The University of Nottingham

Polymer Engineering

(MM3POE)

INJECTION MOULDING

http://www.nottingham.ac.uk/~eazacl/MM3POE

Contents

- Principles of injection moulding
- Reciprocating screw machine
  - *Moulding sequence*
  - *Machine features*
- Injection mould design
- Mould filling calculations
  - *Filling pressures*
  - *Clamping forces*
  - *Filling times*
- Component design for injection moulding

1. Introduction

Principles of Injection Moulding:

Melting : Thermoplastic material (granules/pellets) heated to melt polymer

Melt Transport & Shaping : Polymer melt is forced through a nozzle into a closed mould

Stabilisation : Component cools in relatively "cold" mould prior to ejection

Main Advantages:

- Automation & high production rates
- Manufacture of parts with close tolerances
- Versatility in moulding wide range of products

  eg. appliance housings,washing up bowls, gearwheels, fascia panels, crash helmets, air intake manifolds

1. Introduction

Plunger Type Machines

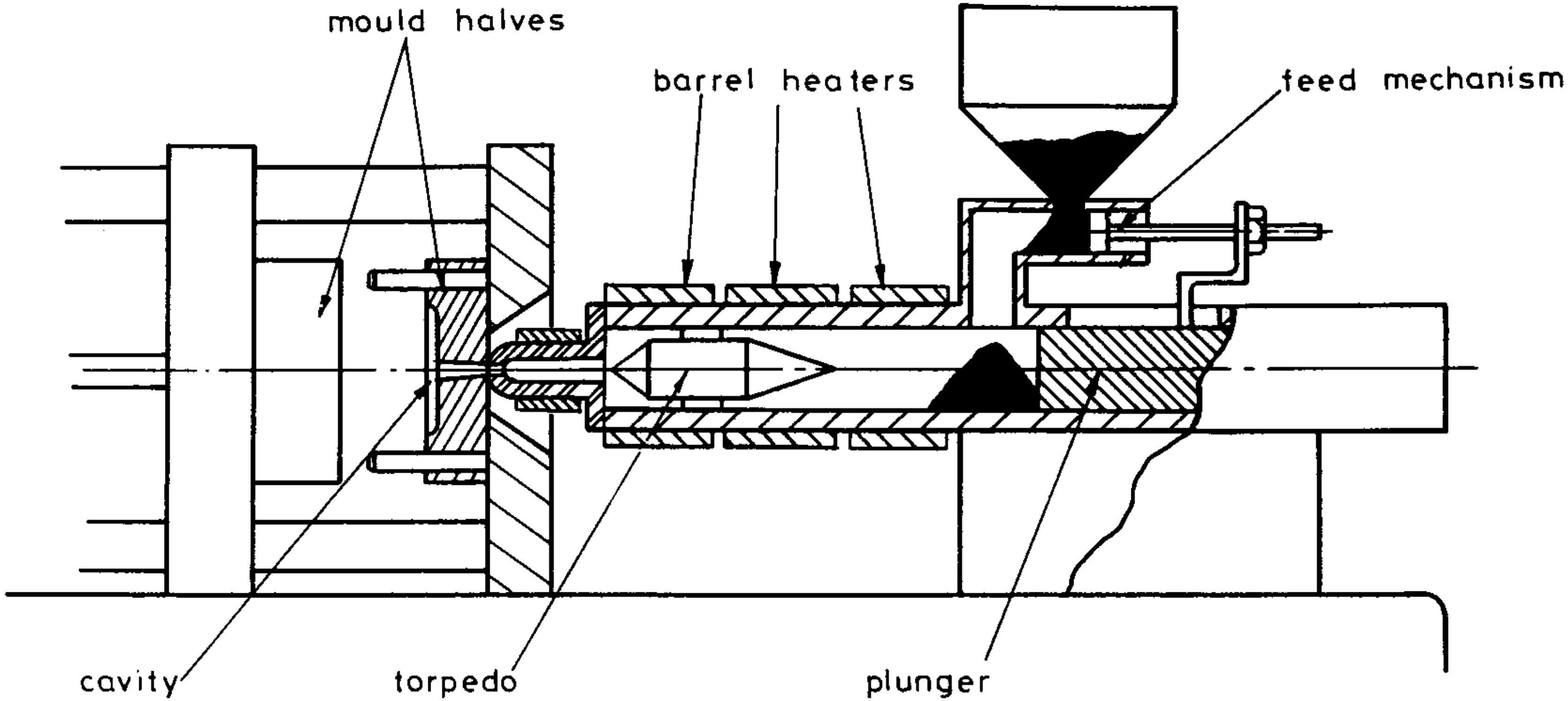


Fig. 4.30 Plunger type injection moulding machine
R J Crawford (1998) Plastics Engineering, Butterworth-Heinemann.

1. Introduction

Plunger Type Machines

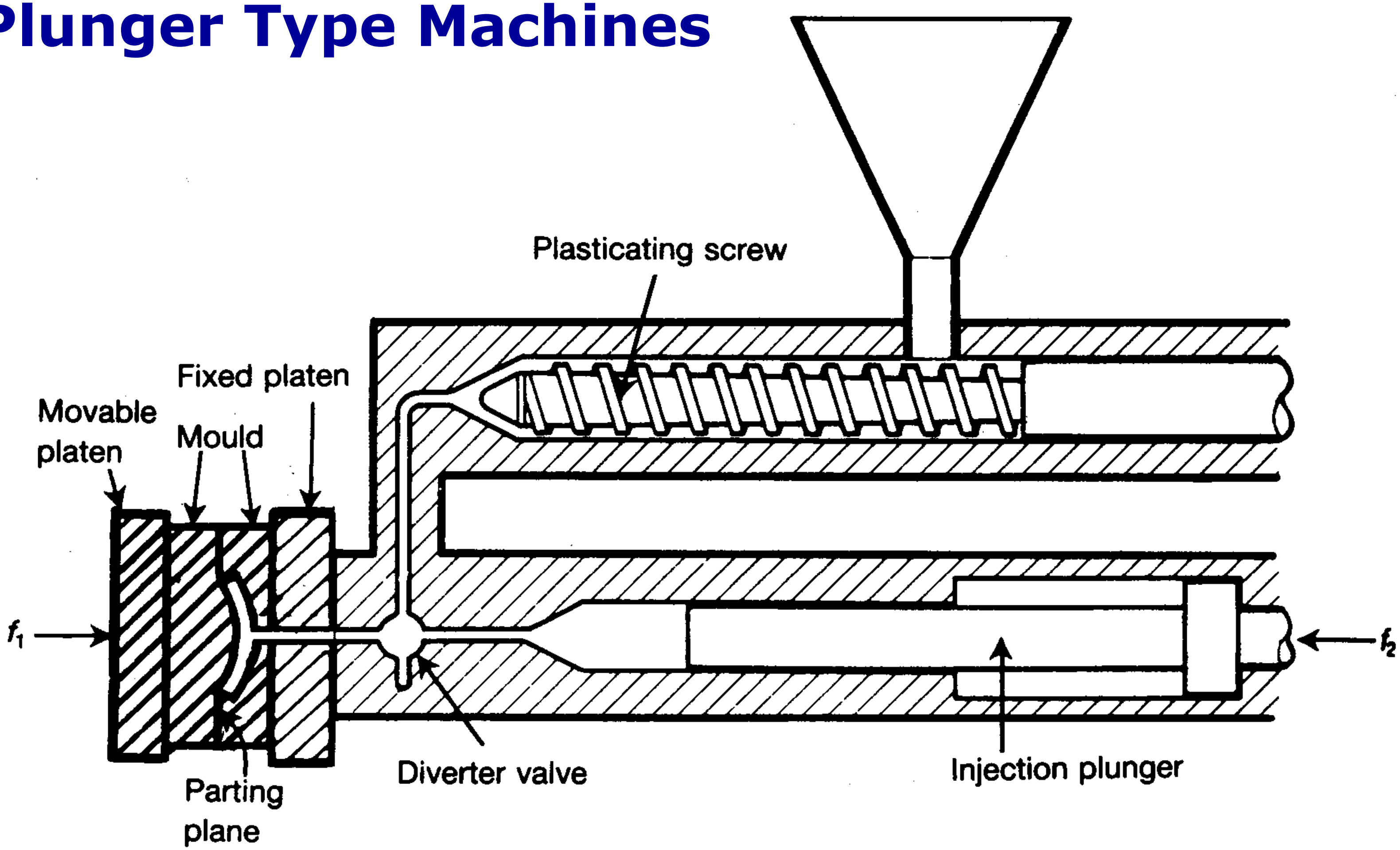
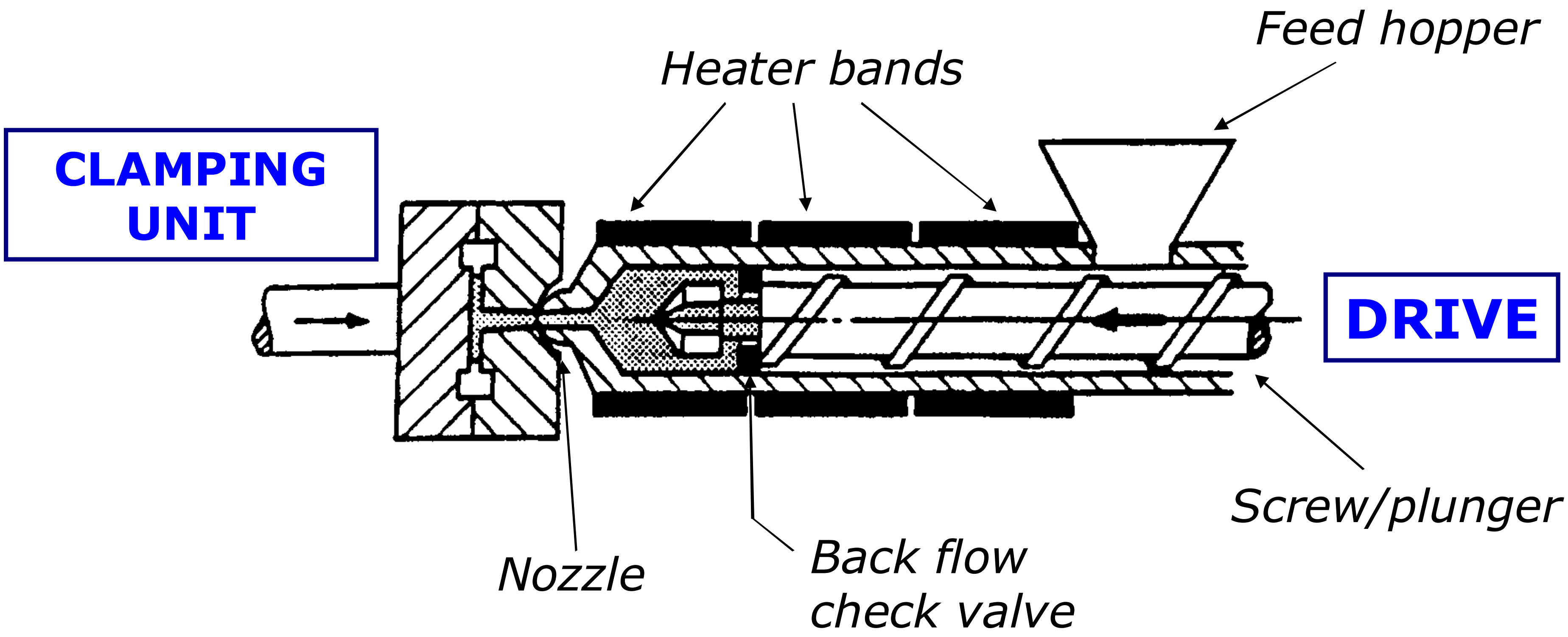


Fig. 7.3 Injection moulding machine with screw preplasticator unit

N G McCrum et al (1997) Principles of Polymer Engineering, Oxford Science Publications.

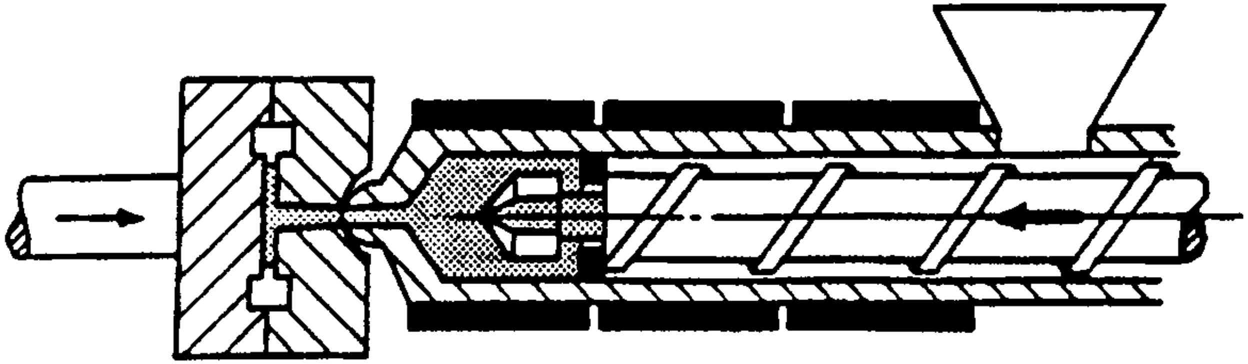
2. Reciprocating Screw Machine

Machine Features:



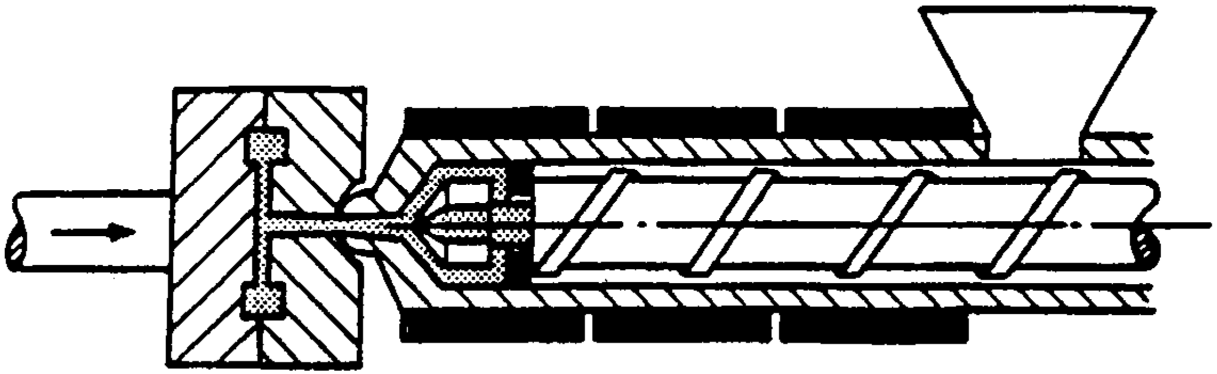
2. Reciprocating Screw Machine

(a) Mould closes & screw (not rotating) injects melt into mould.



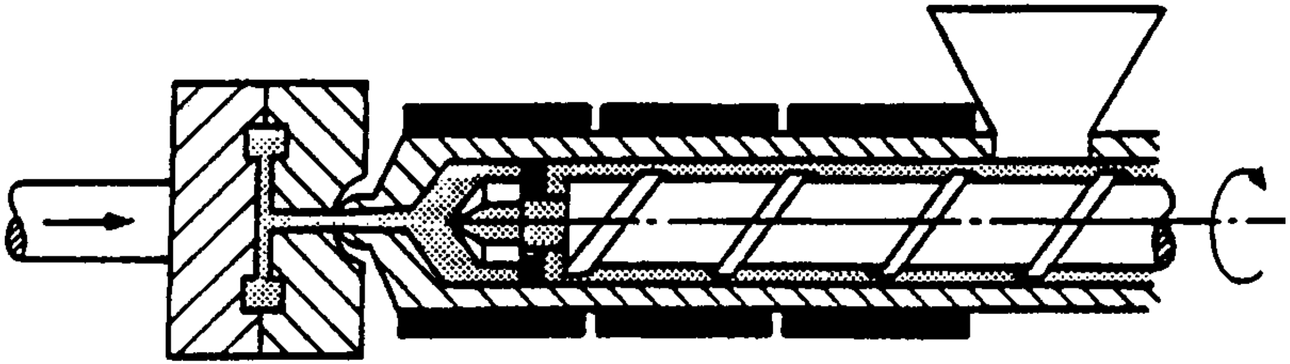
2. Reciprocating Screw Machine

(b) Screw maintains pressure until material sets at the gate.



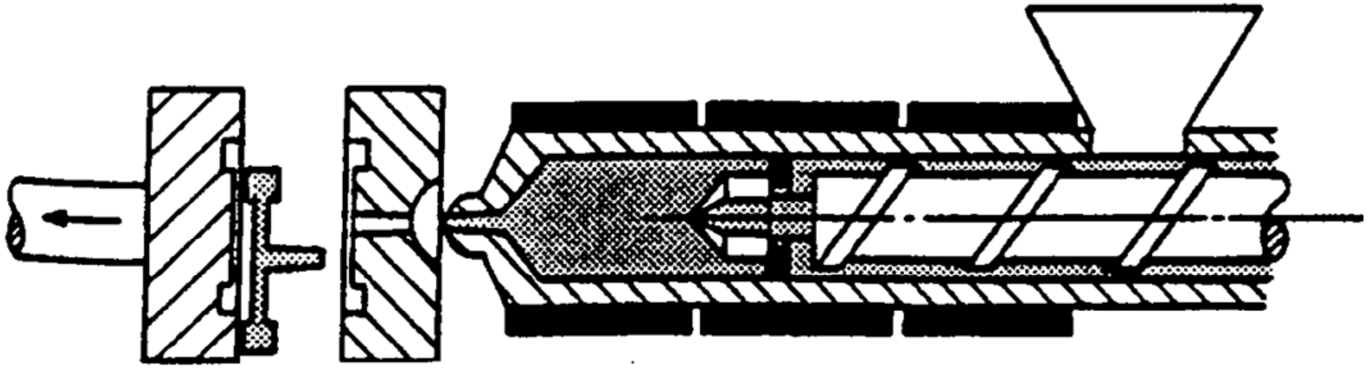
2. Reciprocating Screw Machine

(c) Screw (rotating) draws material from hopper & plasticises it. Back pressure forces screw back until shot volume reached.



2. Reciprocating Screw Machine

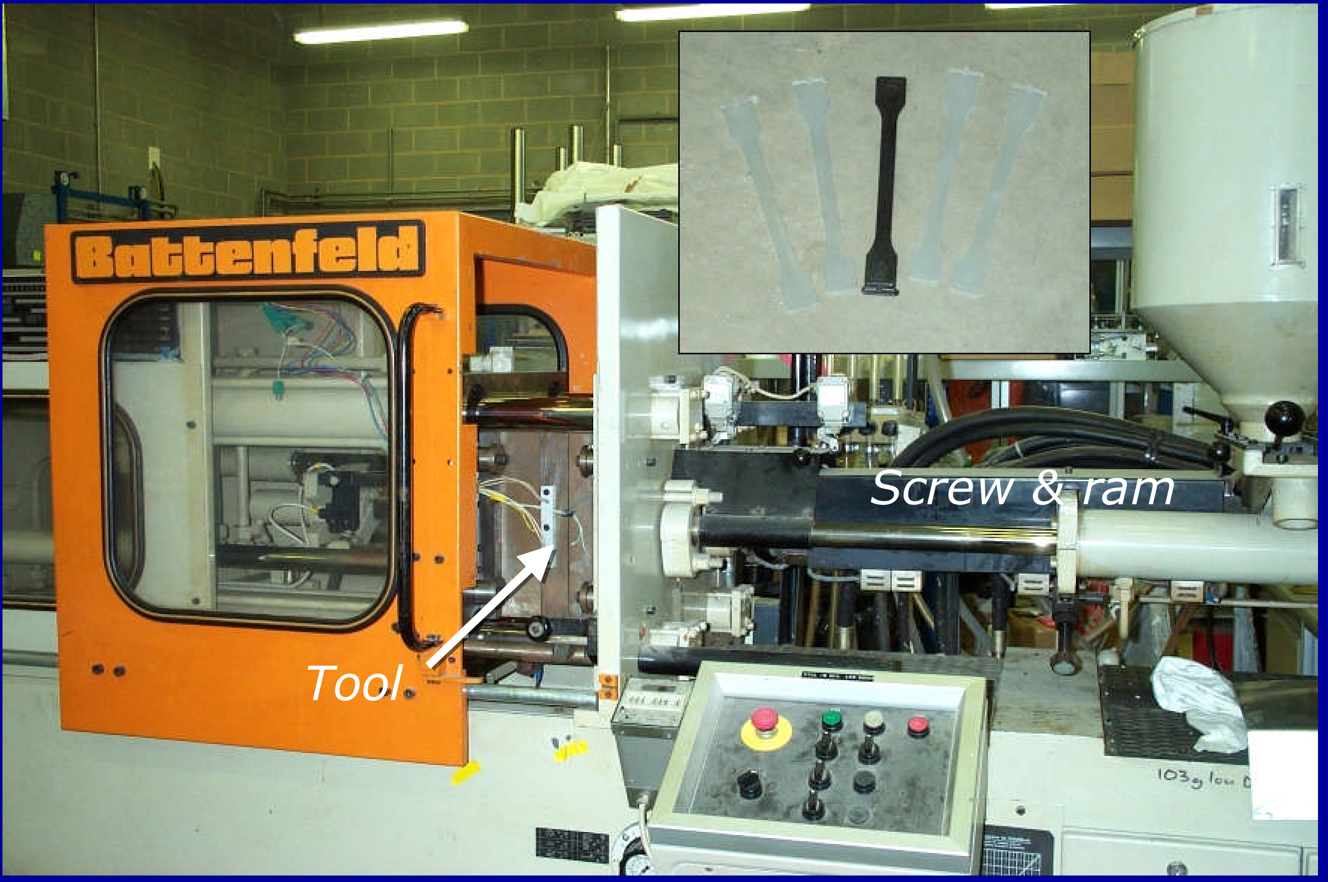
(d) When moulding has set, mould opens & part is ejected.



Animation from: www.bpf.co.uk

2. Reciprocating Screw Machine

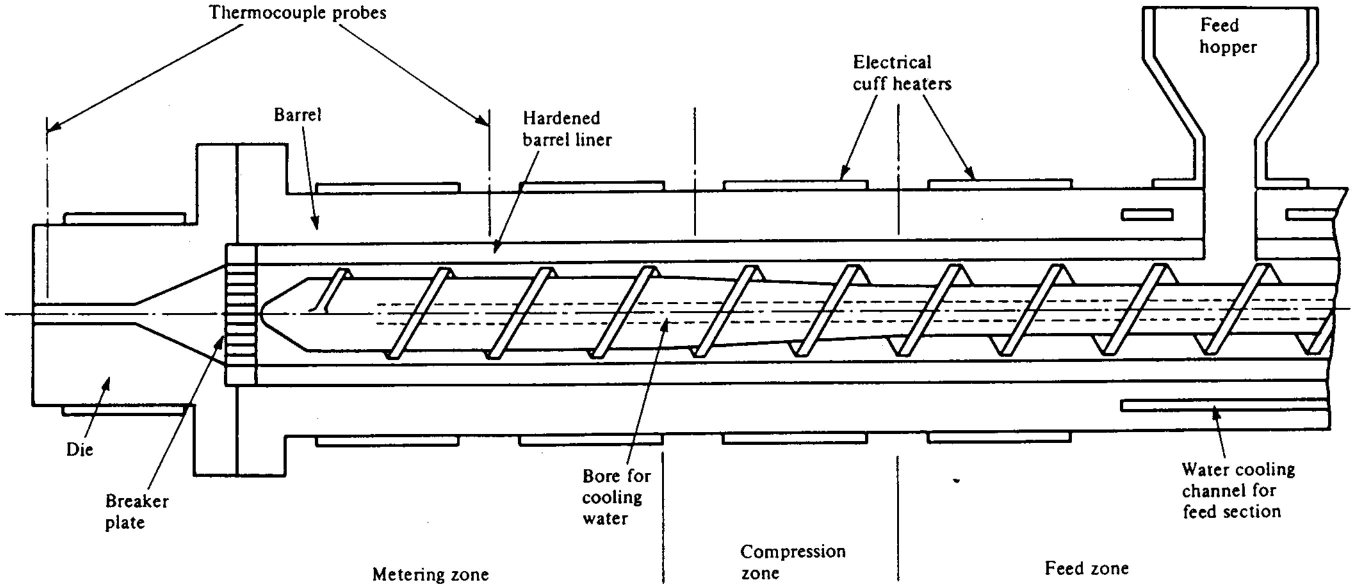
Hopper



Injection moulder with nanocomposite tensile specimens (inset)

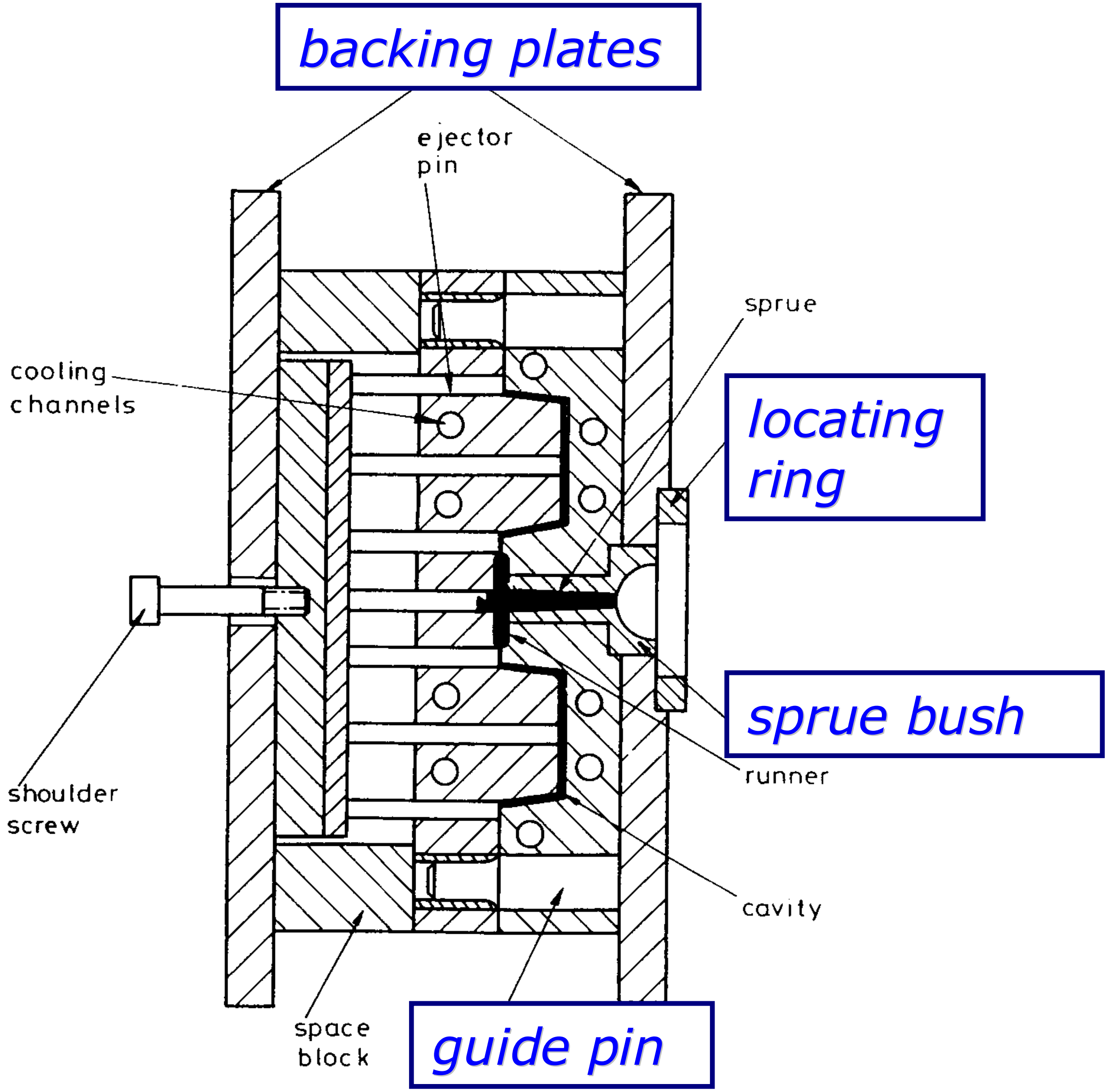
2. Reciprocating Screw Machine

Screws: Similar to extruder screws

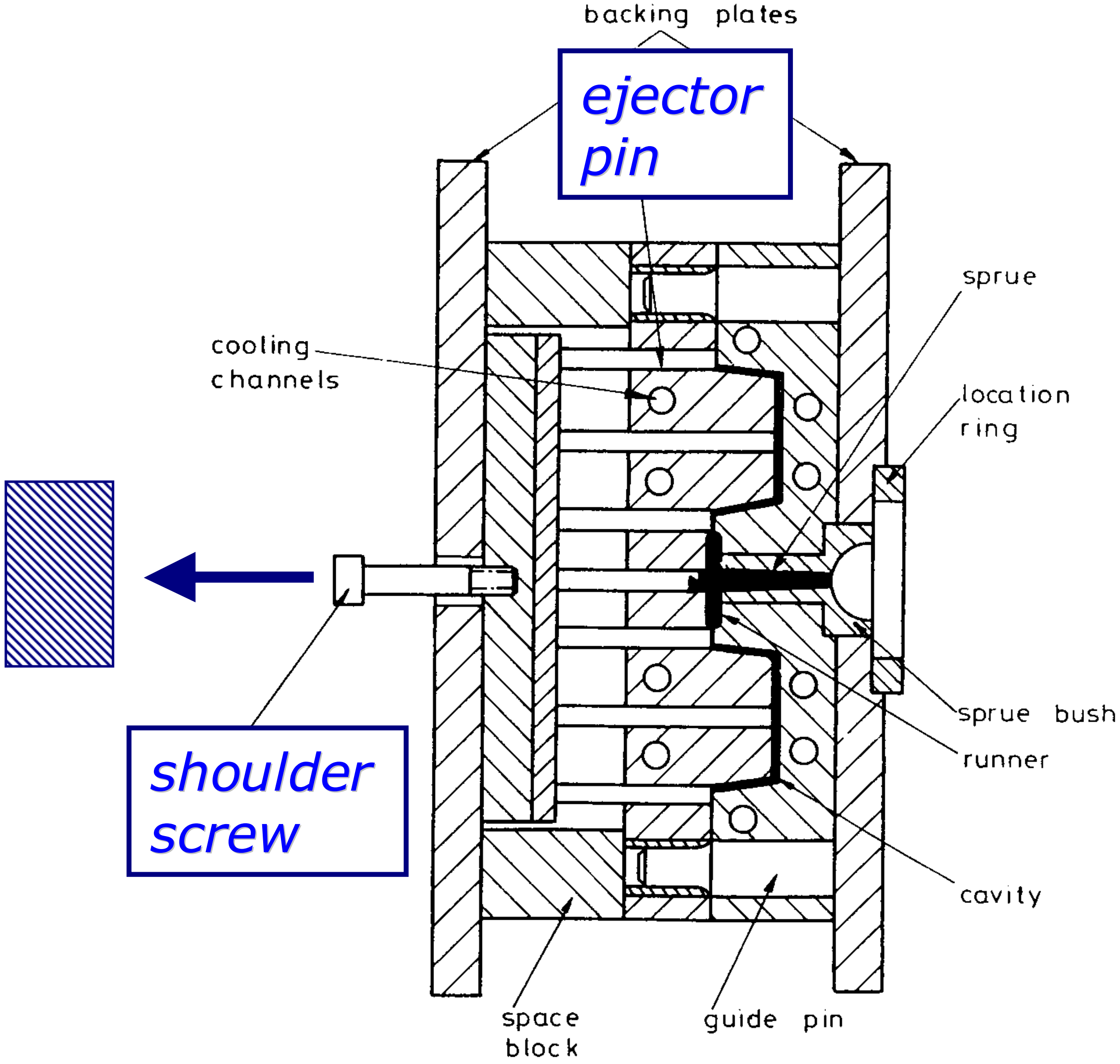


- Length/Diameter ratios 15-25
- Compression ratios 2.5-4.0 : 1
- Injection pressure up to 200 MPa

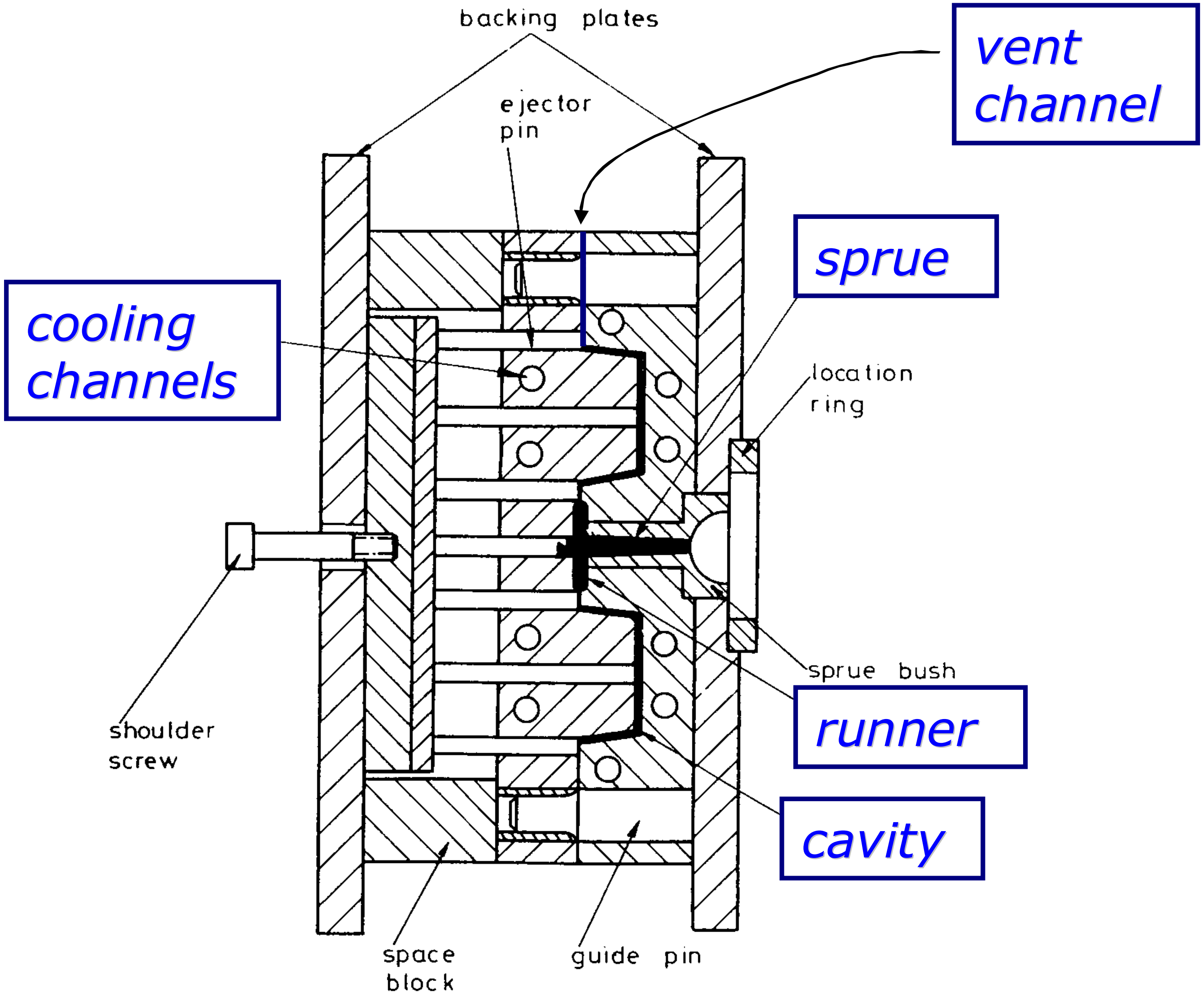
3. Injection Mould Design



3. Injection Mould Design



3. Injection Mould Design



3. Injection Mould Design

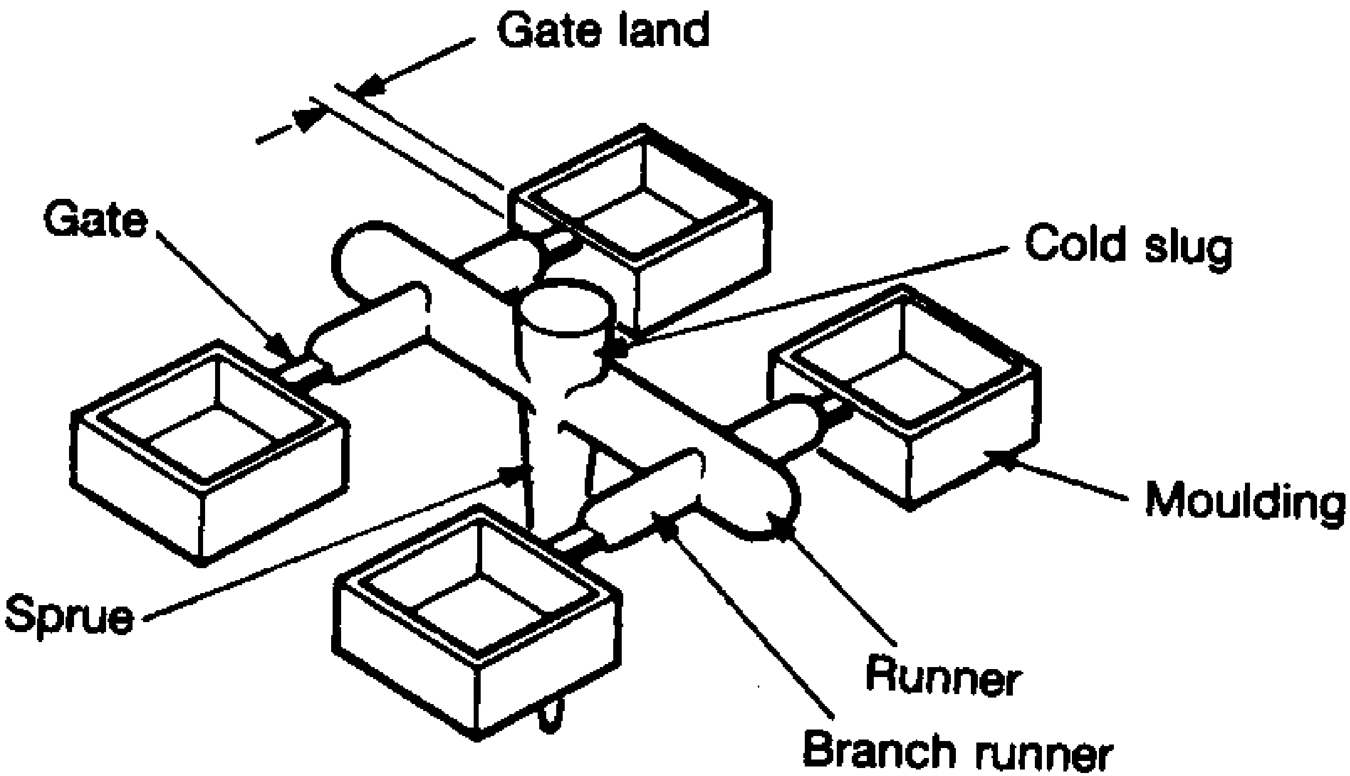


Fig. 7.31 Feed system of multi-impression mould

N G McCrum et al (1997) Principles of Polymer Engineering, Oxford Science Publications.

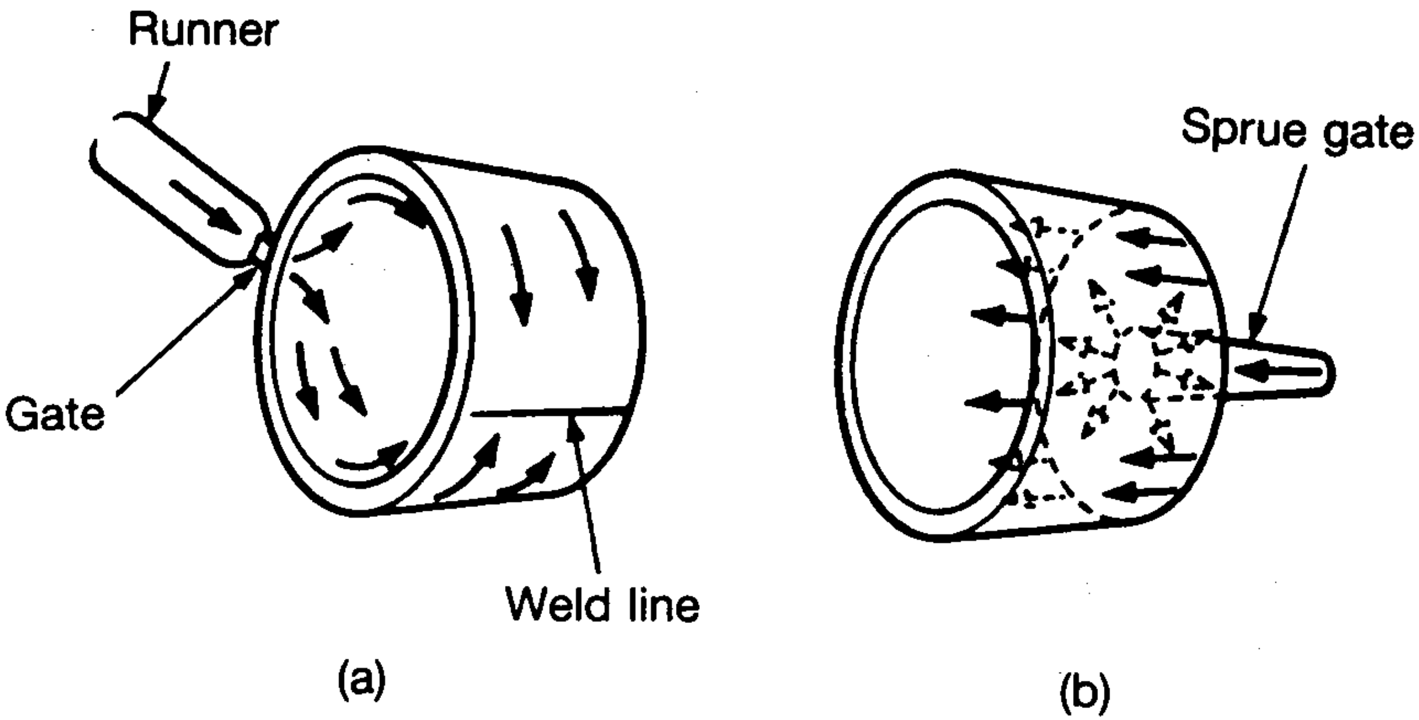
3. Injection Mould Design

Plastic Stool

Aalborg Universitet, Denmark
http://www.aaue.dk/bm/mfg/

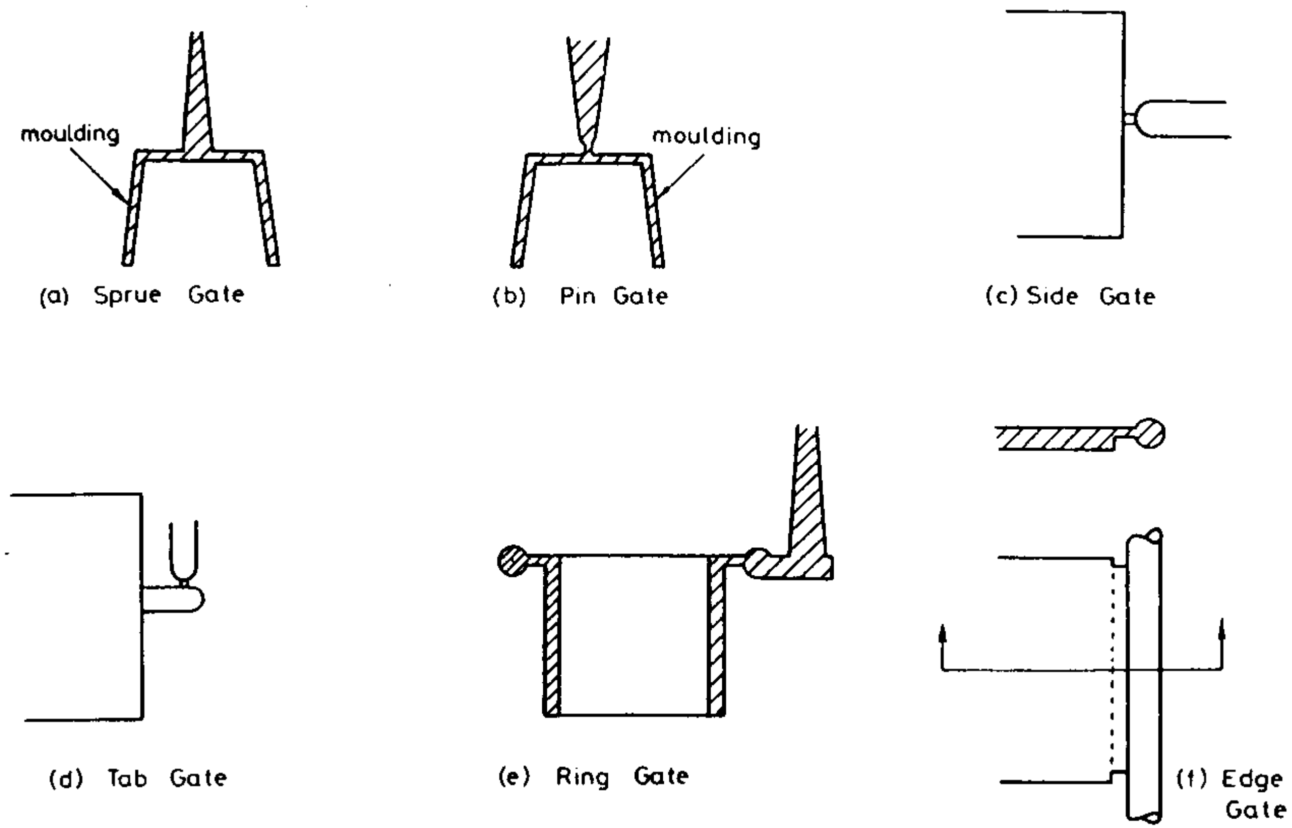
3. Injection Mould Design

Gate: Narrow constriction at entrance to cavity (impression). Incorrect gating can lead to problems during flow:



3. Injection Mould Design

Gate: Narrow constriction at entrance to cavity (impression). Incorrect gating can lead to problems during flow:



3. Injection Mould Design

Typical process conditions:

- Process is **non-isothermal** as mould & barrel are at different temperatures:

Table 1: Injection moulding conditions for thermoplastics (after Elias)

Polymer	T_G/°C	T_M/°C	T_{poly}/°C	T_{mould}/°C
Amorphous polymers				
PC	150	-	280 - 320	85 - 120
SAN	120	-	200 - 260	30 - 85
ABS	100	-	200 - 280	40 - 80
PS	100	-	170 - 280	5 - 70
PMMA	105	-	150 - 200	50 - 90
uPVC	82	-	180 - 210	20 - 60
Semi-crystalline polymers				
PET	70	265	270 - 280	120 - 140
PTFE	40	220	220 - 280	80 - 130
PA 6	50	215	230 - 290	40 - 60
POM	-82	181	180 - 230	60 - 120
PP	-15	176	200 - 300	20 - 60
HDPE	-80	135	240 - 300	20 - 60
LDPE	-80	115	180 - 260	20 - 60

5. Mould Filling Calculations

- Require expressions to calculate maximum injection pressure to fill a part

    To design/select injection system
    To determine clamping force

- In practice moulding operation can be complex:

    Non-isothermal & non-Newtonian - hence $\eta = f\,(T, \dot{\gamma})$
    Flow within sprue, runners, gate & mould cavity
    Injection sequence can be relatively complex

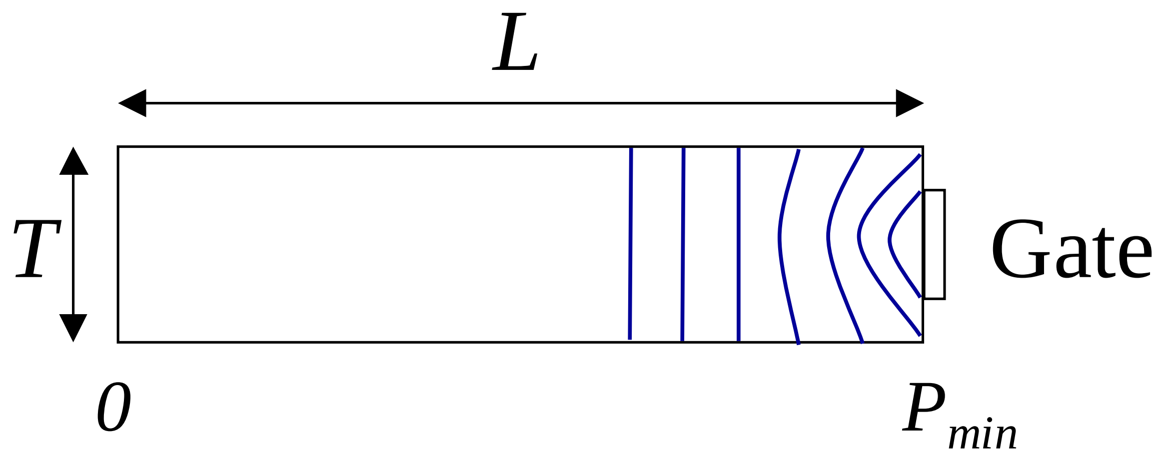
- Can obtain reasonable approximation from:

    Isothermal analysis
    Mould cavity only
    Constant flow rate

5.1 Filling Pressures

Injection pressure (P_{min}) for given flow rate (Q) can be determined from non-Newtonian flow expressions (see *Melt Rheology & Processing* notes).

Rectangular cavity (depth h):



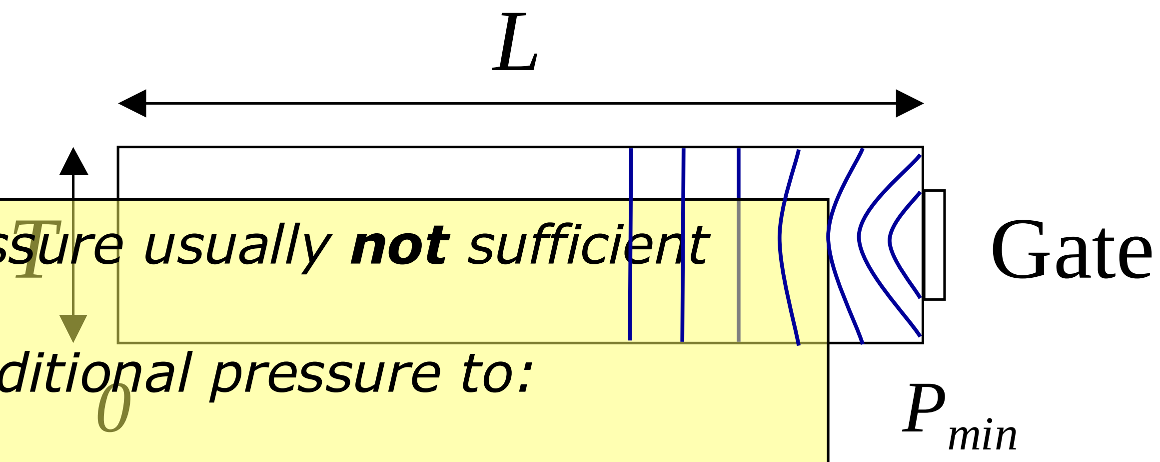
$$P_{\min} = \text{pressure drop } |\Delta P| = 2C \, . \frac{L}{h}\left[\frac{(2n+1).2Q}{nTh^2}\right]^n$$

$$\approx \frac{12\eta_a LQ}{Th^3} \quad \text{(Newtonian, ie. } n=1\text{)}$$

5.1 Filling Pressures

Injection pressure (P_{min}) for given flow rate (Q) can be determined from non-Newtonian flow expressions (see *Melt Rheology & Processing* notes).

Rectangular cavity (depth h):



$$P_{min} = \text{pressure drop } |\Delta P| = 2C \,.\, \frac{L}{h}\left[\frac{(2n+1).2Q}{nTh^2}\right]^n$$

$$\approx \frac{12\eta_a LQ}{Th^3}$$ *(Newtonian, ie. n=1)*

*Min. pressure usually **not** sufficient*

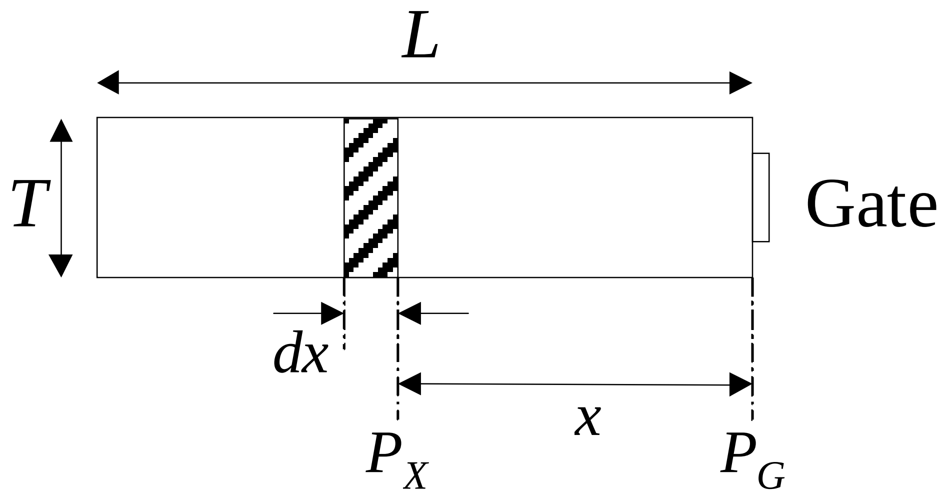
Apply additional pressure to:

- *Compact material*
- *Counteract shrinkage*

Hold-on pressure of up to 2 x P_{min}

5.2 Clamping Forces

Rectangular cavity:



Force required to clamp element of mould dx:

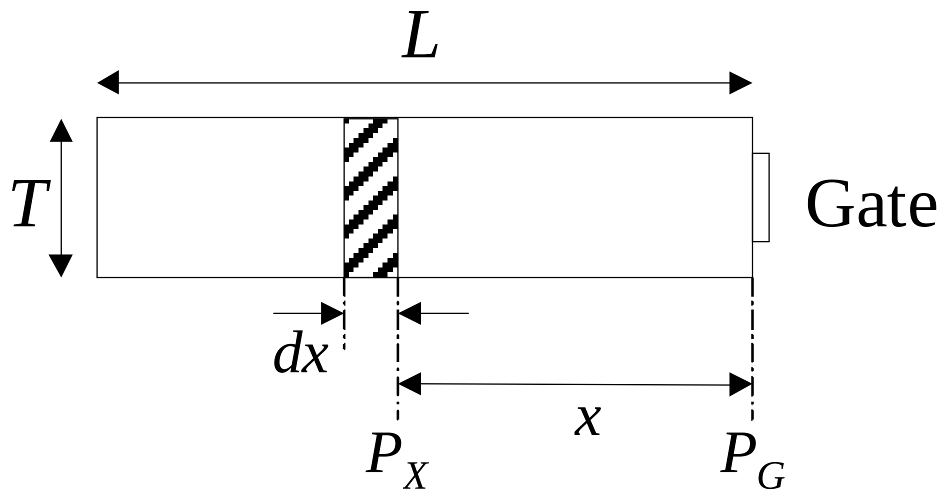
$$\delta F = P_x \, \delta A = P_x \, T \, dx$$

Total clamping force:

$$F = \int_0^L P_x T \, dx \qquad P_x = P_G - \frac{x}{L} |\Delta P|$$

5.2 Clamping Forces

Rectangular cavity:



Assuming linear pressure distribution:

$$P_x = P_G - \frac{x}{L}\left|\Delta P\right|$$

Therefore:

$$F = T\int_0^L \left[P_G - \frac{x}{L}\left|\Delta P\right|\right]dx = T\left[P_G L - \frac{L\left|\Delta P\right|}{2}\right]$$

$$= TL\left[P_G - \frac{\left|\Delta P\right|}{2}\right]$$

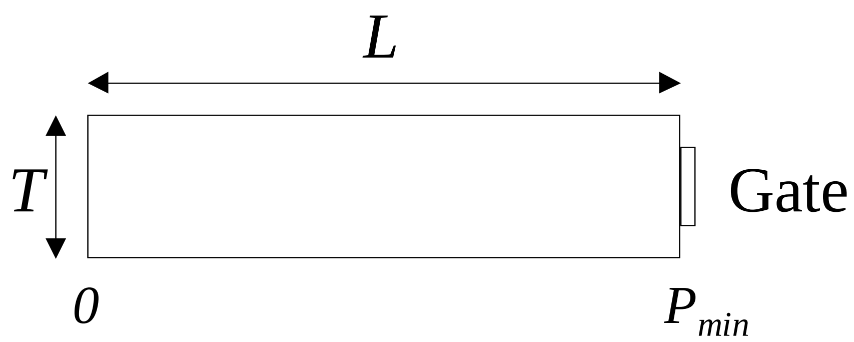
Clamping force = *Projected area* x *Mean pressure*

5.3 Mould Filling Times

The time to fill a mould is simply:

$$t_f = \frac{total\ volume}{volume\ \ flow\ rate}$$

eg. for a *rectangular* mould cavity:



$$t_f = \frac{TLh}{Q}$$

5. Mould Filling Calculations

Worked Example - Injection Mould Filling

Calculate the minumum gate pressure required to fill a rectangular plaque cavity, 150mm x 25mm x 3mm, with Acrylic resin in one second, assuming the following conditions:

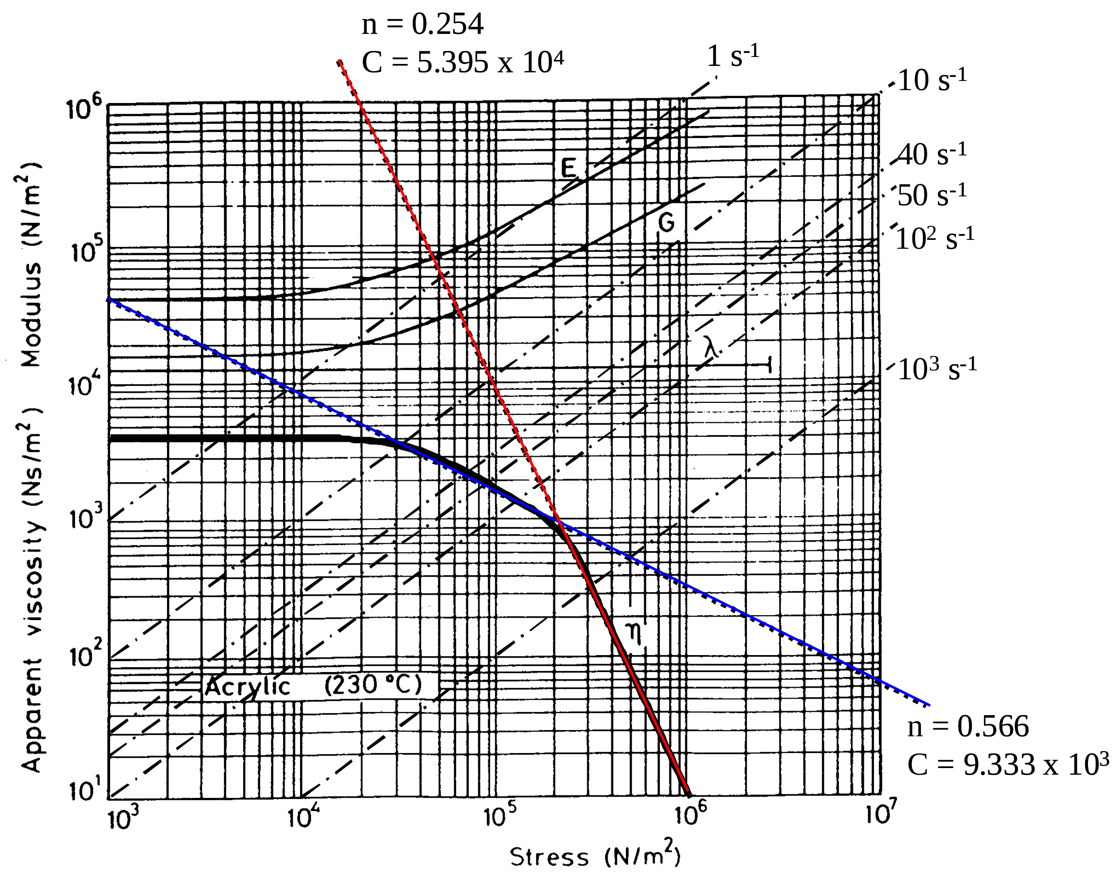
(a) Newtonian flow with apparent viscosity $\eta_a = 1000 \text{ Ns/m}^2$

or (b) Non-Newtonian flow using Acrylic flow data.

If the gate pressure is 1.5 X this minimum, estimate the mould clamping force required for a double impression mould.

Page 11

5. Mould Filling Calculations



Page 13

5. Mould Filling Calculations

Exercise sheet 4,
Qu. 1 – Fig. Q1