Injection Moulding Technology

Part 3

Mould Design & Construction
Session aim

To gain an understanding of general mould design and construction techniques, and to become familiar with the purpose and function of the various component parts.
Session objectives

By the end of the session you will be able to:

- Identify the component parts of a two plate mould.
- List two advantages and limitations for various gate design alternatives.
- Detail the requirement for venting the mould.
- State the three elements of the feed system.
- Identify applications for typical runner less mould designs.
- Explain the importance of mould temperature control.
Mould Design

- Mould material
- Cost restraints
- Component detail
- Component material
- Moulding machine
- Quantity
- Mould making techniques
- Post moulding operations
- Mould life
Question 1

List the advantages & disadvantages of a multi-plate mould?
Multi-plate mould tool
Multi-plate mould tool

Advantages
- Centre gating of multi cavity.
- Side gating easily achieved.
- Multi-point gating easily achieved.
- Automatic de-gating.

Disadvantages
- Higher cost of tooling.
- More moving parts.
- Critical opening stroke.
- Runner wastage.

Stripper plate
Question 2

On a mould that incorporates a hot runner, what might soft start facility be used for?
Hot runner
The hot runner

Ideally the sprue bush, hot tips and the manifold should have separate controllers and thermocouples. On the example four zones are required.
Hot runner systems

The 2 plate tool

Increases the mould height.

Saved material waste from the sprue & runner.

Material delivered to the cavities in the same condition as the melt left the barrel.
Question 3

Please list 3 advantages and 3 limitations when using hot runner moulds?
Limitations of a hot runner

- Increased set-up times.
- Warm up period required.
- Increased tooling costs.
- Manifold leaks.
- Higher maintenance costs.
- Degradation with certain polymers.
- Heat expansion problems.
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When a hot runner leaks… it leaks!
Advantages of a hot runner

- No feed system to be removed.
- Reduced mould open stroke.
- Reduced shot weight.
- Injection time reduced.
- Automatic de-gating.
- Easier to balance gates.
- Increased number of cavities possible.
When using hot runner moulds

- Avoid regrind to avoid blocked nozzles.
- Avoid heat sensitive polymers.
- Do not flick off cold slugs.
- Keep systems fully maintained.
Question 4

What is the primary function of a stack mould?
Stack mould - reduced projected area
Question 5

What are the different types of ejector pins and methods of ejection?
Combination round/blade ejection

Blade ejectors

Round ejectors
Sleeve ejection

Core pin

Sleeve
Sleeve ejection

Good even ejection around bosses but quite expensive.
Stripper plate ejection

Stripper block
Air ejection

Air off - spring returns valve to its rear position
Question 6

When would mechanical or hydraulic core movement be used?
Mechanical core pin movement
Core pulling
Core movement by hydraulics

Points to remember:

- Machines will need to be programmed.
- There are many different sequences.
- Must know the sequence, before opening or closing the mould.

If in doubt ASK!
Question 7

When designing a mould, utilising a cold runner system, what are the primary considerations to be addressed?
The feed system
Runner shape

Which shape will give the best flow?
Runner layout
Runner layout
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• Single Mould

• As the number of cavities increases, so must the machine tonnage

• 2, 4, 6, 8, 12, 16, 24, 32, 48, 64 cavities are typical. No odd numbers!
Question 8

Please list advantages & disadvantages for the selected gates:

- Sprue gate
- Pin gate
- Diaphragm gate
- Tab gate
- Flash gate
- Fan gate
- Tunnel gate
Gates

Sprue gate  Pin gate  Diaphragm gate
Tab gate  Flash gate  Fan gate
Submarine/tunnel gate
Submarine/tunnel gate
Gate considerations

- Size in relation to section thickness of the moulding.
- Always feed into the thickest section.
- Position gate to give even filling.
Question 9

Why is mould venting required?
Mould venting

To prevent burning/dieseling.

Vent depth 0.025mm

Exhaust grooves
Question 10

What are the general considerations for the correct moulding temperature?
Mould temperature control

- High enough to allow filling of the mould, without premature freezing of the polymer melt.

- As uniform as possible, to ensure the mould is cooled equally in all areas.

- **Mould temperature** has the greatest influence on part quality.
Piping up considerations
Cool core pin technology

Coolant flow

Used as an alternative to cooling channels.
Beryllium copper insert to improve cooling
Cooling baffles

- Baffles may be offset to achieve turbulent flow.
- Must be piped correctly.
Material entering the mould will be at its hottest.
Machine Practical 1
Injection Moulding Technology - Part 3

Injection Moulding Technology
Part 3
Mould Design & Construction
Injection Moulding Technology

Part 3

Plastics Materials
Aim

To provide an understanding of plastics materials technology and processing behaviour when injection moulded.
Objectives

By the end of the session you will be able to:

- Describe, in simple terms, the molecular structure of plastics materials.
- State three methods of classifying plastics, giving examples.
- Describe the MFI test and its relevance.
- Identify five common additives to modern plastics.
What are plastics?

- **Synthetic** - Man made
- **Organic** - Based on carbon
- **Polymers** - Many units
  - Describes the MOLECULES of polymers
Polymerisation example

ETHYLENE
Monomer
Polymerisation example

Catalyst - heat, pressure and time

ETHYLENE monomer → POLYETHYLENE polymer
### Polymer examples

- **Propylene monomer** → **Polypropylene polymer**
- **Styrene monomer** → **Polystyrene polymer**
- **Vinyl Chloride monomer** → **Polyvinylchloride polymer**
- **Phosgene Bis-Phenol Acetone monomer** → **Polycarbonate polymer**
Summary

- Polymer chains have a coiled spring like structure.
- About 5,000 times longer than their diameter.
- Chains are upwards of 1,000,000 repeat units long.
- Processing of polymers reduces the chain length and hence the loss of properties when using regrind.
Classifying plastics

Thermosets

Example - Bakelite

Heat

Melt

Flows due to pressure

Heat & Pressure

Cross-linking reaction

Curing/solidification
Classifying plastics

Thermosetting
Bakelite
Rubber
Epoxy
Melamine
Polyester
(Chemical change - Boiled egg)
Classifying plastics

Thermoplastics

Example - Polyethylene

Heat

Melt

Flows under pressure

Cool/remove heat

Solidification
Classifying plastics

Thermoplastics

- Polyethylene
- Polystyrene
- Polycarbonate
- Nylon
- Polyester

*(Physical change - Ice to water)*
Classifying plastics

Commodity

Engineering
Classifying plastics

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Plastic</th>
<th>Price/tonne</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polypropylene</td>
<td>£600 - £950</td>
<td></td>
</tr>
<tr>
<td>HDPE</td>
<td>£500 - £900</td>
<td></td>
</tr>
<tr>
<td>LDPE</td>
<td>£600 - £900</td>
<td></td>
</tr>
<tr>
<td>Polystyrene</td>
<td>£600 - £1200</td>
<td></td>
</tr>
<tr>
<td>SAN</td>
<td>£600 - £1200</td>
<td></td>
</tr>
<tr>
<td>Acrylic</td>
<td>£900 - £1500</td>
<td></td>
</tr>
<tr>
<td>ABS</td>
<td>£1500 - £2500</td>
<td></td>
</tr>
</tbody>
</table>

Prices are only approximate
# Classifying plastics

## Engineering

<table>
<thead>
<tr>
<th>Plastic</th>
<th>Price/tonne</th>
</tr>
</thead>
<tbody>
<tr>
<td>PET</td>
<td>£1000 - £1200</td>
</tr>
<tr>
<td>Acetal (POM)</td>
<td>£1100 - £1900</td>
</tr>
<tr>
<td>Nylon (PA)</td>
<td>£1600 - £2400</td>
</tr>
<tr>
<td>PBT</td>
<td>£1800 - £2700</td>
</tr>
<tr>
<td>PC</td>
<td>£2500 - £3500</td>
</tr>
<tr>
<td>PAI</td>
<td>£35000 - £40000</td>
</tr>
<tr>
<td>PEEK</td>
<td>£38000 - £69000</td>
</tr>
</tbody>
</table>

Prices are only approximate.

**Manifold PA66 GF35**
Classifying plastics

Amorphous versus Semi-crystalline!

What are the differences?
Structural changes of polymers

Molten state

Random structure
Amorphous

Flow

COOL

Ordered structure
Semi-Crystalline
Classifying plastics

Thermoplastics

Amorphous
- Polycarbonate
- A.B.S.
- Polystyrene
- S.A.N.
- Acrylic

Semi-crystalline
- Polyethylene
- Polypropylene
- Nylon
- Acetal
- Polyester
## Property differences

**Why is crystallinity important?**

<table>
<thead>
<tr>
<th>Amorphous</th>
<th>Semi-crystalline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generally clear</td>
<td>Generally opaque</td>
</tr>
<tr>
<td>Low mould shrinkage</td>
<td>High mould Shrinkage</td>
</tr>
<tr>
<td>0.5%</td>
<td>1.5%-2.5%</td>
</tr>
<tr>
<td>Wide melting range</td>
<td>Narrow melting range</td>
</tr>
</tbody>
</table>
Injection Moulding Technology - Part 3

Flow behaviour

Amorphous plastics
Melt and solidify over a WIDE temperature range.

Semi-crystalline plastics
Melt and solidify over a NARROW temperature range. (i.e they have a crystalline melting point)

Ease of flow

Temperature

Semi-crystalline
(PA)

Amorphous
(PMMA)
Homo-polymers

The homo-polymer chains comprise of the same repeat unit for their entire length.

Examples: HDPE, PA, POM, PVC, PS, PP.
Co-polymers

Co-polymer chains comprise of two or more different repeat units, which are linked together.

Examples: ABS, SAN, POM, PP, HIPS.

(ABS – Acrylonitrile-Butadiene-Styrene)
Blends & Alloys

Blends
Two or more different polymers in the same matrix but not linked.

- Noryl
- PPO/PS
- High Impact Polystyrene
- HIPS

Alloys
Two or more different polymers in the same matrix plus a chemically adhesive additive.

- Xenoy
- PC/PBT
- Bayblend
- PC/ABS
Additives in polymers

Why use additives?

- Modify processing performance.
- Modify service performance.
Types of additives

Assist processing

Heat stabilisers
Lubricants

Modify bulk mechanical properties

Plasticisers = Flexible PVC
Reinforcing fillers
Toughening agents

Reduce costs???
Powdered fillers e.g. talc or chalk

Essential additives

Additional additives

Modify surface properties
  Anti-static agents

Modify optical properties
  Pigments and dyes

Prevent ageing
  U.V. stabiliser

Others
  Blowing agents
  Flame retardants
Melt Flow Index apparatus (MFI)
Melt Flow Index apparatus

- Thermometer inside an oil filled well
- Barrel
- Insulation
- Polymer Melt
- Die

Avg. weight of extruded plastic in 10 mins.
Chain lengths can be shortened by processing or regrinding.

First pass

- Lower viscosity
- Higher MFI
- Lower strength material
Melt Flow Index

Summary

- The bigger the value - the easier the flow.
- Values can reflect relative chain lengths.
- Low shear (not representative of injection moulding)
- Spiral flow test better.
- Used as a quality control for incoming material.
- Specific test conditions must be used.
### Common trade names

<table>
<thead>
<tr>
<th>Trade names</th>
<th>Family names</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cycolac, Lustran, Terluran</td>
<td>ABS</td>
</tr>
<tr>
<td>Delrin, Hostaform, Kematal</td>
<td>Acetal (POM)</td>
</tr>
<tr>
<td>Plexiglas, Lucite (Perspex)</td>
<td>Acrylic (PMMA)</td>
</tr>
<tr>
<td>Lupolen, Rigidex, Vestolen</td>
<td>HDPE</td>
</tr>
<tr>
<td>Styron, Lacqrene</td>
<td>HIPS</td>
</tr>
<tr>
<td>Ultramid A, Zytel 66, Maranyl A</td>
<td>Nylon 66 (PA 66)</td>
</tr>
</tbody>
</table>
| Santoprene, EPDM                   | TPE’s
Pre-treatment of plastics

Moisture absorption - Hygroscopic

POM, PE, PP, PS, PVC
Not affected - drying not usually required.

PMMA, ABS, SAN, PP + talc
Water absorbed - may need drying.

PC, PET, PA, PBT, PUR
Damaged by water - needs drying.
Pre-treatment of plastics

Methods for removing moisture:

- Vacuum oven
- Dehumidifying dryer
Pre-treatment of plastics

Key drying considerations:

- Type of material – ABS, PC, PA plus virgin or regrind.
- Temperature and time required.
- Volume held in dryer to give correct throughput.
- Maintenance of dryer.
Injection Moulding Technology
Part 3
Plastics Materials
Injection Moulding Technology

Part 3

Processing & Troubleshooting
Processing
Aims during the injection phase

- Injection Speed & Pressure
- Mould 99% Full
- Start Mould Safety
- Apply Locking Tonnage
- Open Period
- Mould Closes
- Mould Opens
- Cooling Phase
- Holding Phase

Aims during the injection phase:

- **Injection Phase**: Mould 99% Full
- **Holding Phase**: Injection Speed & Pressure
- **Cooling Phase**: Open Period
- **Mould Opens**: Mould Closes
- **Mould Closes**: Start Mould Safety
- **Open Period**: Apply Locking Tonnage
Mould fill analysis
Melt flow behaviour

Frozen layers

Fountain flow

Mould cavity
Example of skin formation

Skin

New colour

Previous colour
Molecular orientation

Slow injection speed

Mould cavity

Low orientation/Stiff flow
Thicker frozen layers
Molecular orientation

Fast Injection Speed

High orientation/Easy flow
Thinner frozen layers
Residual stress

- Slower filling or colder moulds
- Thick frozen layers
- High residual stress!
Residual stress

- Faster filling or hotter moulds
- Thin frozen layers

Low residual stress!
Effect of residual stress

Fast fill rate - Lower internal stress

Slow fill rate - Higher internal stress
Injection phase

Summary

- Aim to fill the mould as quickly as possible.
- Uniform melt front speed as part fills.
- Mould cavities fill evenly.
- Ensure mould is 99% full.
Aims during the holding phase

- Start Mould Safety
- Apply Locking Tonnage
- Injection Speed & Pressure
- Mould 99% Full
- Hold Pressure & Time
- Gate Freeze-off
Polymer compression

Pressure is applied to the melt.

Melt density increases.

Material shrinkage reduces.
Gate freeze-off

Weight (gms)

Holding time (secs)

Gate frozen using 35°C mould & 230°C melt

Gate frozen using 55°C mould & 230°C melt
Holding phase

Summary

- Ensure adequate compression of the melt.
- Reduce sinks and voids by compensating for the shrinkage of the polymer chains.
- Obtain consistent component quality by establishing gate freeze-off time.
- Obtain correct component weight/dimensions by the application of a suitable pressure.

Rule of thumb:

- Amorphous plastics require a low holding pressure.
- Semi-crystalline plastics require a high holding pressure.
Aims of the cooling phase

- Mould Opens
- Injection Phase
- Holding Phase
- Mould Closes
- Cooling Phase
- Open Period

Events:
- Screw Back Completed
- Start Screw Rotation
- Gate Freeze-off
- Hold Pressure & Time
- Mould 99% Full
- Injection Speed & Pressure
- Start Mould Safety
- Apply Locking Tonnage
Factors to consider

- Polymer type – Semi-crystalline or Amorphous.
- HDT – Heat Distortion Temperature.
- Capacity of temperature control unit.
- Cooling time versus refill time (open nozzle).
Cooling rate, shrinkage & distortion

Mould Tool

HOT SIDE

COLD SIDE
Cooling rate, shrinkage & distortion

Residual orientation effect (stress)

- Hot side: Low orientation
- Cold side: High orientation

Normal shrinkage effect

- Hot side: More shrinkage
- Cold side: No shrinkage
Cooling phase

Summary

- To remove heat at an appropriate rate to promote maximum service properties.
- To remove the heat from all cavities evenly.
- To allow the part to be ejected without distortion.
- To provide sufficient time to plasticise a homogeneous mass of molten polymer.
Troubleshooting
Troubleshooting

ASSESSMENT

Is the fault acceptable – check the first off.

CORRECTION

If not, then check the basics first:

- The mould (damage, vents).
- The material (grade, batch, moisture).
- The machine (wear, malfunction).
Residual stress

- Slower filling or colder moulds
- Thick frozen layers
- High residual stress!
Residual stress

Faster filling or hotter moulds
Thin frozen layers

Low residual stress !
### Relationship between faults & cycle steps

<table>
<thead>
<tr>
<th>INJECTION</th>
<th>HOLDING</th>
<th>COOLING</th>
<th>OUT OF CYCLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flash</td>
<td>Sinking</td>
<td>Distortion</td>
<td>Contamination</td>
</tr>
<tr>
<td>Short</td>
<td>Flash</td>
<td></td>
<td>Mica marks</td>
</tr>
<tr>
<td>Gas trap</td>
<td>Voids</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jetting</td>
<td>Weight</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flow lines</td>
<td>Dimensions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weld lines</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dieseling</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Note:** Some faults can be related to more than one specific part of the injection moulding cycle.
# Troubleshooting

Examine the mouldings and determine the:

<table>
<thead>
<tr>
<th>Fault</th>
<th>Cause</th>
<th>Remedy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Example of Fault - Cause - Remedy

<table>
<thead>
<tr>
<th>FAULT</th>
<th>CAUSE</th>
<th>REMEDY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Burn mark</td>
<td>Trapped gas</td>
<td>Clean vents.</td>
</tr>
<tr>
<td>(Dieseling)</td>
<td></td>
<td>Reduce Locking tonnage.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Reduce injection speeds or profile.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Reduce melt temperatures.</td>
</tr>
</tbody>
</table>
Processing variables

Short term
- Locking tonnage
- Holding pressure time
- Cooling time
- Injection speed
- Holding pressure
- Change over position
- Shot weight
- Decompression
- Ejector speed

Long term
- Melt temperature
- Mould temperature (Oil temperature)

Determine actual temperatures using a pyrometer for both mould and melt.

Back pressure
Screw speed
Systematic approach

Eliminate faults in order of priority:

- Those that potentially damage the mould
  - Flash
  - Gas burns/traps

- Optimise the filling phase
  - 95 - 99 % full

- Filling phase faults
  - Jetting
  - Flow lines
  - Weld lines
Systematic approach

- Holding phase related
  - Voids
  - Sinks
  - Undersized

- Optimise the holding phase
  - Holding pressure
  - Gate freeze-off time
  - Cushion Size

- Optimise the cycle time
  - Cooling time
Troubleshooting Summary

- Adopt a logical and systematic approach
- Change one condition at a time
- Consider the interaction of conditions
- Keep samples
- Keep notes
- Be patient
- Don’t be a knob Twiddler!!
Injection Moulding Technology
Part 3
Processing & Troubleshooting
Blade ejection
Round ejection
Sleeve ejection
Sprue bush