POLYMER AND COMPOSITE MATERIALS PROCESSING

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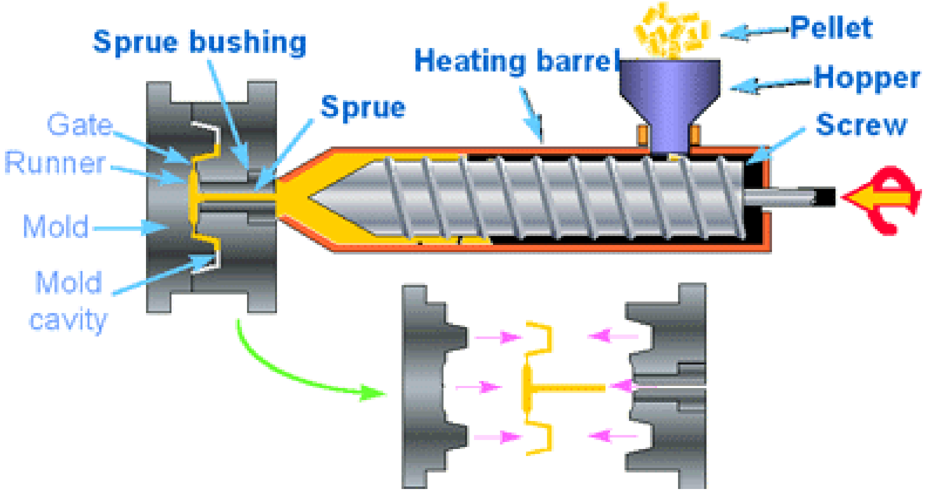
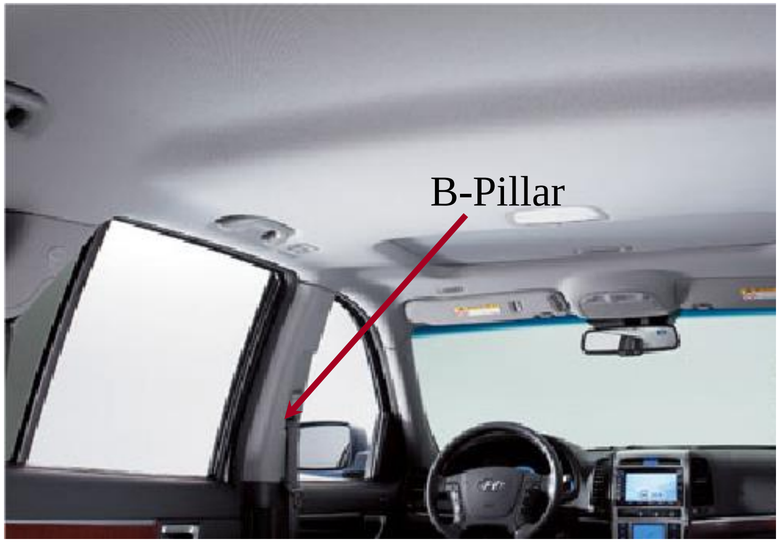
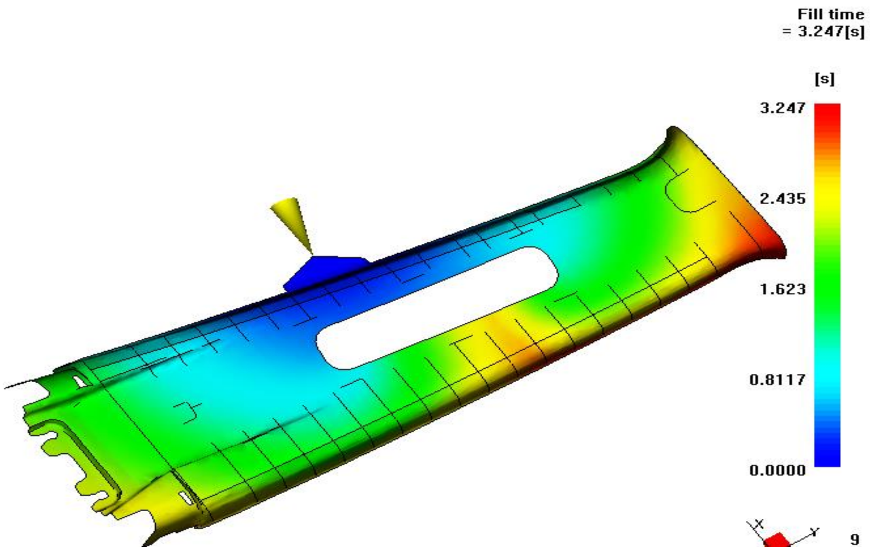
Ch. 5. Injection molding







Principles

- The basic process
  - An injection molding machine has two main sections to it:
    - The injection unit
    - The clamp unit, or press, which houses the mold

- The injection unit
  - In the first section, the process is virtually the same **as the extrusion process**.
  - The one major difference : the **screw can reciprocate, piston-like**, within the barrel during the injection part of the production cycle.
  - During the **plasticizing phase: the output end is sealed by a valve**

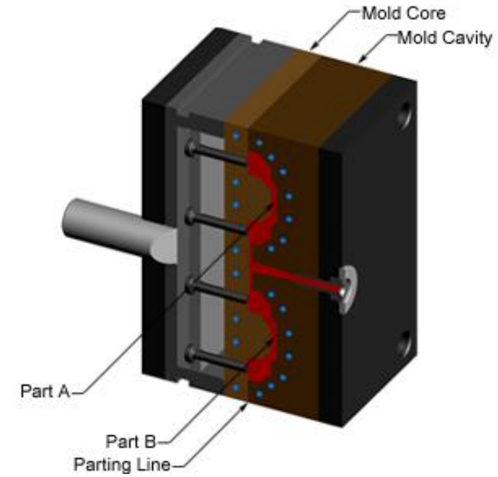
    The screw accumulates a reservoir, or 'shot' of melt in front of itself by moving backwards against the head pressure.
  - **When this phase is complete : the sealing valve opens**

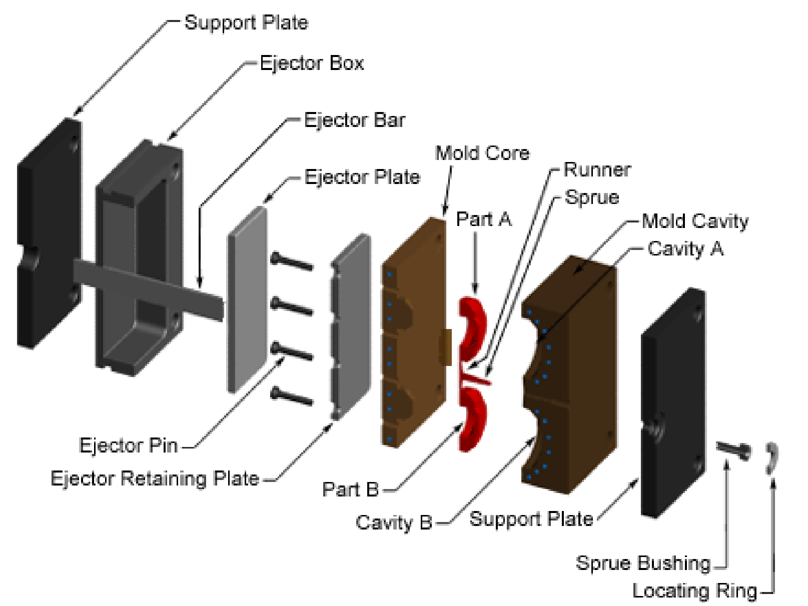
    The screw stops rotating and pressure is applied to it so that it becomes a ram or piston which forces the accumulated melt through the connecting nozzle into the mold.

- The clamp unit
    - The clamping force available :
      resist the force generated by the melt as it is injected.
    - in the largest machines, several thousand tons.

- The mold or tool
    - The mold is mechanically fastened (e.g. bolted) in the clamp unit
    - interchangeable to allow different products to be molded.

- Cavity
  - In which the molded product forms.
- Channels : sprue and runner
  - Along which the melt flows as it is injected.
- Cooling channels
  - Through which cooling water is pumped to remove the heat of the melt.
- Ejector pins
  - Which remove the molding from the cavity.





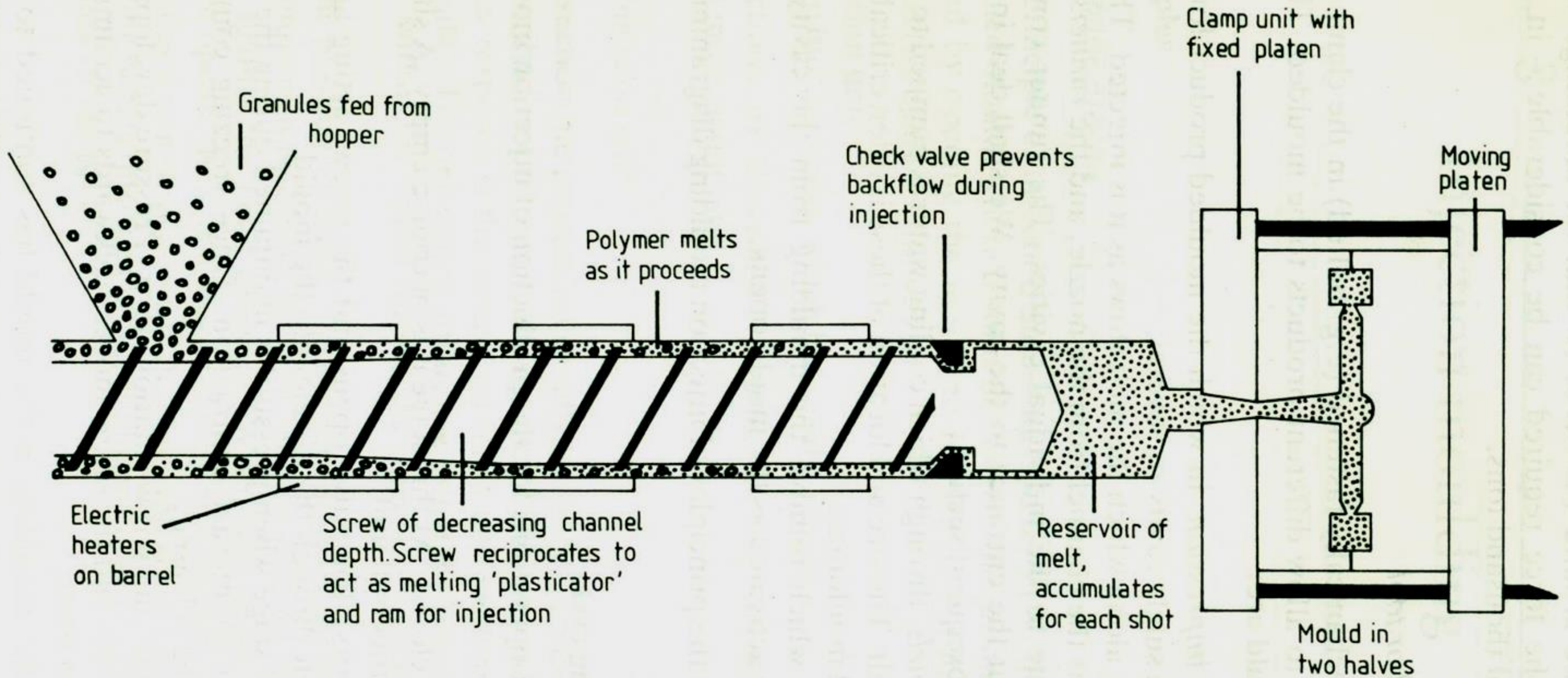
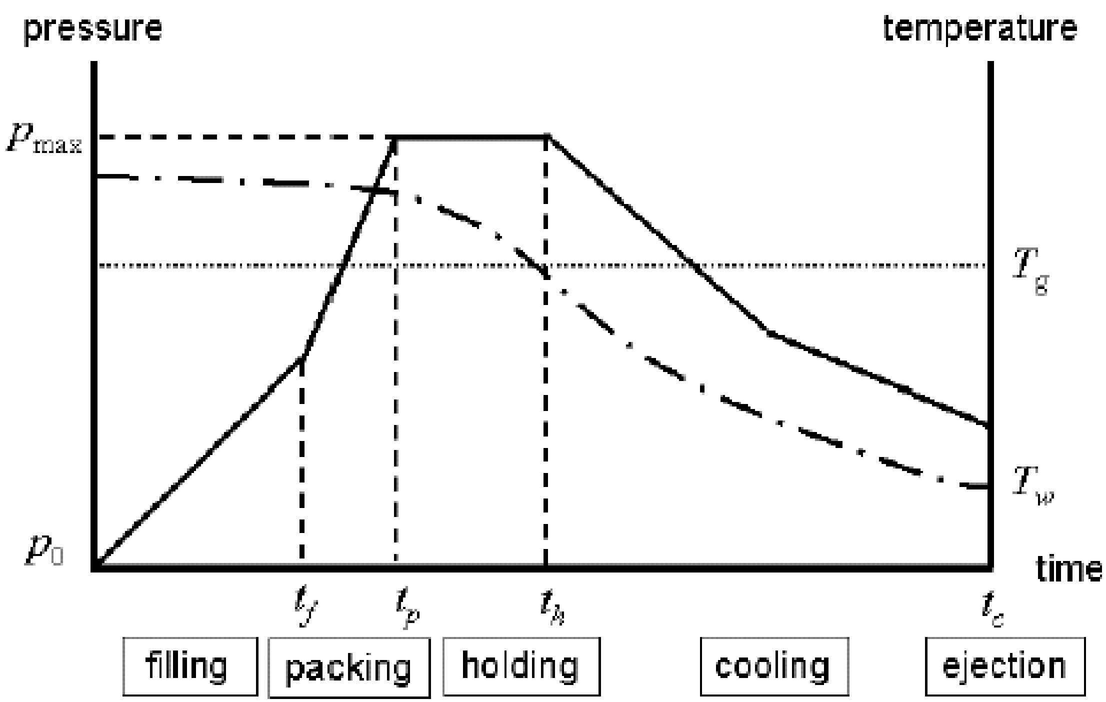


Fig. 8.1 Principles of injection moulding.

- The molding cycle
  - The mold is closed.
  - Injection occurs.
  - The hold-on stage when pressure is maintained.
  - The valve closes and screw rotation starts in the backwards.
  - Meanwhile, the molding has continued to cool.
  - The cycle repeats.



The injection molding machine

- The injection unit
  - Unlike a simple single screw extruder the screw in an injection molding machine **reciprocates to affect the injection**.
  - A valve which is closed during injection to prevent backflow of melt past the screw flight
  - A valve is open when the screw rotates to allow the fresh shot to accumulate.

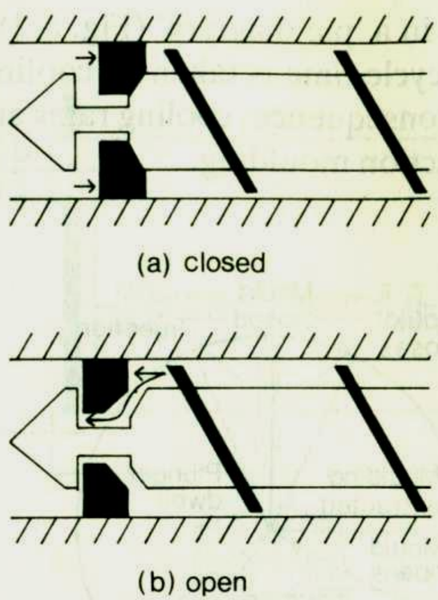


Fig. 8.3 Check valve, open and closed.

- The nozzle

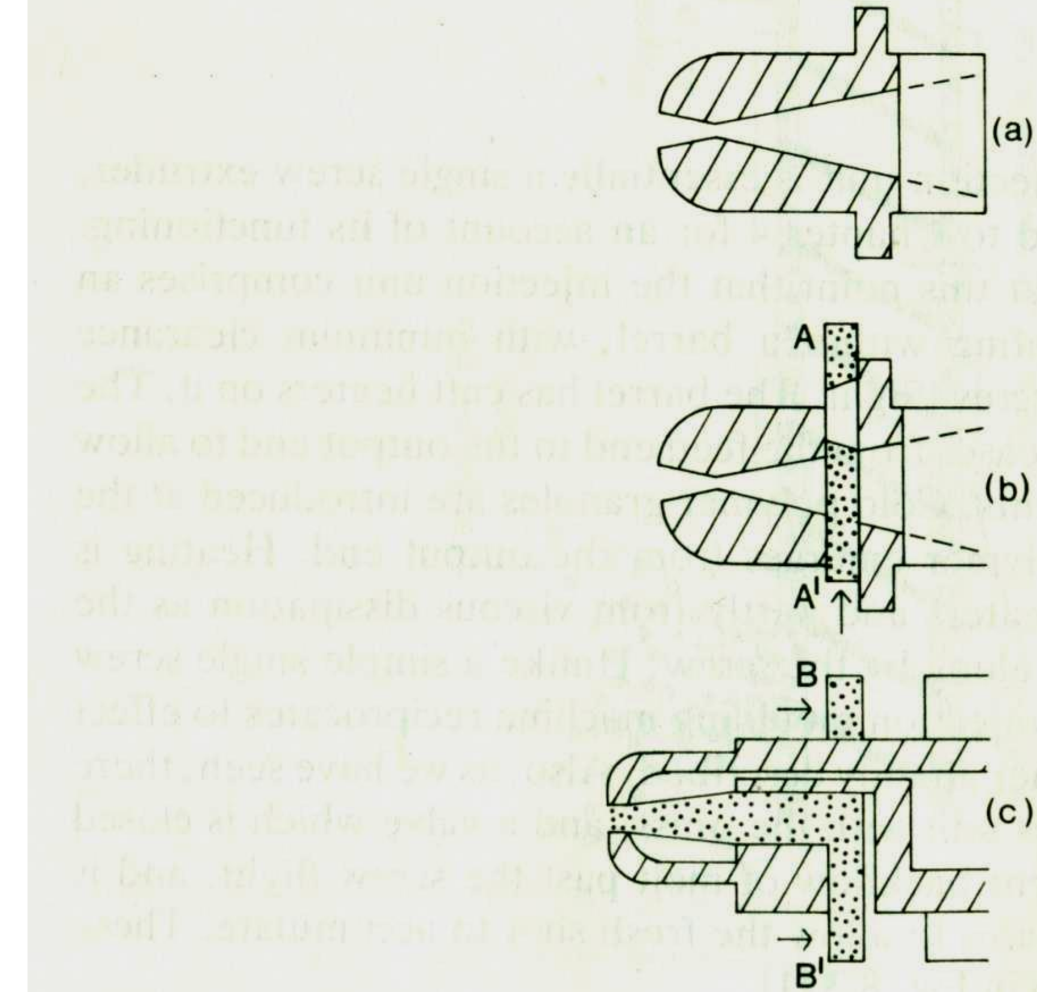


Fig. 8.4 Types of nozzle: (a) open; (b) simple mechanical shut off; (c) needle valve.

- The clamp unit or press
  - The function of the clamp unit is to hold the mold closed with **sufficient force to resist the injection pressure**.

Table 8.1 Sizes of injection moulding machines

Shot capacity (g)	*Clamping force (tonnes)*
30	10
120	125
350	250
800	375
1500	650
8500	2500

- Pressure for injection
    - It is applied via the screw, non-rotating, by a hydraulic system.
    - The line pressure of the system is of the order of 7-14 MPa (70-140 bar).

- Mold

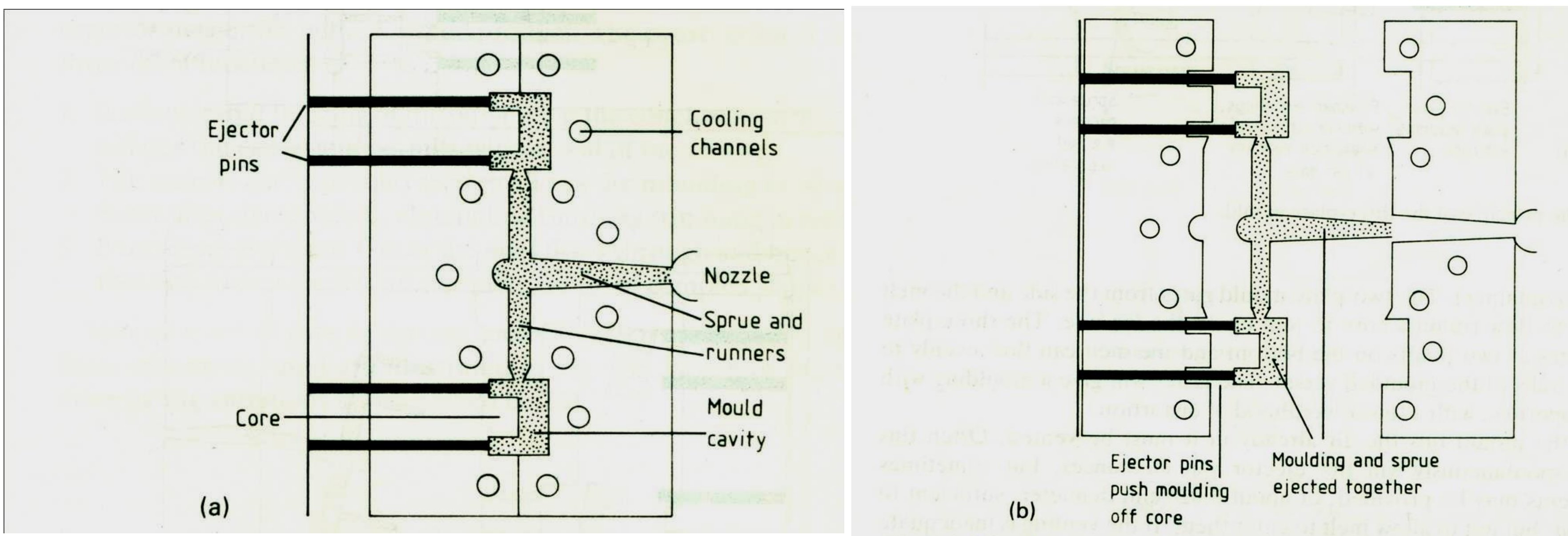


Fig. 8.6 Two-plate mould, closed and opened.

• Gate design

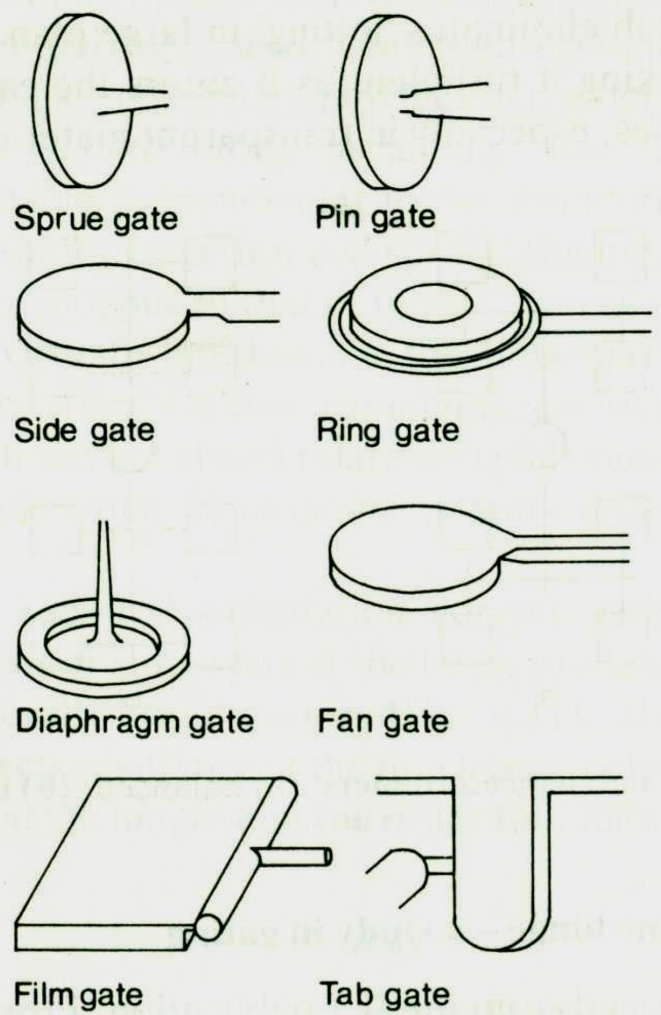


Fig. 8.8 Variations in gate design.

• Runner

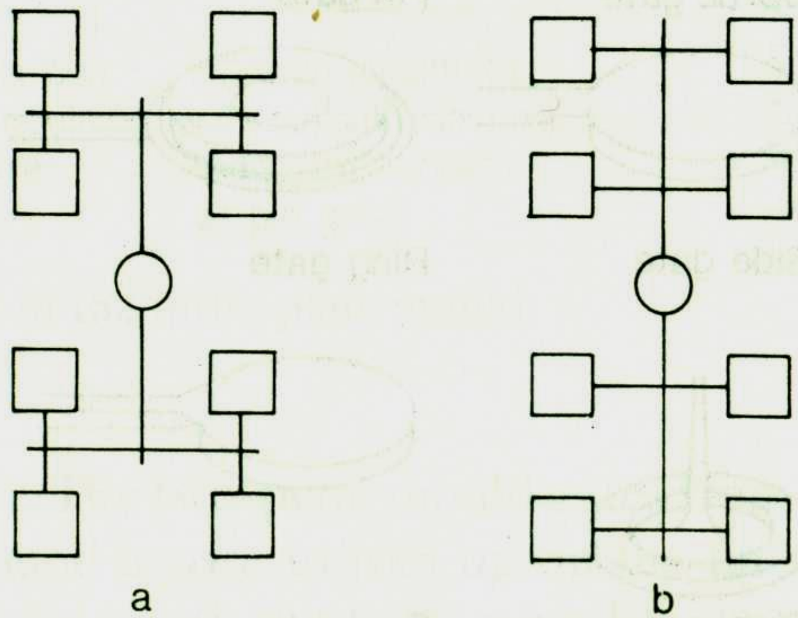


Fig. 8.9 Balanced and unbalanced runners: (a) balanced; (b) unbalanced.

The polypropylene hinge : a study in gating

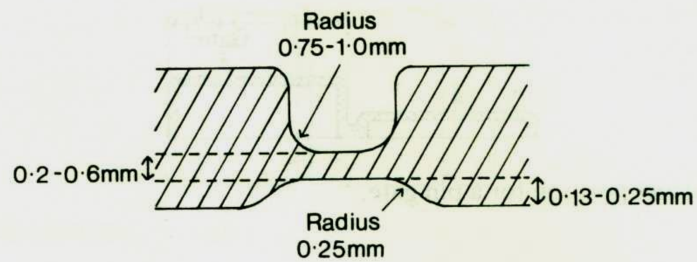


Fig. 8.10 Typical polypropylene hinge configuration.

- Positioning the gate
  - Hesitations or stop-start at the hinge are fatal

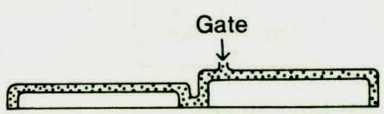


Fig. 8.11 Gating close to the hinge.

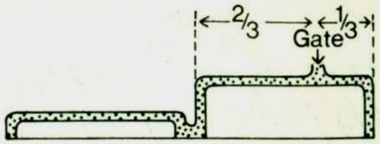


Fig. 8.12 Correct position for a pin gate.

- Gate positions and multiple gating

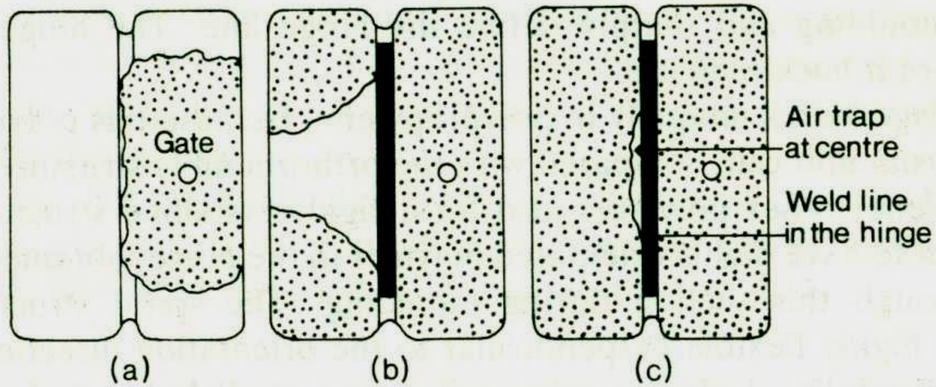


Fig. 8.13 Problems with a single-gated long hinge: (a) the material reaches the hinge but stops while lateral flow occurs; (b) the material stopped in the hinge sets: when flow restarts it is round the edges; (c) the material then flows back towards the hinge from the side of the second cavity, and creates an air trap. This causes either an actual gap or at best a weak mould.

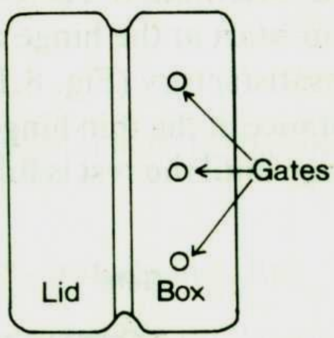


Fig. 8.14 Multiple gating for long hinges.

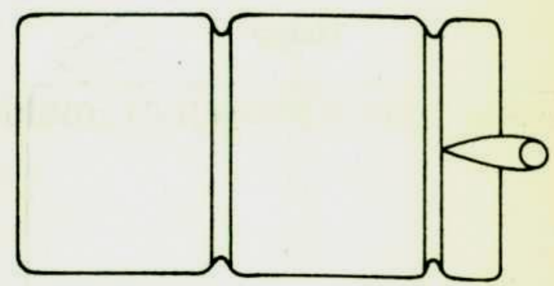


Fig. 8.15 Edge gating.

Some aspects of product quality

- **Basis of material response**
  - The injection unit
  - The mold
  - The polymer

- **The physical basis of polymer processing**
  - Heating of the polymer by viscous dissipation and conducted heat
  - The viscosities of melts and non-Newtonian flow
  - Enthalpy and viscosity values for polymers
  - Non-steady state heat flow during cooling of molding

- **The principal process control parameters**
  - Temperature of melt
  - Temperature of mold
  - Pressure of injection and hold-on pressure
  - Speed of injection
  - Timing of the various parts of the process cycle

- Design aspects
  - Weld lines
    - These form where polymer flows meet and they can sometimes be avoided.
    - If welds are unavoidable they can often be moved to a position on the molding where they are unimportant , by control of the gate position.
  - Sink marks and voids
    - The thick part retains heat and is drawn down by contraction forces.
    - This is essentially a design problem, to be designed out as far as possible by avoiding thick sections.

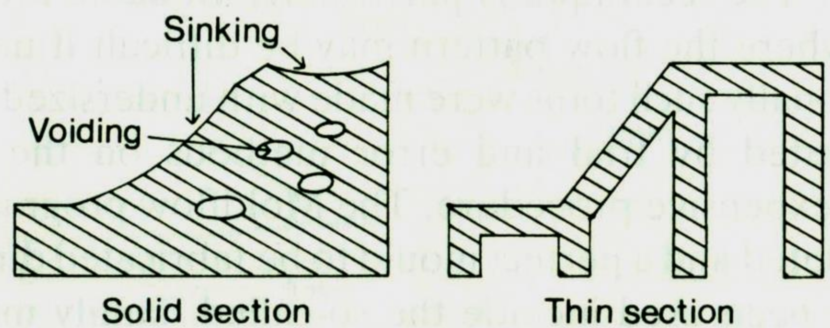


Fig. 8.19 Use of ribs instead of a solid section.

- Stress concentration
  - The consequence of stress concentrations in moldings with sharp corners can often be failure, especially if the product is load-bearing.

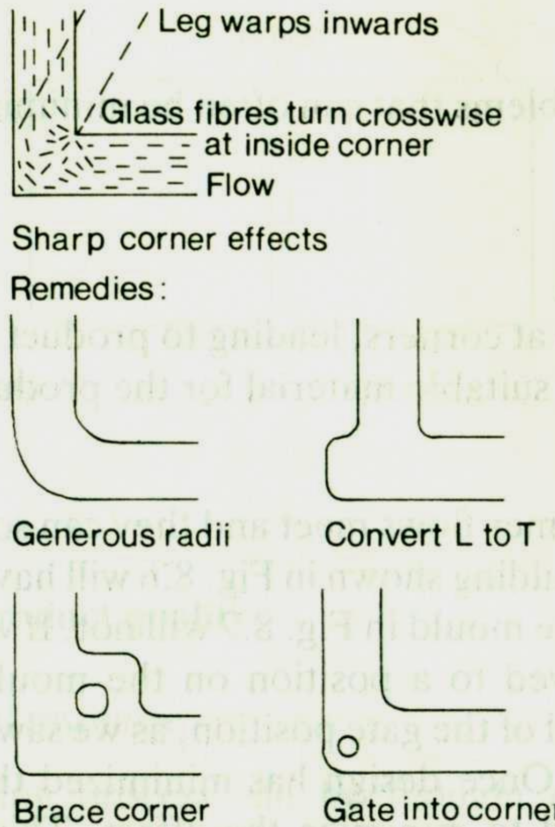
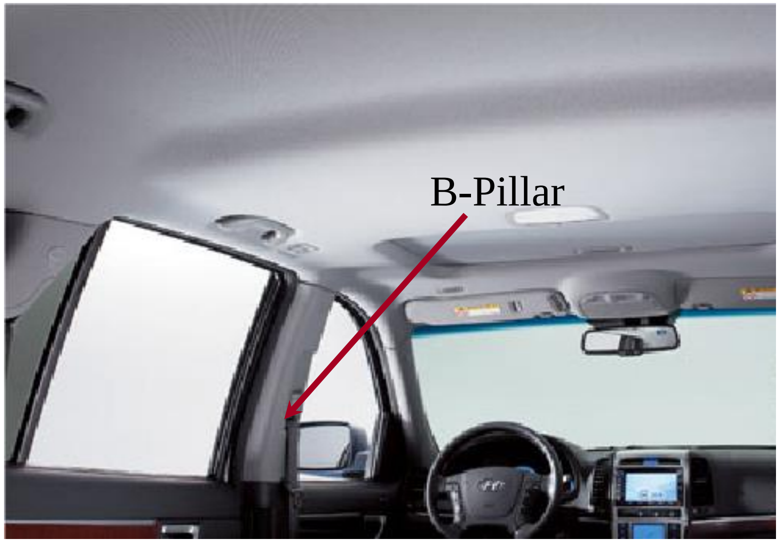
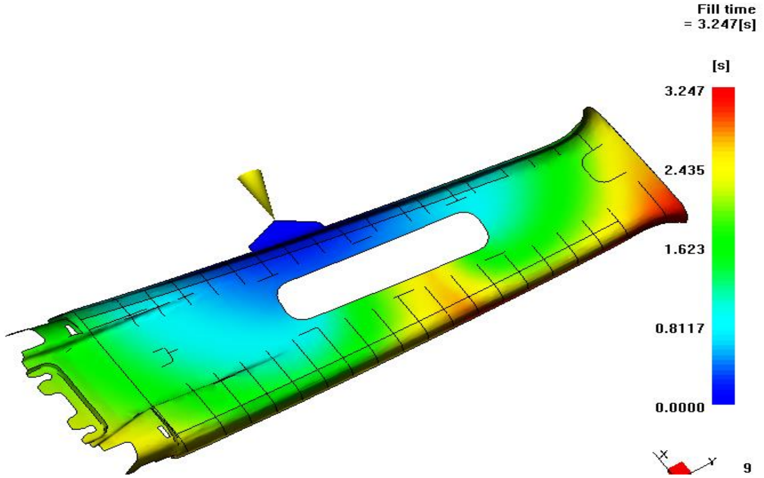


Fig. 8.20 Design features to avoid the effects of sharp corners.

- Computer-aided mold design
  - Mold flow
  - The Moldflow program allows the trials to be simulated and a perfect mold to be fabricated directly.





- Polymer selection
  - Suitable materials are selected by the computer.
    - The advent of cheap computer power has made possible a type of CAD approach.

- Effects of shear heat and pressure
  - In the narrow runners, gates, etc. of an injection mold the shear rate is about $10^3\ s^{-1}$.
  - Therefore, polymer behaves pseudoplastically.
  - Another effect of high shear is the generation of heat.
  - Pressure can be regarded as an equivalent negative temperature.

    (temperature increase = expand, Pressure increase = shrink)

• Orientation

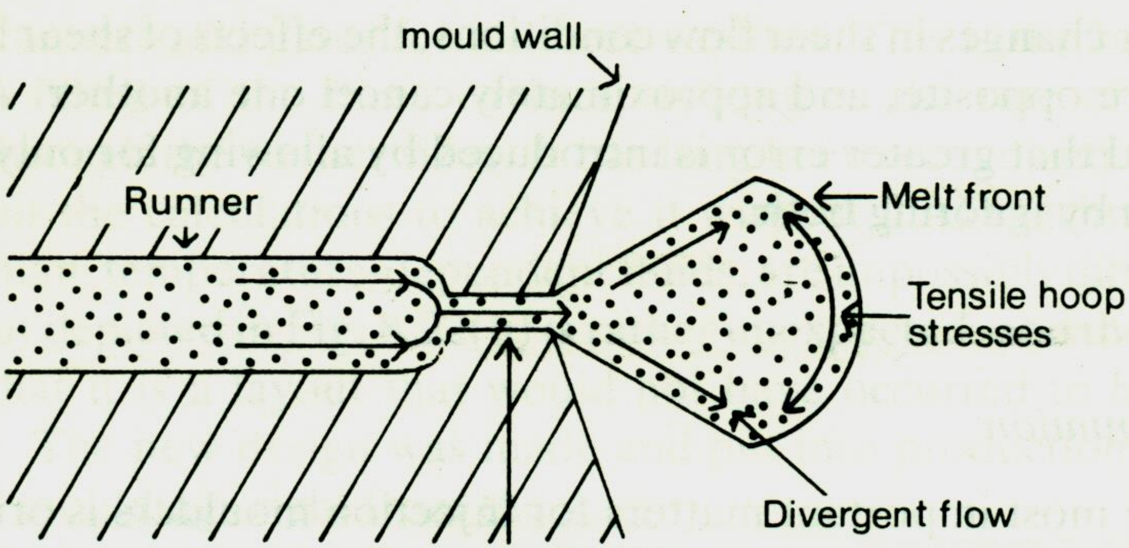


Fig. 8.24 Orientation effects at melt front.

• Shrinkage and warpage

Table 8.2 Some approximate shrinkage values

Polymer	*Percentage shrinkage*
ABS	0.3–0.8
Acetal	0.0–2.2
Acrylic	0.2–0.8
Cellulose acetate	0.5
Nylon 6,6	1.5
Polycarbonate	0.6
Noryl	0.7
LDPE	2.0
HDPE	4.0
Polypropylene	1.5
Polystyrene	0.5
uPVC	0.3
Plasticized PVC	1.0–5.0

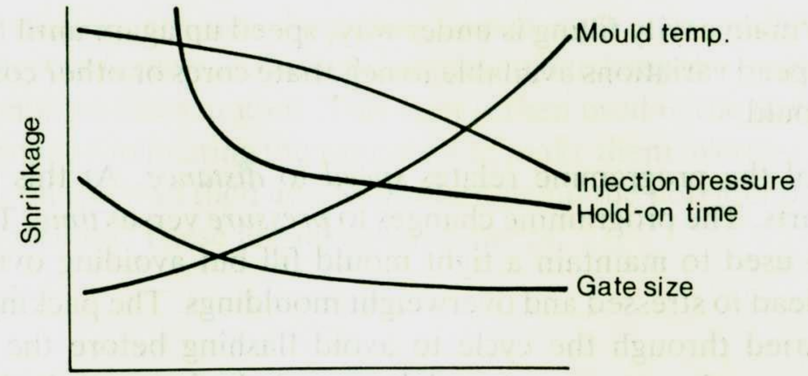
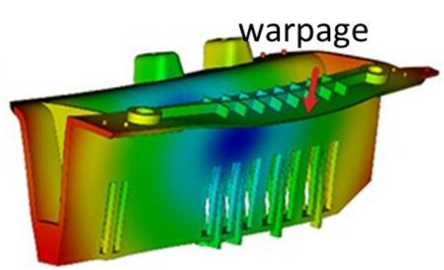
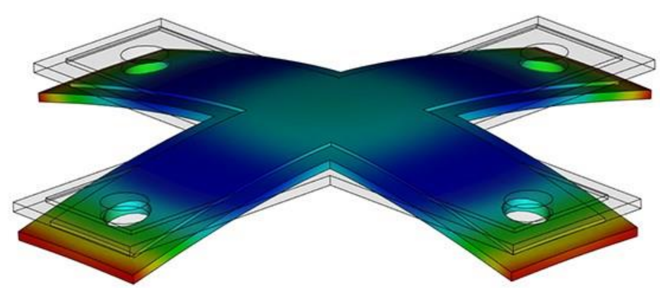


Fig. 8.25 Effects of processing conditions on shrinkage.



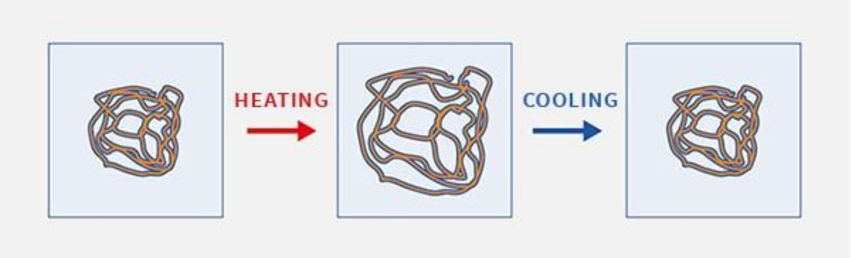


Ref. Plastics technology

• Shrinkage and warpage

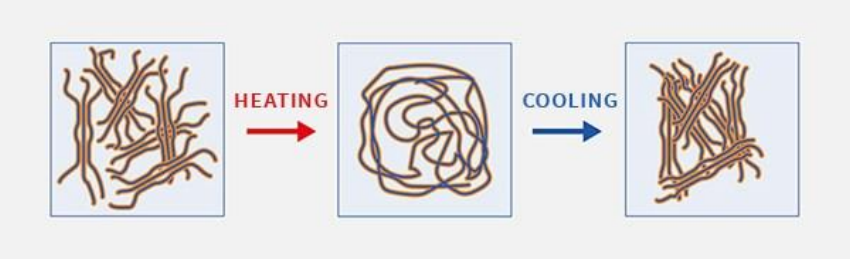
1. Amorphous Materials

- Materials such as ABS, polystyrene, polycarbonate
- Random and entangled molecular orientation
- When flow stops, the molecules relax and return to random orientation



2. Semi-crystalline Materials

- Highly ordered, tightly bundled molecular structures
- Then they melt, the crystalline structures loosen and the molecules align to the direction of flow, much like amorphous polymers
- when the materials cool, they don't relax. Instead, they maintain their orientation in the direction of flow and the molecules begin to recrystallize, resulting in significantly higher shrinkage rates

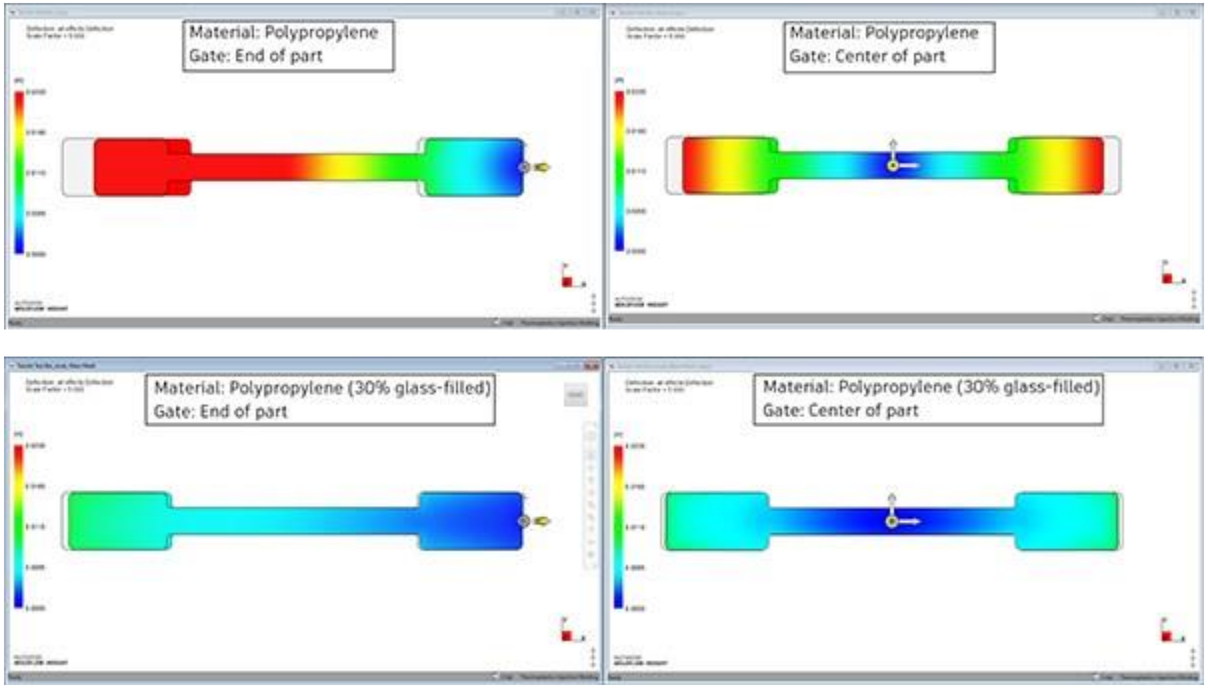


Ref. Plastics technology

• Shrinkage and warpage

3. Fiber-reinforced materials

- When fibers are introduced into the plastic, they may counteract shrinkage effects - Random and entangled molecular orientation
- Fibers do not expand or contract as temperature changes, so fiber-filled materials will typically experience reduced shrinkage in the direction of their orientation



• Shrinkage and warpage

• Causes of shrinkage and warpage

- Cooling rates

: a high cooling rate results in less time for the crystalline structures to form → decrease in total volumetric shrinkage

- Orientation due to filling

: the orientation of long, stringy polymer molecules is caused by shear stress during flow.

- Mold restraint

: While the part is in the mold, it can't shrink within the plane of its surface, but it can shrink in the direction of its thickness.

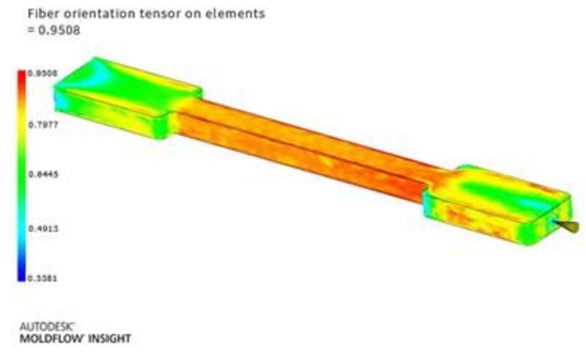
: The higher the mold temperature, the lower the cooling rate, and the more stresses relax from the part.

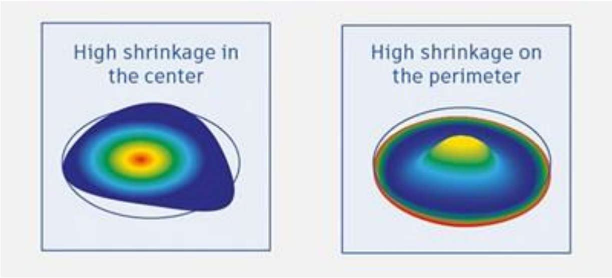
- Temperature differences through the thickness

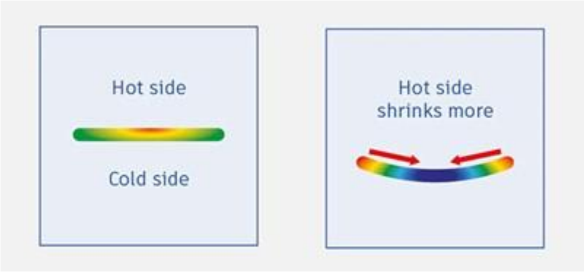
: When the mold temperature on one side of the cross-section is different from the other, shrinkage will not be uniform from side to side.

- Thickness variations

: When there are varying thicknesses of the part, thick areas will take longer to cool, which can lead to higher shrinkage.







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