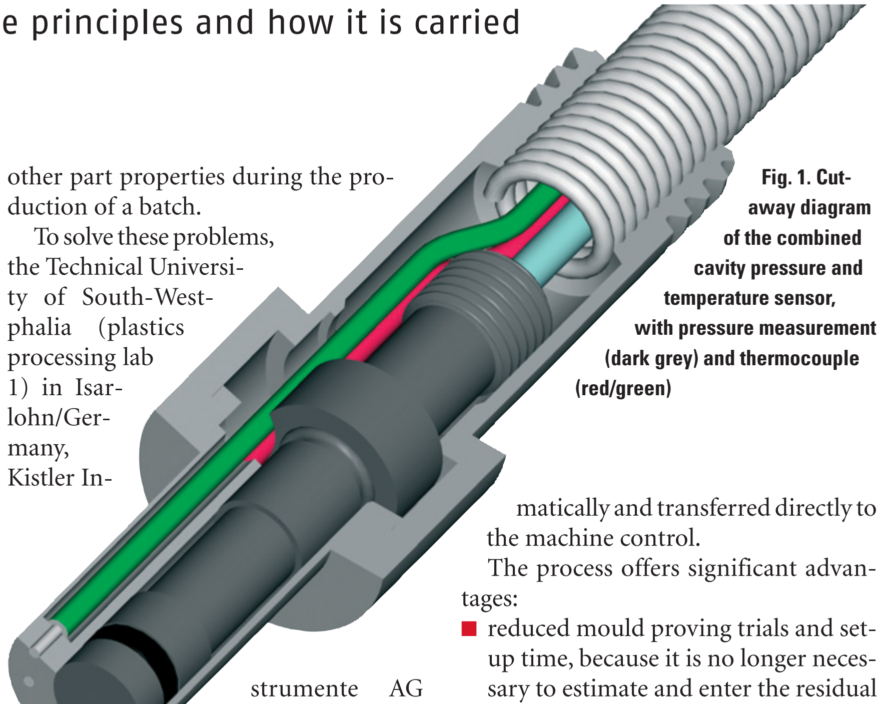

Fig. 1. Cut-away diagram of the combined cavity pressure and temperature sensor, with pressure measurement (dark grey) and thermocouple (red/green)

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The process offers significant advantages:
- reduced mould proving trials and setup time, because it is no longer necessary to estimate and enter the residual cooling time;
- a considerable improvement in economy because the cooling time and therefore the cycle time are kept as short as possible;
- part quality remains as constant as possible because of the constant demoulding temperature.

Sensor for Combined Pressure and Temperature Measurement

The ideal demoulding temperature is determined not only by the plastic used, but also by the part geometry. Because of the complexity of the shrinkage and warpage processes, and the fact that the mould wall and melt temperatures cannot be determined accurately in advance, it is not possible to accurately calculate the demoulding temperature for an injection moulded part. Only an estimate can be carried out, based on guide values, e. g. from raw materials manufacturers, and the experience of tool setters, since at the time of demoulding, with conventional wall thicknesses, the temperature is not com-

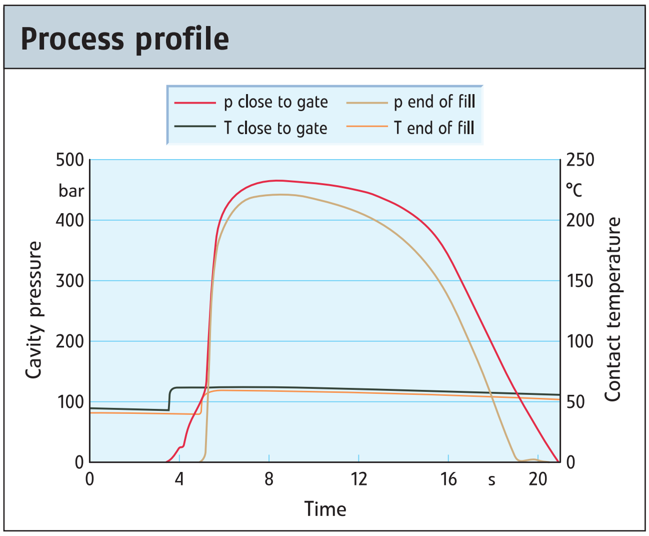

Fig. 2. Process profiles close the gate and end of fill, measured with the combined cavity pressure and temperature sensor

pletely equalised across the part cross-section, and there is always a temperature gradient from the part centre to its outside.

To determine the ideal demoulding point, therefore, the general cooling time equation is used. This allows the residual cooling time to be calculated theoretically. To determine the demoulding point for a given temperature the properties of the plastic, that means mould wall temperature and the melt temperature, must be known at the beginning of the cooling process. However, as mentioned above, the two last-mentioned parameters are not known. Of course, the melt temperature during the injection moulding cycle can be acquired experimentally during the injection moulding cycle by means of thermocouples, which must be re-introduced into the cavity again for each cycle. However, this type of temperature determination is unsuitable for production, and is mainly used for scientific studies.

As a result, for automatic calculation of the residual cooling time in mass production, there is a need to develop a method to accurately determine a profile for the mould wall temperature and melt temperature at the beginning of cooling, i. e. after the actual mould filling process.

This need led to the use of a combined pressure/temperature sensor (Fig. 1). With this special sensor design, the temperature measurement is performed at the surface of the sensor and the contact temperature with the melt is registered as soon as the melt reaches the sensor. Before this point, the sensor registers the mould temperature precisely and supplies the necessary information about the profile of the mould wall temperature. The integrated cavity pressure sensor detects the point of volumetric filling, the start of cooling (Fig. 2). All the information is thus available to automatically solve the cooling time formula, cycle for cycle by means of further algorithms, and to supply the exact cooling time for initiating the demoulding process to the injection moulding machine.

Expectations Confirmed in Production

In the interim, the method presented above has also been tested on a large housing part (part weight approx. 1 kg) of ABS. Its surface is mirror polished and must be absolutely flawless. The process has a total cycle time of 61 s, of which 42 s is taken up by the cooling time. The average mould temperature is 62 °C. After intensive manual optimisation, parts can be produced with sufficient quality at the constant cooling time then established. A reduction of the cooling time to a fixed value of 40 s puts the process into an indeterminate quality state (Table 1). At irregular intervals, crazing appears on the face surface of the parts (Fig. 3). This is caused by an ejector pin, since the part has not yet reached the correct temperature at the demoulding point. This reduction in cooling time by 2 s makes 100 % visual inspection of the parts necessary.

Fig. 3. Sporadically occurring crazing on the part without automatic cooling time computation

Fig. 4. SmartAmp charge amplifier with integrated automatic cooling time computation

The use of automatic cooling time computation at a constant demoulding temperature of 72 °C, with the otherwise natural parameter fluctuations, a cooling time between 39.8 and 40.3 s is achieved. In this case, no crazing appears even over a relatively long production time. In this manner, the cooling time was reduced by 5 % compared with a (customary) safety margin.

To check the system behaviour, the average mould temperature is increased to 70 °C. The system now automatically

	Cooling time [s]	Average mould temperature [°C]	Demoulding temperature [°C]	Quality
Constant residual cooling time	42	62		OK
Constant residual cooling time	40	62	approx. 72	Irregular crazing
Automatic cooling time computation	39.8 – 40.3	62	72	OK

Table 1. The automatic cooling time computation fully exploits the cycle time without a safety margin

increases the cooling time to demould at the same temperature 72 °C. The part surface is also immaculate in this case. In addition to the surface properties, there are further test parameters on the part. They lie within the required tolerance for all the listed settings if the demoulding temperature remains constant.

This example shows that, for processes that have been manually optimised to the limit, automatic computation of the cooling time, and therefore the earliest possible optimum deforming point, can obtain a further reduction in cycle time while maintaining the general condition of optimum quality.

Integration into the Injection Moulding Machine

For industrial use, it is essential to integrate this method as a self-contained process into the injection moulding machine. Methods that intervene in the process with a control action must be incorporated into the machine in a stable manner. A proven solution was chosen to implement this method. The algorithm was integrated into an industrial charge amplifier (Fig. 4). Kistler has used this technique for many years for automatic optimisation of the changeover point. The intelligent charge amplifier is completely integrated into the injection moulding machine control. This ensures maximum process stability. ■

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