MECH 423 Casting, Welding, Heat Treating and NDT

Time: ___ W ___ F 14:45 - 16:00

Credits: 3.5      Session: Fall

Introduction

Lecture 1
Contact Details

Instructor: Dr. Sivakumar Narayanswamy

Office: EV Building
Room: 004 – 124

Phone: 848-2424 (7923)

Office Hours: _ _ _ _ F 10:00 – 12:00

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Course Web Site: http://users.encs.concordia.ca/~nrskumar/
# Outline of the Course

<table>
<thead>
<tr>
<th>Week</th>
<th>Date</th>
<th>Chapter*</th>
<th>Lecture Topics</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>11th Sep ‘12</td>
<td>Degarmo Chp. 11</td>
<td>Introduction; Fundamentals of casting processes</td>
</tr>
<tr>
<td>2</td>
<td>18th Sep ‘12</td>
<td>Degarmo Chp. 11</td>
<td>Solidification of liquid metals; Patterns, Castings Design</td>
</tr>
<tr>
<td>3</td>
<td>25th Sep ‘12</td>
<td>Degarmo Chp. 12</td>
<td>Expendable mould casting</td>
</tr>
<tr>
<td>4</td>
<td>2nd Oct ‘12</td>
<td>Degarmo Chp. 13</td>
<td>Multi-Use mould casting; Casting alloys</td>
</tr>
<tr>
<td>5</td>
<td>9th Oct ‘12</td>
<td>Degarmo Chp. 4</td>
<td>Phase Diagrams; Phase changes (Callister Chp. 9 &amp; 10)</td>
</tr>
<tr>
<td>6</td>
<td>16th Oct ‘12</td>
<td>Degarmo Chp. 5, 35</td>
<td>Heat treatments; Surface treatment (Callister Chp. 11)</td>
</tr>
<tr>
<td>7</td>
<td>23rd Oct ‘12</td>
<td>Degarmo Chp. 30</td>
<td>Fundamentals of Joining Processes</td>
</tr>
<tr>
<td>8</td>
<td>30th Oct ‘12</td>
<td>Degarmo Chp. 30</td>
<td>Fundamentals of welding/brazing/soldering processes</td>
</tr>
<tr>
<td>9</td>
<td>6th Nov ‘12</td>
<td>Degarmo Chp. 31</td>
<td>Gas welding; Arc welding</td>
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<tr>
<td>10</td>
<td>13th Nov ‘12</td>
<td>Degarmo Chp. 32</td>
<td>Resistance welding; Other welding processes</td>
</tr>
<tr>
<td>11</td>
<td>20th Nov ‘12</td>
<td>Degarmo Chp. 33, 34</td>
<td>Brazing &amp; soldering; Weld effects/defects, joint design</td>
</tr>
<tr>
<td>12</td>
<td>27th Nov ‘12</td>
<td>Degarmo Chp. 10</td>
<td>Non-Destructive Testing (NDT)</td>
</tr>
<tr>
<td>13</td>
<td>4th Dec ‘12</td>
<td></td>
<td>Review</td>
</tr>
</tbody>
</table>

There will be 2 midterm exams during the tutorial period of Weeks 5 and 10

*Chapter #s are from 10th Edition*
About the Course

- The course is about learning different manufacturing processes that add value to material, like casting, welding, heat treating, NDT
  - 13 lectures of all - one is a review lecture
  - 2 Midterm tests
  - 3 assignments
  - 1 Project / Presentation
  - Lab experiment report (Interim and Final)
  - Final exam

- [http://users.encs.concordia.ca/~nrskumar](http://users.encs.concordia.ca/~nrskumar)
Text book and other reference

TEXTBOOK

• Material Science and Engineering, W.D. Callister, 5th Edition, Wiley, 1999 (or similar)

REFERENCES (not exhaustive)

1. ASM Metals Handbook; Volumes 4 (Heat-Treating), 6 (Welding, Brazing and Soldering) and 15 (Casting).
Midterm test

- You will write 2 optional midterm tests on Oct 4th and Nov 8th, 2013 during the tutorial period starting at 4.15pm.
- Duration of the test will be 50 minutes.
- Write the midterm test – this is a good measurement means for your performance.

Final Test

- The final test may have a number of multiple choice, short answer and comprehensive questions that will require answer.
- Duration of the test: 3 Hrs.
- Write the final exam with confidence that you will do very well.
Assignments

- Three assignments that will require significant effort must be completed during the term.
- The timetable of the assignments is below. Late submissions (regardless of reason) not allowed:
  - Sep 27th 2.45pm Assignment #1
  - Oct 25th 2.45pm Assignment #2
  - Nov 22nd 2.45pm Assignment #3
- Work must be submitted **DIRECTLY** to the TUTOR or IN CLASS. Tutor Coordinates available in the outline and in course webpage.
- Good presentation, including legibility, spelling and grammar, is expected for all work.
The Laboratory

- There is a laboratory component to this course.
- The aim is to illustrate the effects of various welding and heat treatment on the mechanical properties of bare and welded metals.
- Mr. Peter Sakaris will be supervising this in the Materials Laboratory (H 1058/59) and will be assisted by Mr. Ehsan Rezabeigi.
- This section involves experiments and report writing.
- Lab Manual is available for purchase from the COPY CENTER.
- Note: Safety is of utmost importance. Wearing a lab coat and covered shoes during the session is mandatory.
Each student/group will select a topic related to this course and will prepare a 20 minute presentation giving an overview of the subject, major advantages/disadvantages, applications etc.

Time will be set aside in the tutorial(s) for each student/group to make their presentation to the rest of the class. Each talk will be followed by a short question period. Each student/group will submit an hard and soft copy of the presentation/report.

Marks will be awarded for:

- Presentation style (audibility, structure, clarity, quality etc.).
- Technical content (understanding of subject, explanation etc.).
Grading Scheme

- Grade composition:
  - Final: 50% 65%
  - Midterm: 15% 0%
  - Assignments (4): 15% 15%
  - Lab (Heat Treating): 10% 10%
  - Presentation (topic to be discussed): 10% 10%

- To pass the course you have to
  - Pass the final
  - Submit your assignments and lab and project report on or before due date
  - Option A is if your midterm grades are very good and option B is if your midterm grades are not better than the final or you did not take midterm
Coursework–Certificate of Originality

- In keeping with the faculty policy, all coursework submitted as part of this course must have the certificate of originality form filled-in appropriately and attached as the cover page.

- The form is available on the following website:
  
  http://www.encs.concordia.ca/scs/Forms/expectations.pdf
Content of the Lecture 1

- Fundamentals of Casting Processes
- Introduction to Materials Processing
- Introduction to Casting
- Casting Terminology
Basic Manufacturing Processes

• Casting or moulding (liquid to solid with new shape)
• Forming (deformation of solid into new shape)
• Machining (material removal to make new shape)
• Joining and assembly (making new shape from smaller shapes)
• Surface treatments (changing or adding to surface)
• Heat treating (changing properties without changing shape)
• Other (vapour deposition, dissolution etc)

Often more than one process will be involved; e.g. casting, heat treating, machining, surface treatment.
Basic Manufacturing Processes

- A 3D model is made with artist impression on a plaster
- The model is then digitized
- The digitized model is used to cut die
- Bronze metal strip is used and abrasive jet is used to cut circular Blanks
- The blanks are placed into the die and heat and pressure is supplied to get the medal
- Final finishing and coating is done with gold, silver, bronze to get the model
Basic Manufacturing Processes

- **Shaping Processes**
  - Casting/Moulding
  - Cutting/separating
  - Deformation/Forming
  - Joining

- **Non-shaping processes**
  - Heat treatment
  - Surface finishing
Basic Manufacturing Processes

Consolidation/casting

Laminating
- Filament winding
- Lay-up
- Pultrusion
- Permanent mould

Casting
- Permanent pattern
- Expendable mould and pattern
- Gravity die casting
- Pressure die casting
- Squeeze casting
- Centrifugal casting
- Compression moulding
- Reaction inj. moulding
- Injection moulding
- Rotational moulding
- Contact moulding
- Sand casting
- Shell moulding
- Investment casting
- Evaporative pattern casting

Deposition techniques
- Chemical techniques
- Physical techniques
Basic Manufacturing Processes

**Deformation/Forming**

**Sheet**
- Sheet metal forming
- Vacuum forming
- Blow moulding
- Superplastic forming

**Forging**
- Hot Forging
- Cold Forging

**Bulk**
- Wire/tube drawing
- Rolling
- Extrusion

**Powder processing**
- Bending
- Die
- Spinning
- Drop
- Press
- Upset
- Swaging
- Cold heading
- Sheet
- Structural
- Pierce
- Direct
- Indirect
- Impact
- Slip casting
- Pressing and sintering
- Isostatic pressing
Basic Manufacturing Processes

Cutting/separating

Mechanical machining

Electromachining

Shearing

Thermal cutting

Chemical milling

- Single point cutting
- Multiple point cutting
- Grinding/Abrasives
- Electrochemical
- Electrical discharge
- Piercing
- Blanking
- Torch cutting
- Electric discharge
- Immersion
- Photo etching
Basic Manufacturing Processes

Joining

- Resistance welding
  - Spot welding
  - Seam welding
  - Projection welding
  - Electroslag welding
    - GMAW
    - GTAW
    - SMAW
    - FCAW
    - PAW
  - Electric arc welding
  - Gas welding
  - Laser welding
  - Electron beam welding

- Fusion welding
  - Forge welding
  - Friction/Ultrasonic welding
  - Cold welding
  - Explosive welding
  - Diffusion bonding

- Solid state welding
  - Cold welding
  - Explosive welding
  - Diffusion bonding

- Mechanical joining
  - Fasteners
    - Screws
    - Rivets
    - Bolts
    - Nails
    - Seams

- Liquid state bonding
  - Adhesive bonding
  - Brazing
  - Soldering
Basic Manufacturing Processes

Non-shaping processes

Heat Treatment

Annealing

Recrystallization

Recovery

Surface

Through

Hardening

Surface Finishing

Coatings

Modification

Stress relieve

Temper

Full Process

Carburizing

Carbonitriding

Nitriding

Chromizing

Flame

Induction

Quenching

Martempering

Ausforming

Age Hardening

Spray

Metallizing

Electroplate

Chemical

Peening

Implantation
Processing and Property

• A fabricating process can change the properties of a material as well as the shape.

• This can be advantageous:
  • Deformation (forging) changes the shape and internal structure of the grains (crystals) in a metal which can increase strength and fatigue resistance.

• Or it can be deleterious:
  • Casting may produce large columnar grains that result in lower strength and toughness.

• It is important to understand the effects that a process has on the structure and properties of a material.
Processing and Property

- There is a interrelationship between
  - the designed component and its function
  - the chosen material and
  - the chosen processing route

- A component is usually designed for its “purpose” or final use. However it should also be “designed for manufacture.”

- One should not select any of the above without due consideration to the remaining two factors.
Introduction to Casting

Consolidation/casting

Laminating
- Filament winding
- Lay-up
- Pultrusion

Casting
- Permanent mould
- Permanent pattern
- Expendable mould and pattern

Deposition techniques
- Chemical techniques
- Physical techniques

Gravity die casting
- Pressure die casting
- Squeeze casting
- Centrifugal casting
- Compression moulding
- Reaction inj. moulding
- Injection moulding
- Rotational moulding
- Contact moulding
- Sand casting
- Shell moulding
- Investment casting
- Evaporative pattern casting
Introduction to Casting

- Casting is a process where molten material is poured into a mould of the required shape and then allowed to solidify.
- Moulding is a similar process used for plastic materials.
- The mould should be shaped so that molten material flows to all parts of the mould.
Introduction to Casting

• Advantages
  • This process is widely used as a primary forming process and suitable for bulk shaping of a material.

• Disadvantages
  • The shape of the finished casting may be different to the shape of the mould because metals shrink as they cool.
Introduction to Casting

Considerations when selecting a method of casting

- The type of casting process most suitable for a particular application is dictated by a number of factors.
  - The number of castings
  - The cost per casting
  - The material being cast
  - The surface finish and tolerances of the finished casting
  - The size of the casting
Fundamentals of Casting

CASTING – Pouring liquid into cavity & solidifying material

1. Design and production of mould or die system
2. Melting of solid work material
3. Introduction of molten metal into die cavity or mould
4. Solidification of shaped molten metal
5. Removal of solidified component from mould or die
6. Cleaning and finishing
1. Design and production of mould or die system
   • Desired shape and size
   • Due allowance for shrinkage of solidifying material.
   • Any feature desired in the final casting must exist in the cavity.
   • Able to reproduce the desired detail and have a refractory character to prevent impurities in casting
   • Single-use Molds or Multiple-use Molds
Fundamentals of Casting

2. Melting of solid work material
   - Process must be capable of providing molten material not only at the proper temperature, but also in the desired quantity, with acceptable quality, and at a reasonable cost

3. Introduction of Molten Material
   - Pouring technique - devised to introduce molten metal into mold.
   - Provision should be made for the escape of all air or gases present in the cavity prior to pouring, as well as those generated by the introduction of the hot metal.
   - The molten material is then free to fill the cavity, producing a high-quality casting that is fully dense and free of defects.
4. Solidification

- Process should be properly designed and controlled
- Castings should be designed so that solidification and solidification shrinkage can occur without producing internal porosity or voids.
- Molds should not provide excessive restraint to the shrinkage that accompanies cooling.
- If they do, the casting may crack when it is still hot and its strength is low.
Fundamentals of Casting

5. Removal of cast from the die

• It must be possible to remove the casting from the mold
• With single-use molds that are broken apart and destroyed after each casting, mold removal presents no serious difficulty.
• With multiple-use molds, however, the removal of a complex-shaped casting may be a major design problem.

6. Cleaning, Finishing and Inspection

• Extraneous material is usually attached where the metal entered the cavity
• Excess material may be present along mold parting lines, and mold material often adheres to the casting surface
• All of these must be removed from the finished casting
Fundamentals of Casting

Casting variations:

- Mould type (container that imparts shape to liquid metal):
  1. Permanent mould or die (re-used)
  2. Non-permanent mould (used once)

- Pattern type (produces shaped cavity in mould):
  1. Permanent (re-used for next mould)
  2. Non-permanent (used once - expended)

- Pouring principle
  1. Pressure (high or low)
  2. Gravity
Fundamentals of Casting

1. The pattern is removed.
2. The pattern is formed in foundry sand.
3. The sand is compacted.
4. The sand mold is assembled and the cores inserted.
5. Molten metal is poured into the mold.
6. The casting solidifies.
7. The sand mold is destroyed to remove the casting.
Casting Terminology

- **Construction of a pattern**: duplicate of final casting.
- **Molding material** packed around the pattern and the pattern is removed.
- **Flask** is the rigid metal or wood frame that holds the molding aggregate.
- **Cope** is the name given to the top half of the pattern, flask, mold, or core.
- **Drag** refers to the bottom half.
Casting Terminology

- **Core** is a sand (or metal) shape that is inserted into a mold to produce the internal features of a casting.
- **Core print** is a region that is added to the pattern, or mold to locate and support the core within the mold.
- The mold material and the core produce the **Mold cavity**, to produce the desired casting.

FIGURE 13-2 Cross section of a typical two-part sand mold, indicating various mold components and terminology.
Casting Terminology

- **Riser** is an extra void created in the mold.
- It provides a reservoir to compensate for shrinkage occurring during solidification.
- If the riser contains the last material to solidify, shrinkage voids should be located in the riser and not the final casting.

*FIGURE 13-2  Cross section of a typical two-part sand mold, indicating various mold components and terminology.*
Casting Terminology

- **Gating system** is the network of channels used to deliver molten metal to the mold cavity.
- **Pouring cup** receives the molten metal.
- Metal travels down a **sprue**, then along horizontal channels, called **runners**, and finally through controlled entrances, or **gates**, into the mold cavity.

**Figure 13-2** Cross section of a typical two-part sand mold, indicating various mold components and terminology.
Casting Terminology

- **Parting line** is the interface between cope and drag.
- **Draft** is the taper that permits withdrawal.
- **Core box** is the mold or die used to produce cores.
- The term **casting** is used to describe both the process and the product when molten metal is poured and solidified in a mold.

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**FIGURE 13-2** Cross section of a typical two-part sand mold, indicating various mold components and terminology.
### Table 3  Major markets for metal castings

Ranked in order of tonnage shipped. In some cases, the total of "Other major markets" is larger as a whole than the individual markets listed.

<table>
<thead>
<tr>
<th>Ferrous castings</th>
<th>Nonferrous castings</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gray iron</strong></td>
<td><strong>Aluminum</strong></td>
</tr>
<tr>
<td><strong>Ingots molds</strong></td>
<td><strong>Auto and light truck</strong></td>
</tr>
<tr>
<td><strong>Construction castings</strong></td>
<td><strong>Aircraft and aerospace</strong></td>
</tr>
<tr>
<td><strong>Motor vehicles</strong></td>
<td><strong>Other transportation</strong></td>
</tr>
<tr>
<td><strong>Farm equipment</strong></td>
<td><strong>Engines</strong></td>
</tr>
<tr>
<td><strong>Engines</strong></td>
<td><strong>Household appliances</strong></td>
</tr>
<tr>
<td><strong>Refrigeration and heating</strong></td>
<td><strong>Office machinery</strong></td>
</tr>
<tr>
<td><strong>Construction machinery</strong></td>
<td><strong>Power tools</strong></td>
</tr>
<tr>
<td><strong>Valves</strong></td>
<td><strong>Refrigeration, heating, and air conditioning</strong></td>
</tr>
<tr>
<td><strong>Soil pipe</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Pumps and compressors</strong></td>
<td></td>
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<tr>
<td><strong>Pressure pipe</strong></td>
<td></td>
</tr>
</tbody>
</table>

Other major markets include machine tools, mechanical power transmission equipment, hardware, home appliances, and mining machinery, oil and natural gas pumping and processing equipment.

<table>
<thead>
<tr>
<th><strong>Malleable iron</strong></th>
<th><strong>Steel</strong></th>
<th><strong>Magnesium</strong></th>
<th><strong>Zinc</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Motor vehicles</strong></td>
<td><strong>Railroad equipment</strong></td>
<td><strong>Power tools</strong></td>
<td><strong>Automotive</strong></td>
</tr>
<tr>
<td><strong>Valves and fittings</strong></td>
<td><strong>Construction equipment</strong></td>
<td><strong>Sporting goods</strong></td>
<td><strong>Building hardware</strong></td>
</tr>
<tr>
<td><strong>Construction machinery</strong></td>
<td><strong>Mining machinery</strong></td>
<td><strong>Anodes</strong></td>
<td><strong>Electrical components</strong></td>
</tr>
<tr>
<td><strong>Railroad equipment</strong></td>
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<td><strong>Automotive</strong></td>
<td><strong>Machinery</strong></td>
</tr>
<tr>
<td><strong>Engines</strong></td>
<td><strong>General and special industrial machinery</strong></td>
<td></td>
<td><strong>Household appliances</strong></td>
</tr>
<tr>
<td><strong>Mining equipment</strong></td>
<td><strong>Motor vehicles</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Hardware</strong></td>
<td><strong>Metalworking machinery</strong></td>
<td></td>
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</tr>
</tbody>
</table>

Other major markets include textile machinery, woodworking and paper machinery, mechanical power and transmission equipment, motors and generators, refrigeration and heating equipment, air conditioning.

| **Other major markets include chemical processing, utilities, desalination, petroleum refining** |
| **Other major markets include office machinery, health care, aircraft and aerospace** |
| **Other major markets include scientific instruments, medical equipment, radio and television equipment, audio components, toys, sporting goods** |
Casting Quality

- Casting Quality - at least two types of defects
- Porosity (“holes” or “bubbles” in the solid)
- Inclusions (unwanted particles)

Can be minimised by:
- using good foundry practice (such as pouring metal without creating turbulence and placing filter in mould)
- use advanced techniques (e.g. applying vacuum over liquid or squeeze casting).

Certain casting techniques produce better quality castings than others but are usually more expensive
Sand Casting

Repeat process for top half – with runner and riser pins
Casting Quality

- **PROCESS** - Sand moulds are produced around a permanent pattern which is withdrawn to leave a cavity. Molten metal is poured into the mould and solidifies. Mould (and core) is broken up to retrieve the casting.

- **SHAPE** - Mainly solid components but complex internal shapes produced using friable cores. Very large & small castings possible but thin sections difficult.

- **MATERIALS** - All metals excluding refractory and reactive alloys (e.g. Ti).

<table>
<thead>
<tr>
<th>CYCLE TIME</th>
<th>QUALITY</th>
<th>FLEXIBILITY</th>
<th>MATERIALS UTILIZATION</th>
<th>OPERATING COST</th>
</tr>
</thead>
<tbody>
<tr>
<td>Usually long as limited by rate of heat transfer out of the casting. Use of multiple moulds increases production rate.</td>
<td>Surface texture poor. Porosity endemic. Nonmetallic inclusions difficult to control.</td>
<td>Patterns cheap and easy to make.</td>
<td>Up to 50% of casting in runners and risers. Both mould and scrap metal can be directly recycled.</td>
<td>Very low as pattern costs are low and mould making is relatively easy.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>RATING 2</th>
<th>RATING 1</th>
<th>RATING 5</th>
<th>RATING 2</th>
<th>RATING 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>( 1 = Poor , 5 = Excellent )</td>
<td>Mech 423 Lecture 1</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
Full Mould Casting

Evaporative pattern (EPS) Casting
Expanded Poly-Styrene

1. Inject polystyrene beads into a heated aluminium die. Pass steam through mould to fuse and expand polystyrene beads to form solid pattern.

2. Cool die, open to eject pattern.

3. Glue on additional runners and risers where necessary. Cover pattern with refractory slurry and dry to form a refractory coating.

4. Place pattern in a ‘flask’ of loose dry unbonded sand and consolidate by vibration. Apply vacuum to flask and pour metal. Cool, remove casting and recycle sand.
Full Mould Casting

- **PROCESS** *(Expendable mould and pattern)* - A refractory coating is applied to a volatile or combustible pattern which is used in a sand mould. The pattern is destroyed by the molten metal.

- **SHAPE** - Very complex 3D shapes possible.

- **MATERIALS** - Non-refractory metals with casting temperatures high enough to vaporize the pattern.

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</tr>
</thead>
<tbody>
<tr>
<td>Long due to process complexity. Multiple moulds increase production rate.</td>
<td>Normal sand casting defects. Surface texture similar to that of pattern.</td>
<td>Ideal for the manufacture of one-offs.</td>
<td>Pattern material entirely wasted. Metal usage poor due to runners etc.</td>
<td>All equipment involved is rudimentary and process is very cheap to operate.</td>
</tr>
</tbody>
</table>

RATING 1 | RATING 2 | RATING 5 | RATING 2 | RATING 4

( 1 = Poor, 5 = Excellent )
Investment (Lost Wax) Casting

1. Molten wax injected into metal or rubber die
2. Wax pattern removed from die
3. Wax patterns assembled on a tree with feeding and gating system
4. Tree invested with a refractory slurry
5. Slurry stuccoed with refractory powder
6. Investment dried or chemically set
7. Investment dewaxed in steam autoclave or furnace
8. Ceramic mould fired and pre-heated
9. Metal cast into ceramic mould
10. Ceramic shell removed
11. Components fettled i.e. removed from tree
12. Components finished i.e. grinding, polishing, heat treatment etc.
Investment (Lost Wax) Casting

- **PROCESS** *(Expendable mould and pattern)* - A ceramic shell (investment) is slip cast around a wax pattern. Wax is melted and molten metal cast into the investment which is broken up to remove the casting.

- **SHAPE** - Best for relatively small, complex 3D components. Re-entrant angles possible.

- **MATERIALS** - Suitable for most metals. Reactive metals can be cast under vacuum.

<table>
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</tr>
</thead>
<tbody>
<tr>
<td>Limited by rate of heat transfer out of the casting. Production rates low because of process complexity. Increased by using multiple moulds and patterns.</td>
<td>Surface texture good. Higher mould temperatures decrease porosity but produce coarse microstructures.</td>
<td>Moderately high because of the ease of production of patterns.</td>
<td>Near net shape process with little material contained in feeding systems. Wax recycled, investment lost.</td>
<td>Equipment costs can be high especially where reactive alloys are concerned. Labour costs are high due to the many stages in the process.</td>
</tr>
</tbody>
</table>

RATING 2 RATING 4 RATING 4 RATING 4 RATING 3

( 1 = Poor , 5 = Excellent )
Gravity Die Casting

1. Mould and cores (where applicable) sprayed with coating. Mould heated using gas burners and lubricant sprayed on.

2. Mould parts assembled and clamped. Metal poured into runner.

3. Mould set opened and casting ejected, finished and heat treated (when necessary).
Gravity Die Casting

- **PROCESS** *(Permanent mould)* - Molten metal is poured into a metallic mould where it solidifies.

- **SHAPE** - Mostly used for small, simple shapes with only simple coring.

- **MATERIALS** - Mainly used for light alloys. Steels and cast irons also possible.

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<thead>
<tr>
<th>CYCLE TIME</th>
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</tr>
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<tbody>
<tr>
<td>Limited by rate of heat transfer across the interface. Production rates can be increased by using multiple moulds or multiple cavities.</td>
<td>Surface texture is good. Porosity unavoidable but can be minimized by slower mould filling to reduce turbulence.</td>
<td>Negligible setting up time for manual operation. Mould making relatively difficult.</td>
<td>Rarely better than 60% utilization. Scrap in the runners and risers can be directly recycled.</td>
<td>Equipment cost can be limited to mould and melt preparation apparatus.</td>
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RATING 4  RATING 3  RATING 2  RATING 2  RATING 2

(1 = Poor, 5 = Excellent)
Pressure Die Casting

High or Low Pressure

Cold-chamber high pressure die casting:
Molten metal is poured into a cold shot chamber. A high pressure plunger forces metal into the single or multi-die cavity.

Hot chamber high pressure die casting:
A gooseneck hot chamber is submerged in a pot of molten metal. Metal is injected directly from the pot via the gooseneck.
Pressure Die Casting

- **PROCESS** (Permanent mould) - Molten metal is forced into a water-cooled metal mould (die) through a system of sprues and runners. The metal solidifies rapidly and the casting is removed with its sprues and runners.

- **SHAPE** - Used for complex shapes and thin sections. Cores must be simple and retractable.

- **MATERIALS** - High fluidity requirement means low melting temperature eutectics usually used (e.g. Al-Si). Hot chamber method restricted to very low melting temperature alloys (e.g. Mg and Zn).

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<td>Solidification time is typically &lt; 1 s so cycle is controlled by time taken to fill mould and remove casting.</td>
<td>Good surface texture but turbulent mould filling produces high degree of internal porosity.</td>
<td>Tooling dedicated so limited by machine setting up time.</td>
<td>Near net shape process but some scrap in sprues, runners and flash which can be directly recycled.</td>
<td>High, since machine and moulds are expensive.</td>
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(1 = Poor, 5 = Excellent)
Squeeze Casting

Stage 1
Preheated mould set is positioned on hydraulic press and coated with a releasing agent such as graphite. Liquid metal is accurately metered into the mould cavity via a launder.

Stage 2
Press withdrawn, mould set separated and component ejected.

Stage 3
Press actuated to bring two parts of the mould together. Metal displaced to fill mould cavity and pressure held until solidification is complete.

A ceramic fibre/particle preform may be placed in the mould prior to pouring to fabricate MMC’s
Squeeze Casting

- **PROCESS** *(Permanent mould)* - Accurately metered quantity of molten metal is poured into preheated mould. The mould is then closed and pressure applied until solidification is complete.

- **SHAPE** - Retractable and disposable cores used to create complex internal and re-entrant features.

- **MATERIALS** - Principally used for light alloys (temperatures) but can be used for most non-refractory metals.

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<td>Solidification times short but long cycle times needed to ensure adequate process control.</td>
<td>Low levels of porosity and fine microstructures due to imposed pressure and rapid rate of solidification. Surface texture good.</td>
<td>Restricted by dedicated tooling and long setting up times.</td>
<td>Accurate metering of liquid metal leads to approx. 100% material utilization.</td>
<td>Costs are extremely high because of the complex tooling and the accuracy of process control required.</td>
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RATING 3 RATING 4 RATING 1 RATING 5 RATING 1

( 1 = Poor , 5 = Excellent )
Centrifugal Casting

Sand mould casting

Metal mould casting

Dry-sand core
Guide rollers
Sand lining
Core
Pouring basin
Flask
Casting
Driving rollers
Spiral path of metal
Pouring basin
Water-cooled mould
Copper liner
Horizontal
**Centrifugal Casting**

- **PROCESS** *(Permanent mould)* - Molten metal is introduced into a sand- or copper-lined, cylindrical steel mould which is rotated about its long axis, distributing the metal over its inner surface.

- **SHAPE** - Technique used to produce relatively long, hollow objects (e.g. pipes) without the need for cores.

- **MATERIALS** - Metals excluding refractory and reactive metals.

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<td>Determined by the rate of introduction of metal into the mould and the rate of solidification of the metal. The latter is lower for sand-lined moulds.</td>
<td>Porosity and nonmetallic inclusions migrate towards the inner surface because of their lower density, giving a high quality outer surface.</td>
<td>Setting up times are relatively short.</td>
<td>Absence of runners and risers leads to near 100% use of material.</td>
<td>Equipment is relatively simple and can cost little. Increased complexity of water-cooled copper-lined moulds more costly.</td>
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( 1 = Poor , 5 = Excellent )
For small parts, mould cavity has many cavities connected by runners.
**Injection Moulding**

- **PROCESS** *(Permanent mould)* - Permanent mould Molten polymer is forced at high pressure into a cool metal mould. The polymer solidifies under pressure and the moulding is removed.

- **SHAPE** - Complex shapes although thick sections are problematical. Small re-entrant angles possible if material flexible. Screw threads possible.

- **MATERIALS** - Mainly thermoplastics, also rubbers, thermosets and composites.

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<td>Limited by solidification time and demoulding time.</td>
<td>Can be reasonable but normally compromised in the pursuit of high production rates.</td>
<td>Restricted by mould changeover and machine setting up time.</td>
<td>Scrap in sprues and runners. Thermoplastics can be recycled with some degradation of properties.</td>
<td>High due to cost of machines and moulds.</td>
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RATING 4 \hspace{1cm} RATING 3 \hspace{1cm} RATING 1 \hspace{1cm} RATING 4 \hspace{1cm} RATING 1

(1 = Poor, 5 = Excellent)
Rotational Moulding

1. Add measured amount of polymer to mould
2. Close mould and rotate around two or more axes in a heated chamber.
3. Cool mould and open
4. Remove product.
# Rotational Moulding

- **PROCESS** *(Permanent mould)* - Polymer is introduced, as powder or slurry, into a closed mould. Mould is heated, to melt the material, then cooled to solidify it, whilst being rotated about two orthogonal axes.

- **SHAPE** - Principally used to produce containers and similar hollow articles with uniform, thin sections (e.g. buoys, kayaks)

- **MATERIALS** - Mainly thermoplastics.

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<td>Limited by heat transfer into and out of the material so cycle times increase dramatically with wall thickness.</td>
<td>Isotropic properties as little molecular orientation. Low molecular mass materials used have poor mechanical properties.</td>
<td>Tooling dedicated, but moulds relatively cheap.</td>
<td>100% of material in mould is incorporated into the product.</td>
<td>Mould and equipment costs can be low.</td>
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RATING 2 (1 = Poor, 5 = Excellent)
Compression Moulding

1. A charge of material is placed in the open mould which is then closed.

2. The mould is heated to soften the material and/or initiate a chemical reaction.

3. The mould may be cooled before the moulding is removed.
Compression Moulding

- **PROCESS** *(Permanent mould)* - Closed mould process where mould is heated to soften the material and/or initiate a chemical reaction. The charge may be preheated before loading into the mould.

- **SHAPE** - Limited to relatively simple shapes because of short flow lengths. Re-entrant angles possible in materials which are flexible at demoulding temperatures.

- **MATERIALS** - Very widely used for thermosets but more recently developed for thermoplastics and composites.

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<td>Limited by rate of heat transfer and, for thermosets, the rate of reaction of the polymer. Multiple cavity moulds increase production rate.</td>
<td>Highly operator dependent. Problems include premature chemical reaction, air entrapment and inadequate filling of the cavity.</td>
<td>Process uses dedicated tooling. Mould changing is fast and changeover time is dictated by the heating up time.</td>
<td>Scrap consists of flash alone (no sprues or runners). This is not recyclable in the case of thermosets.</td>
<td>Machine and tooling costs low compared to most other permanent mould casting processes.</td>
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( 1 = Poor , 5 = Excellent )
Reaction Injection Moulding

In steady state, valves in mixing head allow reactants to circulate without mixing.

Mixing head opens and reactants mix as they enter the mould at high speed. Mixing head closes again when mould is full.

After curing time mould is opened and component ejected.
Reaction Injection Moulding

• **PROCESS** *(Permanent mould)* - Two streams of preheated, low molecular mass reactants are mixed and injected at high speed into a closed mould. Polymerization produces high molecular mass casting which is removed from the mould.

• **SHAPE** - Use of low modulus materials allows slight re-entrant angles to be accommodated.

• **MATERIALS** - Polymer & polymer matrix composites A wide range of chemically reactive systems possible. Mostly used for polyurethanes, polyamides and composites incorporating glass

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<td>Limited by reaction rate of the polymer and time taken to remove casting from mould.</td>
<td>Surface texture can be variable. Flaws created by premature reaction of the polymer result in poor mould surface reproduction.</td>
<td>Tooling dedicated. Mould changing relatively easy but process is complex to set up.</td>
<td>Moulds do not need runners. Some scrap, which cannot be recycled, at start-up.</td>
<td>Equipment is expensive although moulds are relatively cheap.</td>
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RATING 3  RATING 2  RATING 2  RATING 4  RATING 2

( 1 = Poor , 5 = Excellent )
Monomer Casting / Contact Moulding

Monomer casting
Reactive chemicals mixed and cast into water-cooled moulds. Used to produce high molecular mass polymer sheet for certain thermoforming applications.

Contact moulding
Mixtures of fibre reinforcement and reactive chemicals applied to mould either by hand or automatically using spraying techniques.
Monomer Casting / Contact Moulding

- **PROCESS** (Permanent mould) - Low molecular mass polymer is mixed with catalysts and introduced into the mould. Fibre or particulate reinforcement may be incorporated.

- **SHAPE** - Mostly used for simple shapes. Re-entrant angles can be produced by using flexible moulds.

- **MATERIALS** - Used for all polymers that will polymerize at low temperatures and at atmospheric pressure.

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<td>Controlled by the reaction rate of the polymer which is designed to be slow to allow time to mix and apply the material.</td>
<td>Highly operator dependent. Problems include inadequate mixing, air entrapment and gas evolution.</td>
<td>Moulds are cheap and easy to produce. Setting up times are short.</td>
<td>Some excess material is normally produced, since accurate metering is rarely employed.</td>
<td>Costs can be very low.</td>
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| RATING 1 | RATING 2 | RATING 4 | RATING 4 | RATING 4 |

(1 = Poor, 5 = Excellent)

Mech 423 Lecture 1