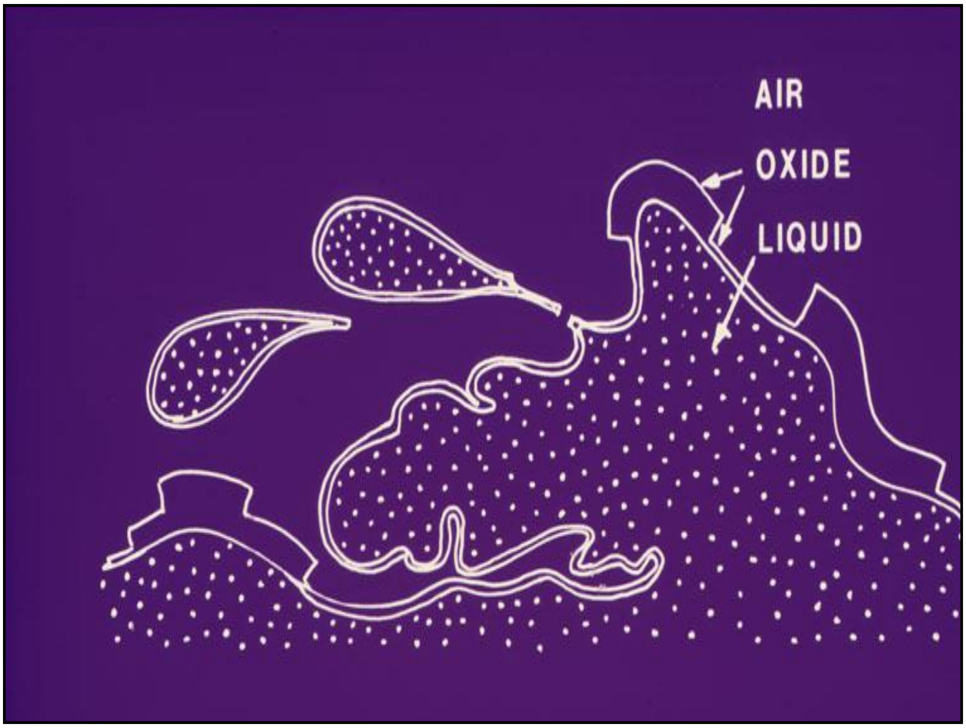


MME 345

Lecture B:01

Chapter B1: Introduction

1. Creating quality casting

Topics to discuss today ....

1. Introduction
2. Defects in casting
3. Ten casting rules
4. Three steps to make quality castings

1. Introduction

- Casting or founding is one of the principal primary forming process of producing near-net-shaped objects using metals and alloys.
- Metal castings are fundamental building blocks, the three-dimensional integral shapes, indispensable to practically all other manufacturing industries.

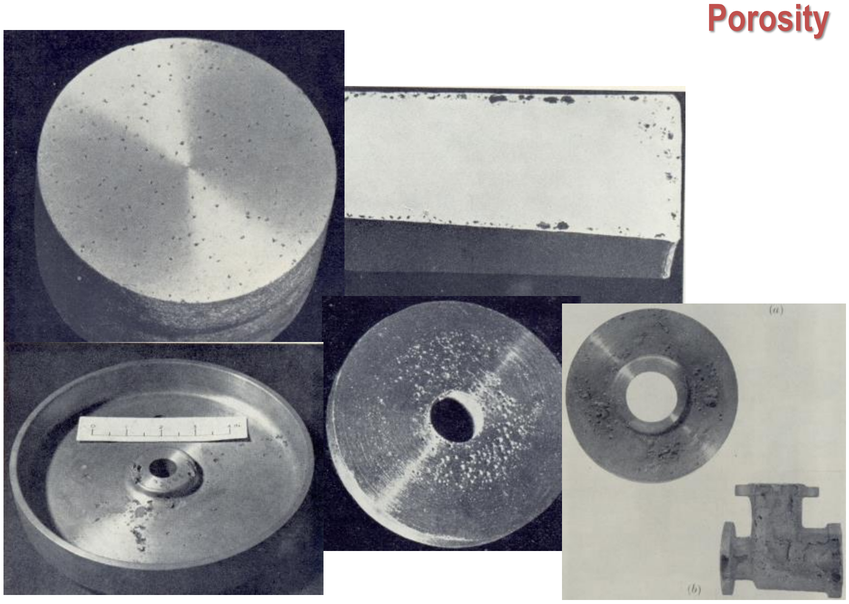
- Castings can be difficult to get right. Creating things never is easy.
- Casting represents a miraculous transformation from the original 2D drawing to a 3D shape, from a mobile liquid to a permanently shaped, strong solid. It is an achievement worthy of pride!
- The clean lines of the finished casting, sound, accurate, and strong, are a pleasure to behold. The knowledge that the casting contains neither defect nor residual stress is an additional powerful reassurance.
- The production of good castings can be highly economical and rewarding. The production of bad castings is usually expensive and damaging.

- The 'good casting' can be defined as one that meets or exceeds the customer's specification.
- Creating good casting every time, without any defect is a challenge to behold!
- In this lecture, we shall first see the type of defects commonly found in casting and then discuss, generally, the method of obtaining good quality castings.

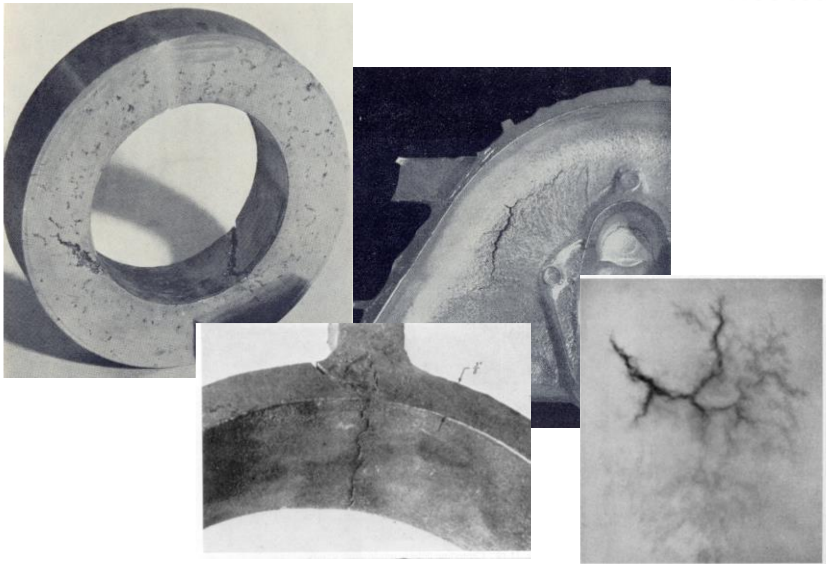
2. Defects in casting

- Porosity (gas hole, pin hole, blow hole)
- Slag, inclusion, oxide film
- Metal penetration and other surface defects
- Hot tear
- Shrinkage cavity
- Cold shut and misrun

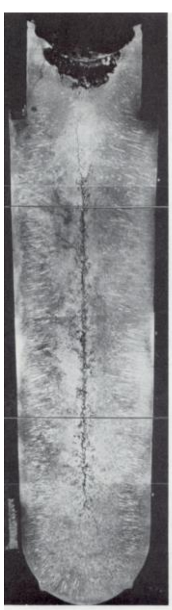
Porosity

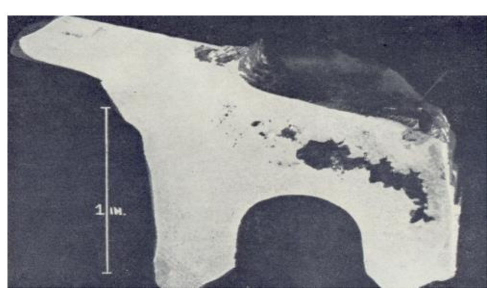


Hot tear

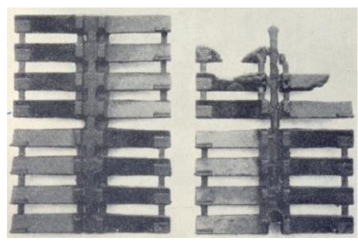


Shrinkage cavity





Cold shut



Misrun

3. "Ten casting rules"

Ref: J. Campbell, Casting Practice: The 10 Rules of Castings, Elsevier, 2004

1. Start with a good quality melt

- Immediately prior to casting, the melt shall be prepared, checked, and treated, if necessary, to bring it into conformance with an acceptable minimum standard.
- However, preferably, prepare and use only near-defect-free melt.

2. Avoid turbulent entrainment of the surface film on the liquid

- This is the requirement that the liquid metal front should not go too fast.
- The maximum meniscus velocity is approximately 0.5 m/s for most liquid metals.
- This requirement also implies that the liquid metal must not be allowed to fall more than the critical height corresponding to the height of a sessile drop of the liquid metal.

3. Avoid laminar entrainment of the surface film on the liquid

- This is the requirement that no part of the liquid metal front should come to a stop prior to the complete filling of the mould cavity. The advancing liquid front must be kept 'alive' (i.e. moving) and therefore free from thickened surface film that may be incorporated into the casting.
- This is achieved by the liquid front being designed to expand continuously. In practice this means progress only uphill in a continuous uninterrupted upward advance; i.e. (in the case of gravity poured casting processes, from the base of the sprue onwards).
- This implies
  - Only bottom gating is permissible.
  - No falling or sliding downhill of liquid metal is allowed.
  - No horizontal flow of significant extent.
  - No stopping of the advancing front due to arrest of pouring or waterfall effects, etc.

4. Avoid bubble entrainment

- No bubbles of air entrained by the filling system should pass through the liquid metal in the mould cavity. This may be achieved by:
  - Properly designed offset step pouring basin; fast back-fill of properly designed sprue; preferred use of stopper; avoidance of the use of wells or other volume-increasing features of filling systems; small volume runner and/or use of ceramic filter close to sprue/runner junction; possible use of bubble traps.
  - No interruptions to pouring.

5. Avoid core blows

- No bubbles from the outgassing of cores or moulds should pass through the liquid metal in the mould cavity. Cores to be demonstrated to be of sufficiently low gas content and/or adequately vented to prevent bubbles from core blows.
- No use of clay-based core or mould repair paste unless demonstrated to be fully dried out.

6. Avoid shrinkage

- Demonstrate good feeding design by following all Feeding Rules, by an approved computer solidification model, and by test castings.

7. Avoid convection

- Assess the freezing time in relation to the time for convection to cause damage.
- Thin and thick section casting automatically avoid convection problems.
- For intermediate sections either (i) reduce the problem by avoiding convective loops in the geometry of the casting and rigging, (ii) avoid feeding uphill, or (iii) eliminate convection by roll-over after filling.

8. Reduce segregation

- Predict segregation to be within limit of the specification, or agree out-of-specification compositional regions with customer. Avoid channel segregation formation if possible.

9. Reduce residual stress

- No quenching into water (cold or hot) following solution treatment of light alloys. (Polymer quenchant or forced air quench may be acceptable if casting stress is shown to be negligible.)

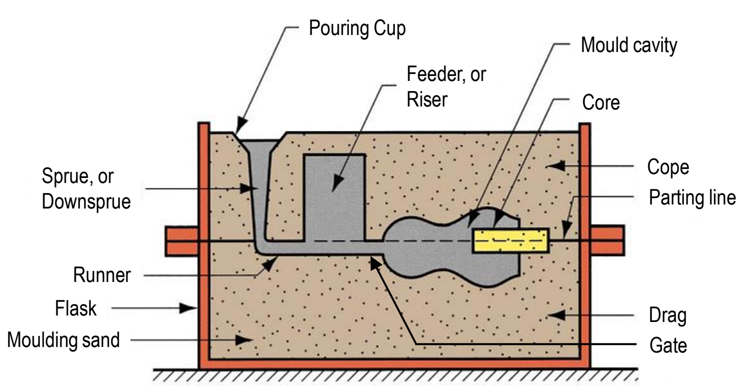
10. Provide location points

- All castings to be provided with agreed location points for pickup for dimensional checking and machining.

4. Three steps to make quality castings

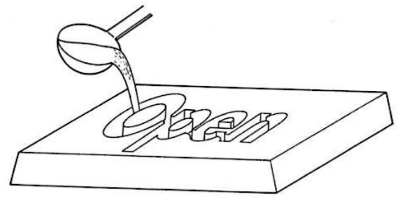
1. Making a perfect mould
2. Preparing a clean melt
3. Pouring efficiently of liquid metal into the mould cavity

4.1 Making a perfect mould



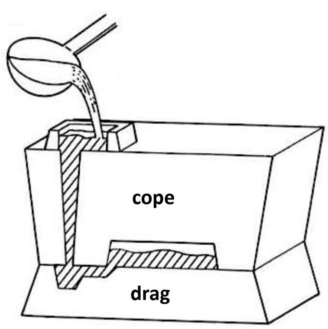
Cross section of a typical mould showing its different elements

An open mould



- Cope (top halve) not required
- Simple to make, easy to pour
  (as everything can be seen)
- Liquid metal poured directly into the mould cavity
- Somewhat skill required during pouring

A closed mould



(Partially Sectioned)

- Difficult to make, easy to pour
- Skill during pouring is not required !!
- Offer the greatest challenge
  in designing the moulding system
- Flow of liquid is controlled by the laws of
  fluid dynamics
- Only a carefully worked out gating system
  will give filling with low surface turbulence,
  and, therefore, reproducible every time.

Why is a perfect mould necessary?

- High temperature of liquid metal
- High pressure of liquid metal and dissolved gases
- Expansion of sand due to high temperature
- Reaction of liquid metal with the mould
- Velocity of liquid metal inside the mould cavity
- Turbulence of liquid metal inside the mould cavity

Requirements of an ideal mould

- Adequate strength and hardness
- Adequate refractoriness
- Adequate permeability
- Appropriate design of the gating/running system
- Adequate use of feeder, if necessary

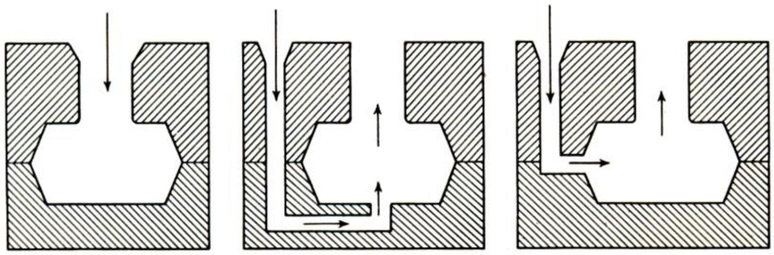
Method of making an ideal mould

1. Use of an appropriate moulding and casting process
   - Greensand (natural sand-clay-water) system
   - Dry sand (sand-chemical binder) system
   - Gravity die / Pressure die (metal mould, high/low pressure) system

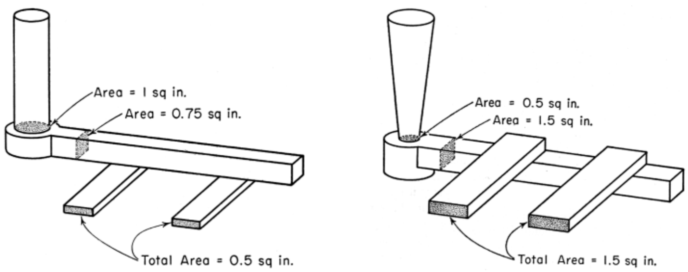
2. Use of appropriate moulding materials of required amount
   - Use of sand with adequate AFS number, size distribution, and shape;
   - Use of required amount of clay and water;
   - Making of greensand mixture with adequate properties;
   - Use of special additives to obtain specific properties, etc.

3. Use of appropriate gating design
   - Controlling velocity of liquid metal (250-500 mm/s) at the gate
   - Streamlining gating system
   - Top pouring vs. bottom pouring system
   - Pressurised vs. unpressurised system

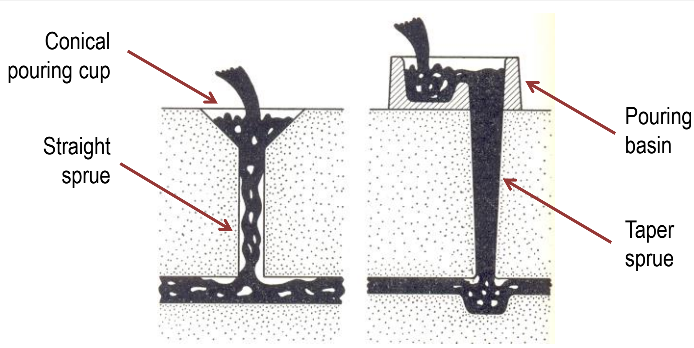
4. Use of adequate and proper feeder, if needed
   - Follow appropriate feeding rules to design the feeding system
   - Open feeder vs. blind feeder
   - Top feeder vs. side feeder



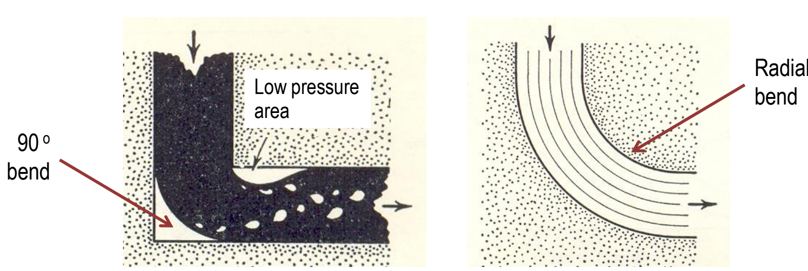
(a) Top pouring system, (b) Bottom pouring system, (c) Side pouring system



(a) Pressurised gating system, (b) Unpressurised gating system



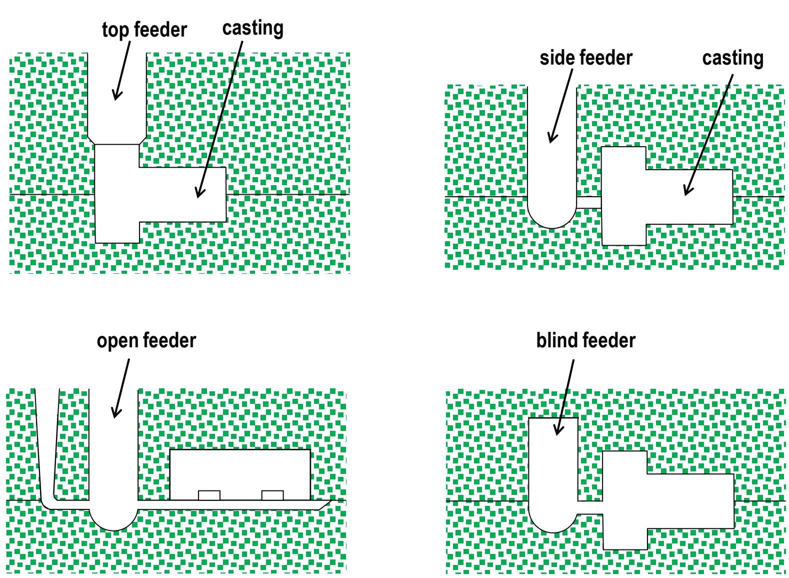
Use of pouring basin instead of pouring cup



Streamlining gating system

Feeding rules

1. Do not feed (unless necessary)
2. Heat transfer requirement
3. Volume requirement
4. Junction requirement
5. Feed path requirement
6. Pressure differential requirement
7. Pressure requirement



4.2 Preparing a clean melt

- A clean melt is one which is
  1. substantially free from suspension of non-metallic inclusions in general, and bi-films in particular, and
  2. relatively free from bi-film-opening agents (gas in solution and certain alloy impurities such as Fe in Al-alloys in solutions)
- Such melts are not to be assumed, and without proper treatment, are probably rare.

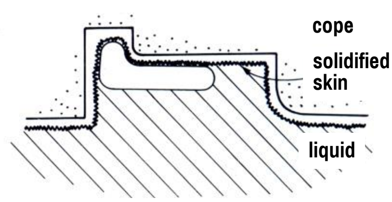
It would be of little use for the casting engineer go to great lengths to adopt the best design of filling and feeding systems if the original melt was so poor that a good casting could not be made from it.

Method of preparing a clean melt

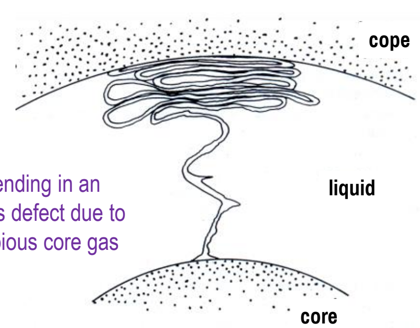
- Use of appropriate, clean and dry raw materials
- Use of appropriate furnace
- Use of clean and dry furnace, ladle, and tool
- Removal of dissolved gas and dross from melt
- Eliminate or, reduce turbulence

- The major source of gas porosity
  - Moisture
  - Core gas

- Some common source of moisture
  - Atmosphere
  - Greensand mould
  - Wet refractories
  - Wet charge materials
  - Wet tools



A core blow – a trapped bubble containing core gases

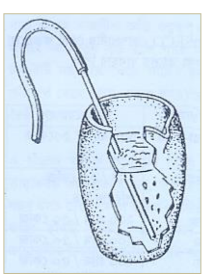


A bubble trail, ending in an exfoliated dross defect due to passage of copious core gas

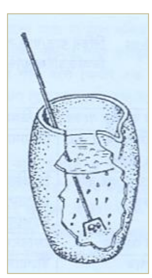
Methods of control of gas porosity

1. Reduce moisture content in charge, furnace lining, tools, etc.
2. Melt and pour at as low a temperature as possible
3. Use adequate metal head pressure to suppress nucleation of gas pore
4. Pour the liquid metal inside the mould at a low pressure (to readily form and eliminate the gas bubbles), but raise the pressure during solidification (to suppress the formation of gas bubble)
5. Use appropriate methods (flushing, solid degasser or rotary degasser) to eliminate dissolved gases from the liquid metal

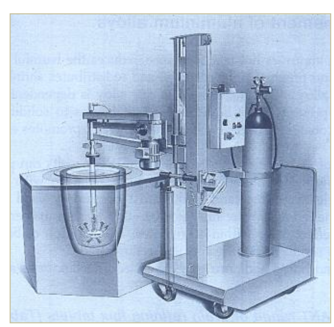
Removing dissolved gases from the melt



Flushing with inert gas (argon or nitrogen)



Use of solid degasser

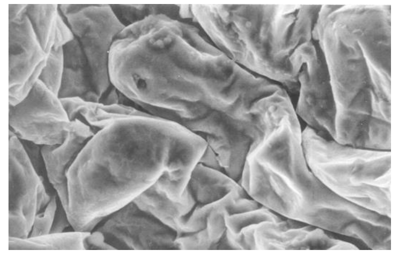


Rotation speed: 500-600 rpm
Time of rotation: 3-5 min

Use of rotary degasser

Oxide film

- An oxide film is not harmful when it remains on top of the surface.
  - in case of aluminium, the surface film protects the liquid from catastrophic oxidation (as in the case with magnesium).
- A surface film only becomes problematic when it becomes a submerged film.



Oxide film

In fluid dynamics, (bulk) turbulence is measured by using the **Reynold's number :**

$$R_e = \frac{V\,\rho\,d}{n}$$

V = velocity of melt
ρ = density of melt
d = linear dimension of flow path
n = viscosity of melt

R_e < 2000, smooth, laminar, turbulent-free flow
R_e > 2000, turbulent flow

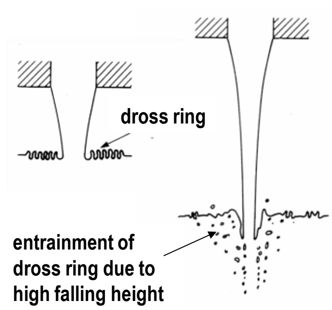
Surface turbulence is measured by using the **Weber number :**

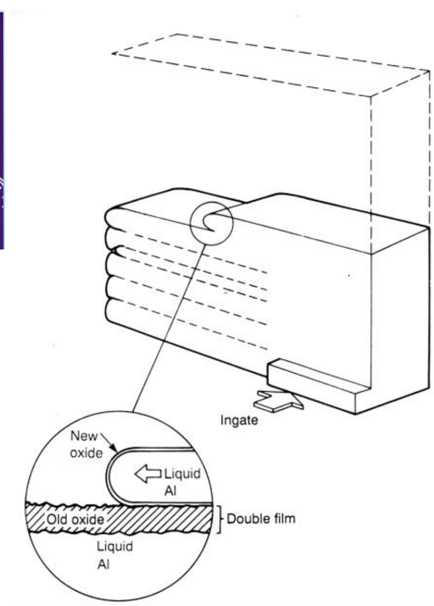
$$W_e = \frac{V^2\,\rho\,r}{\gamma}$$

γ = surface tension of melt

W_e = 0.2 – 0.8, free from surface turbulence
W_e = 100, surface turbulence becomes problematic
W_e = 100000, creates atomization !!

surface flooding and formation of bi-film



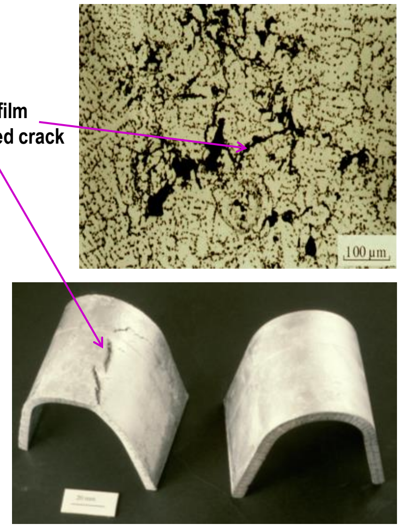


how an oxide film becomes a submerged film

Problem with Oxide Films

- Act as nucleating sites for pores and shrinkage cavity
- Constitute cracks in the liquid and in the finished products.
- Other problems: machining problem, leak tightness, reduced fluidity, reduced strength and ductility, low fatigue strength

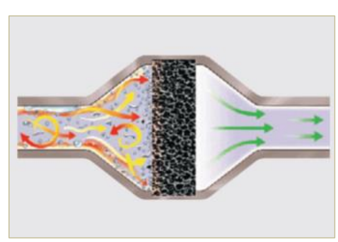
oxide film
initiated crack



Removing oxide film, slag and inclusion from the melt

Strainers and foam filters used to remove oxide film and inclusions

Pouring cup
with filter attached



Use of filter at the gating system

4.3 Efficient pouring of melt into the mould

- ❑ Pouring of liquid metal inside the mould without creating any turbulence
- ❑ Pouring of liquid as quickly as possible
- ❑ Pouring of melt without any interruption

Next Class

MME **345**, Lecture **B:02**

Chapter B2: Solidification

1. Thermodynamic considerations