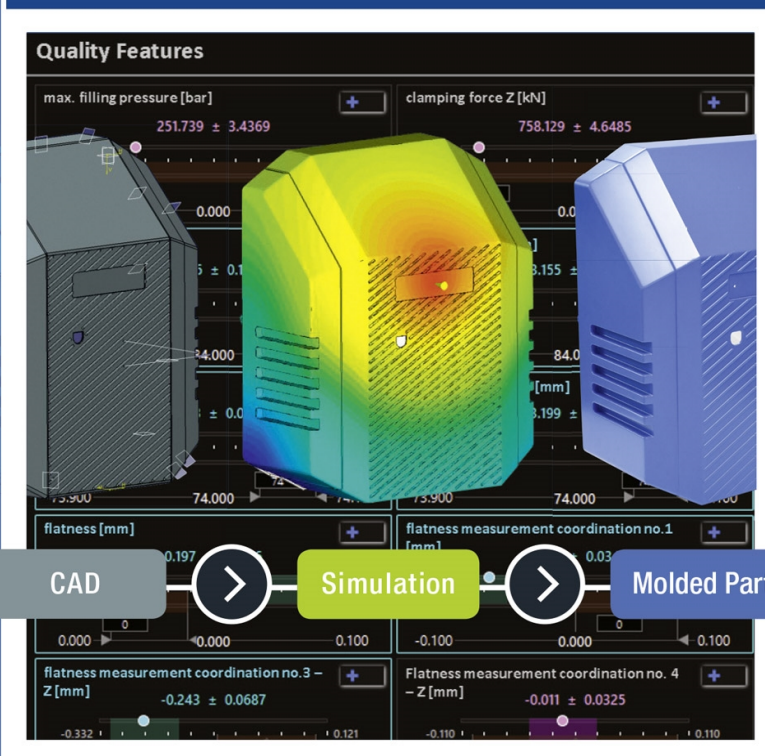


Thomas Schröder



# Simulation in Injection Molding



HANSER



Schröder  
**Simulation in  
Injection Molding**



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Thomas Schröder

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HANSER



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# Preface

Simulation software programs are now a staple in the field of injection molding for the design of molded parts and molds. They assist designers early in the development of the molded part and mold design, thereby reducing the often time-consuming modification cycles. This shortens development time and lowers development costs. Additionally, the programs can enhance the quality of the molded parts and the efficiency of the injection molding process. Given the wide range of simulations that these programs can perform, the breadth of the simulation results is equally extensive. The challenge usually lies not in generating the results produced, as these programs are all very user-friendly, but in understanding and interpreting them. Only when this is the case can the user draw meaningful conclusions from them and suggest potential improvements. This is exactly where this book comes in. It begins with a general introduction to the injection molding process, meshing, and basic mathematics, followed by simple basic exercises. These are designed to provide the reader with an initial understanding of the simulation technique of how to interpret the results. Each chapter then explains the prerequisites for injection molding, the framework conditions and mathematical correlations, before conducting sample simulations out on real parts. For each specific simulation case, the results are interpreted and solutions developed. Finally, the aim is to use these simulations to make the reader aware of the essential points, which can vary extensively from part to part.

As the book contains numerous pictures and graphics and these are not always very easy to see due to their size, we have decided to provide the reader with all the pictures additionally in the form of image data. At [plus.hanser-fachbuch.de](http://plus.hanser-fachbuch.de), you can access the images using the code on the first page of the book.

Darmstadt 2024

*Dr. Thomas Schröder*



# Foreword

For the most successful companies in plastic injection molding, simulating every part in advance has become the standard way of working. Whether you're a seasoned professional or still learning the ropes, simulation amplifies your skills, allowing you to identify and prevent process or part issues before any metal is machined. This includes issues like filling errors, warpage or excessive cycle times, among others. Another key advantage that is often overlooked is how simulation results and images bring clarity and focus to discussions with colleagues, superiors, and customers. By visualizing potential outcomes you can have a more constructive discussion, because your customers and colleagues will more quickly understand what you mean.



Naturally, mastering such a powerful tool takes some practice. You need to gain a deep understanding of how to represent reality as accurately and efficiently as possible if you want accurate results. But even the best simulation results are only as valuable as the insights you draw from them. Simulation is not just a prediction tool – it's a decision-making tool. That's why Prof. Dr. Thomas Schröder's focus on correctly interpreting simulation results is spot-on. His 30 years of expertise in plastics technology, distilled into this book, will save you from many potential missteps, and help you capture the full value of simulation.

Mastering the insights from this book can significantly advance your career. Given the pace at which engineering departments are digitalizing their ways of working, skilled simulation experts are increasingly in demand. By reading this book, you will not only enhance your professional knowledge but also your market value.

*Ines Oud*

CEO of injection molding simulation company **SIMCON** and Chairwoman of the German plastics industry association **Kunststoffland NRW**



# The Author

Prof. Dr. Thomas Schröder teaches injection molding, rheology, mold technology and simulation technology at Darmstadt University of Applied Sciences (h\_da Hochschule für Angewandte Wissenschaften), Germany, and is a member of EUt+ (European University of Technology). After studying mechanical engineering with a specialization in plastics technology at RWTH Aachen University, he completed his doctorate under Prof. Dr. Dr. h. c. Walter Michaeli on the subject of gas injection technology. After working for several years at a well-known plastics manufacturer, he moved to Krupp Corpoplast in Hamburg, where he was responsible for injection molding systems that produce preforms. Following this position, he moved to Netstal Maschinen AG in Näfels, Switzerland. There, he headed the application technology SPA of the injection molding machine manufacturer until he received a call to the University of Applied Sciences Darmstadt in 2001. He is also the author of the book *Rheologie der Kunststoffe* (Rheology of Plastics), the second edition of which was published by Hanser Verlag in 2020. Prof. Dr. Thomas Schröder is a member of the Institut für Kunststofftechnik Darmstadt ikd and chairman of the Gesellschaft zur Förderung technischen Nachwuchses GFTN e. V. (Society for the Promotion of Young Technical Talent) at Darmstadt University of Applied Sciences. Furthermore, he is a member of the PhD Centre for Sustainability Sciences and has the right to award doctorates, due to his numerous research projects, i. e., third-party funded projects in the field of injection molding, rheology, simulation, and tool technology. Prof. Dr. Thomas Schröder is also the managing partner of PlastSolutions Consulting GmbH, based in Mannheim.



## Acknowledgments

This book could not have been written without the invaluable cooperation of many Bachelor's and Master's students. In this respect, I would first of all like to thank the many graduates whom I was able to supervise in various subject areas. I wish you all the best and much success in your professional career and also privately! In

particular, I would like to thank the following people for their active participation in the book project: Aletta Berger, Sophie Dolata, Mary Göhler, Laura Gollan, Markus Hammermeister, Fabian Nebel, Bardo Palmberg, Bastian Paulsen and Maximilian Teich.

Furthermore, I would like to thank the company Simcon, which has always supported me with the software modules Cadmould and Varimos. Finally, I would like to thank the company Mold and Hotrunner Technology MHT, which also assisted me with the preparation of this book.

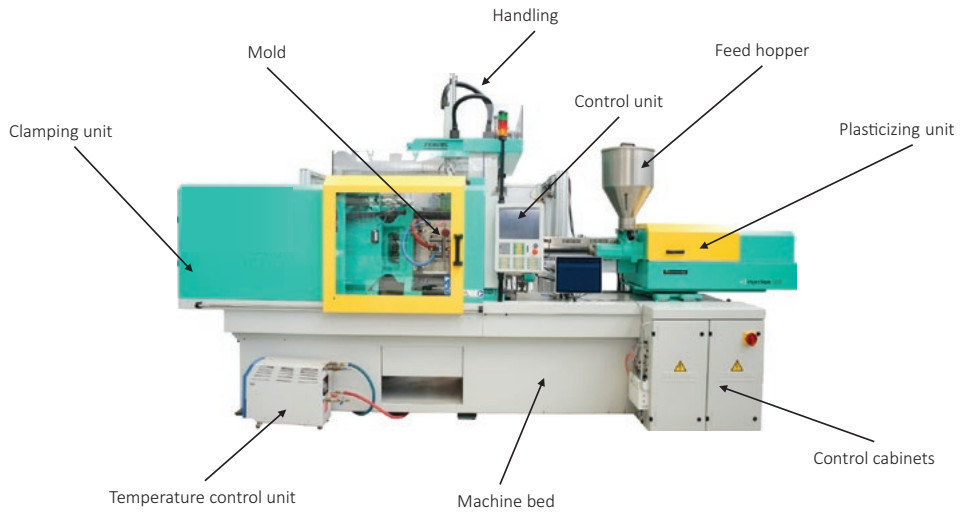
# 1

## Basics of Injection Molding

### ■ 1.1 Components of an Injection Molding Machine

Almost one third of all plastics are processed by injection molding. This master-molding technique is a discontinuous process. Injection mold machines are used for producing moldings from thermoplastics, elastomers and thermosetting plastics. These machines consist of several modules such as the machine bed, the plasticizing and injection unit, the clamping and locking unit, the temperature control unit as well as the mold and the control unit (Figure 1.1) [1].

The machine bed serves to accommodate the clamping, locking and injection units. In addition, pumps and tanks for hydraulics oil are built into the base of machines that need hydraulics. In fully electric injection molding machines, electric motors drive the five main movement axes (dosage, injection, plasticizing and injection unit, machine movement and ejection). The control cabinets are on one hand necessary for accommodating the mold and on the other hand for raising the clamping forces. These forces prevent the mold from opening during the shaping process. Another one of their tasks is closing and opening the mold. The mold is responsible for the shaping of the plastics and releasing the warm air so that a molded part can be formed out of plastics melt. The plasticizing and injection unit is used to melt and supply the plastic. The plastic granules are added through a hopper into a screw that is surrounded by a heated cylinder. The movement of the screw and the thermal conduction of the cylinder plasticizes the granules into a melt, which is pushed into the antechamber of the screw. The melt is then pushed forward into the closed mold. The control unit is needed for adjusting and observing the setting parameters whereas the temperature control unit regulates the temperature of the mold at a pre-set temperature [1].



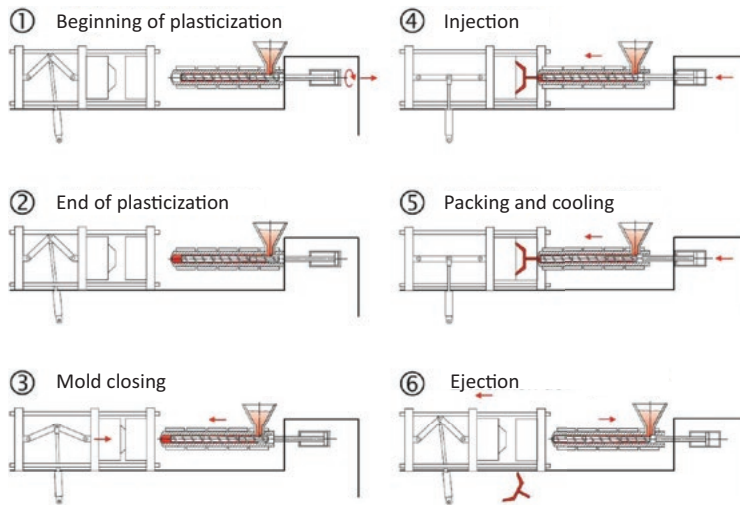
**Figure 1.1** Set-up of an injection molding machine

Injection molding machines can be differentiated on the basis of their design and drive type. Thus, a distinction can be made between horizontal and vertical injection machines and fully electric, hydraulic and hybrid machines. The difference between a horizontal and vertical injection machine is the position of the mold or the molded parting line in the machine. The type of drive used determines whether the injection machine is fully electric, hybrid or hydraulic. The axes of fully electric machines are driven by an electric motor. Hydraulic machines are driven by hydraulics while hybrid machines have a mixture of hydraulics and electrically driven axes [2].

## ■ 1.2 The Injection Molding Cycle

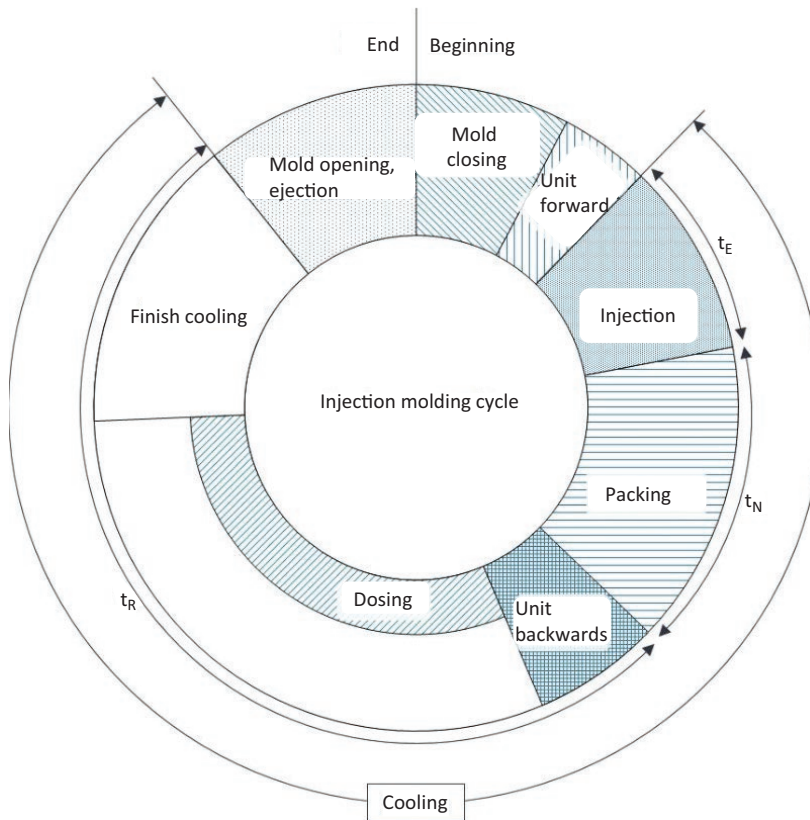
A typical injection molding cycle runs in five steps. A new cycle commences when the mold closes. As soon as the mold is closed and the clamping forces are built up, the plasticizing and injection unit is pushed forward onto the mold. Then, the molten plastic (plastic melt) is injected into the cavity under a speed-controlled axial advance of the screw. The holding pressure phase commences when the mold is 95–98% filled and serves to regulate shrinkage of the molded part. In this phase, the holding pressure is regulated and the plastic melt is pushed further into the mold to balance the volume shrinkage caused by the temperature. The phase ends when the connection of the sprue to the molded part solidifies. This means that the sealing point has been reached. From this point on, the plasticizing and injection

unit of the mold returns to its original position and the so-called residual cooling time begins. During this phase, the dosage process for the next cycle begins, which means that plastic melt again fills up the antechamber of the screw. As soon as the molded part reaches its ejection temperature, the mold opens and ejects the molded part. Alternatively, a handling system removes the molded part from the mold. Figure 1.2 shows the injection molding process.



**Figure 1.2** The injection molding cycle [1]

The cycle time consists of the time needed for opening and closing the mold, the deployment of handling and ejectors, as well as the injection time, the holding pressure time and the residual cooling time. It is essential for the financial planning to give consideration to the cycle time, as reducing it is one of the most important aims of the injection molding process. Based on the cycle time, the mold and number of cavities can be calculated for the required number of molded parts per year. Figure 1.3 shows a typical injection molding cycle [2, 1].



**Figure 1.3** Injection molding cycle

The run time of the cycle can be calculated as follows (Equation 1.1):

$$t_z = t_E + t_N + t_{RK} + t_{WZopen} + t_{Ejector/Handling} + t_{WZclose} \quad (1.1)$$

Where:

$t_z$  = Cycle time

$t_E$  = Injection time

$t_N$  = Holding pressure time

$t_{RK}$  = Residual cooling time

$t_{Ejector/Handling}$  = Ejection time

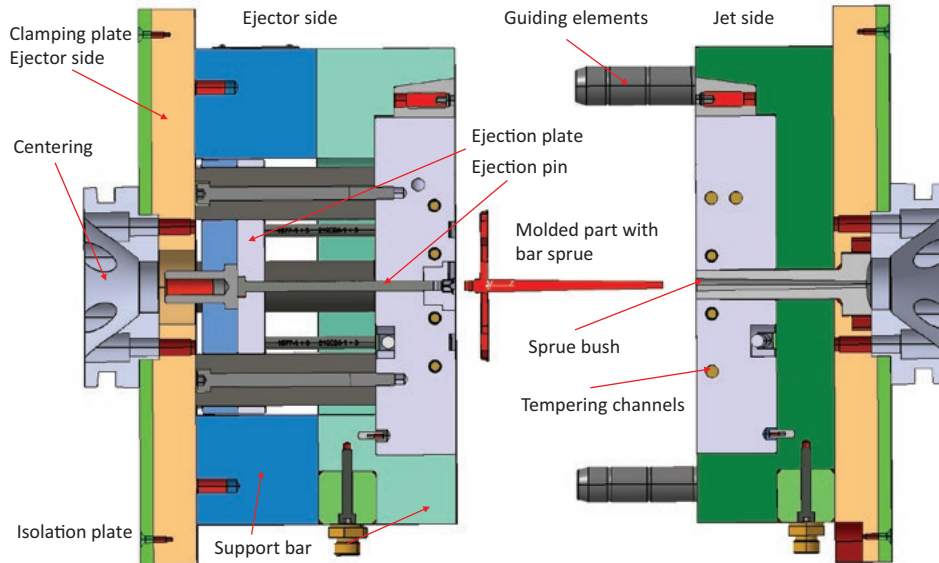
$t_{WZopen/close}$  = Mold opening and closing

As soon as the mold is closed, the injection phase begins. This phase also affects the cooling time. The reason for this is that, when the material enters the mold, the plastic melt touches the wall of the mold and that starts the cooling process. The holding pressure phase is needed to balance the volume shrinkage when the molded part solidifies. During this phase, a specified holding pressure pushes more plastic melt into the mold.

Immediately after the holding pressure phase is concluded, the residual cooling time before the molded part is ready to be ejected begins. During the residual cooling time, the granules for the next shot are being prepared, that is to say, plasticized. Once the molded part is stable enough to be ejected, the mold opens and the part can be pushed out of the mold by the ejectors. It is also possible to take out the part by means of a handling system. The time required for this needs to be taken into consideration when calculating the cycle time.

## ■ 1.3 The Injection Mold

Generally, each injection mold consists of two mold halves (Figure 1.4): one is fixed (nozzle side) and the other is movable (ejector side). The molded part is formed by the cavity. The plastic melt streams through the sprue bush until reaches the cavity. The sprue bush is located on the fixed-nozzle side and, during the injection phase, it is in contact with the plasticizing and injection unit. In general, the cavity consists of a cavity plate, which usually is on the nozzle side, and a core that sits on the ejector side.



**Figure 1.4** Structure of a two-plate injection mold (Source: PlastSolutions GmbH)

Cooling channels in both mold halves are necessary to dissipate the heat of the molded part. A cooling medium (usually water) flows through these cooling channels. With water and under pressure, cooling is possible up to 200 °C. For higher temperatures, oil is used in most cases to dissipate the heat. However, water has better heat transfer properties than oil. The goal is to achieve turbulent flow, as that allows for better heat transfer. The cavity plate as well as the core are located in the mold plate. After the molding process, when the molded part has reached the ejection temperature, the ejector pins remove the molded part from the core on the ejector side. During this process, an ejector bolt is pushed forward, usually by a hydraulic ejector. The ejector plate in which the ejector pins are located push the molded part out of the ejector side.

The supporting bars are behind the intermediate plate and in between the supporting bars is the ejector plate. For fixing the mold on the movable machine plate, a clamping plate is located at the end of the ejector side. The same applies to the nozzle side. Here, the clamping plate is located at the end of the fixed plate to attach this side to the fixed machine plate. If necessary, an additional isolation plate can be added to these to plates to reduce the heat transfer from the mold to the clamping plate. It is possible to install a centering ring on the nozzle side as well as the ejector side. This aids the installation of the mold inside the machine and the centering of the mold (center line to the plasticizing unit). Guide elements guide the mold and hold it together when not assembled.

One of the main tasks of the injection mold is to let the plastic melt stream from the plasticizing and injection unit through the sprue bush and finally into the cavity. In the cavity, the heat of the plastic melt needs to be reduced so that the molded part can be cooled down to ejection temperature. This means that the mold is tasked with giving the molded part its form and transferring the heat. After the ejection temperature is reached, the ejectors push out the molded part. In general, it is important that the mold is rigid enough to withstand the high pressure during the injection phase as well as deformation due to the high clamping force.

Injection molding simulation programs can interpret injection molds rheologically, thermally, and mechanical. This means that it is possible to simulate the flow of the plastic melt from the tip of the screw, to the sprue system to the end of the flow path. Finally, the injection molding simulation program is able to simulate the holding pressure and cooling phases. This allows the pressures, speed, shear rate and stress, temperatures and other measurements to be depicted during the injection, holding pressure and cooling phases. The injection molding simulation process and the cooling can be optimized and the shrinkage and warpage can be predicted. A prediction of the shrinkage and warpage enables early optimization of the injection mold and, if necessary, adjustment of the mold [3]. Statistical methods (Design of Experiments or DoE) support the user of the simulation program during the evaluation of the major parameters on the qualitative features and the process optimization [4].

Current simulation programs make it possible to simulate the starting process of an injection molding machine. As it takes some time for the thermal balance of the injection mold to be reached, simulation of the startup process is especially important. In addition to the deformation of individual mold elements, it is also possible to predict the offset of the core. A mechanical interpretation of the mold can also be executed by the simulation programs.

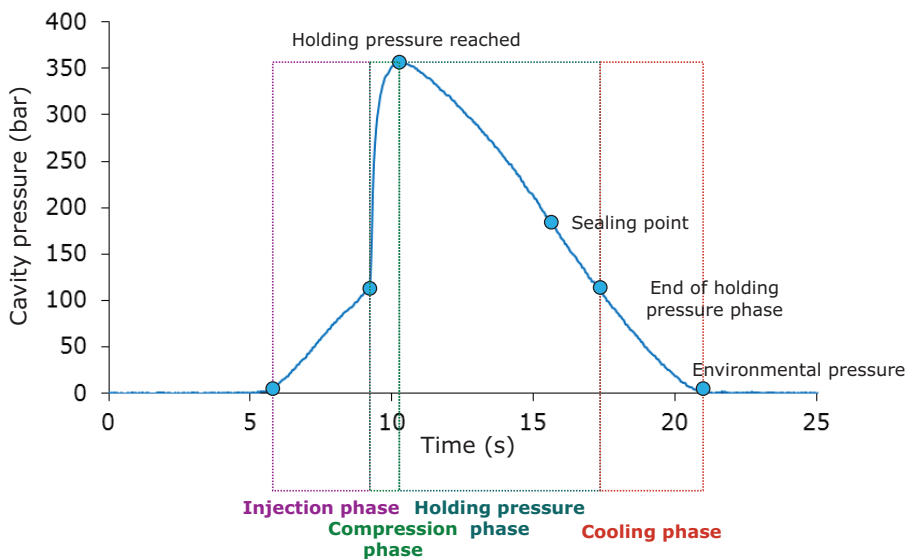
## ■ 1.4 The Phases of Injection Molding – Forming the Molded Part

Generally, the molded part is produced in three phases:

- injection phase (dynamic phase)
- compression phase (quasi-static phase)
- holding pressure phase (quasi-static phase)

These three phases define the quality of the plastic molded part. Figure 1.5 shows the cavity pressure gradients and the three phases of molded part formation during injection molding.

All the main quality features, such as weight, dimensional stability, surface quality and so on are mostly formed during these three phases. Therefore, it is crucial to know the pressure gradients during these phases. Computer-aided simulation programs can be of service here as well.



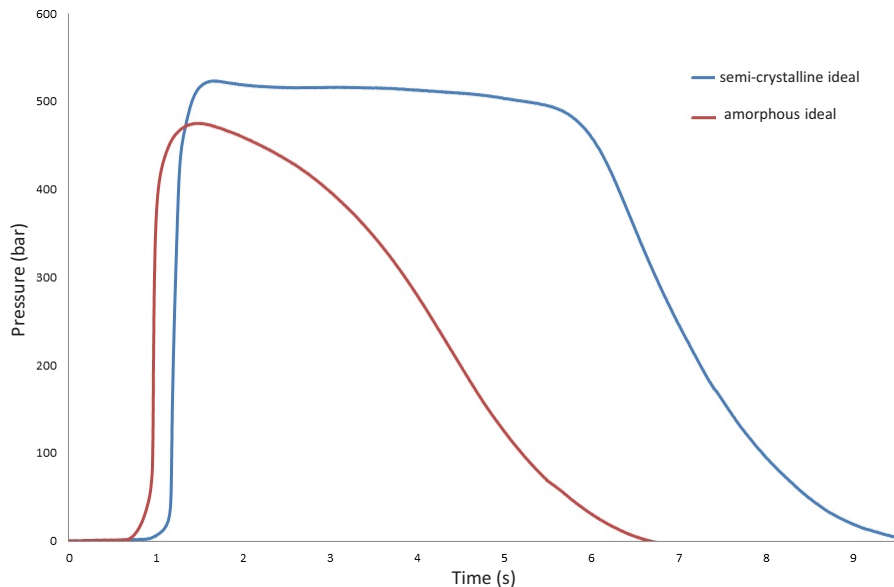
**Figure 1.5** Cavity pressure curve during injection

These programs help with making statements about the formation of the molded part (pressure, flow rate, shear, shear stress, temperature, etc.). As the process of forming the molded part (Figure 1.5) is directly connected to the quality of the molded part, it is essential to be aware of possible weak spots or faults in the molded part in advance. A high level of expert knowledge is generally necessary since the correlations in this process are usually very complex.

### 1.4.1 Injection Phase

In the dynamic injection phase, the liquid plastic that has been prepared by the plasticizing and injection unit is injected into the closed mold by the axial advance of the screw. This process is usually speed-controlled. This means that the injection molding machine provides the injection pressure (up to 2600 bar) necessary for the filling of the mold. Therefore, it is crucial that the switching point, where the speed-controlled injection phase switches over to the pressure-controlled holding pressure phase, is precisely timed. The switching point has to occur somewhere between 95 and 98% of volumetric filling of the cavity. The injection phase is followed by the compression phase.

In the injection phase, the surface quality of the part is defined by fountain flow at the melt front and the wall adhesion of the plastic melt. Furthermore, the orientations, caused by the flow direction, of molecular chains and fillers, such as glass fiber, are formed. If the switching point takes place at the right time, the cavity pressure will look similar to Figure 1.6.



**Figure 1.6** Cavity pressure at the right switching point during injection molding