Casting Processing, MH2252, 6hp

Lecture 7a+7b
Precipitation of pores and slag inclusions at casting processes

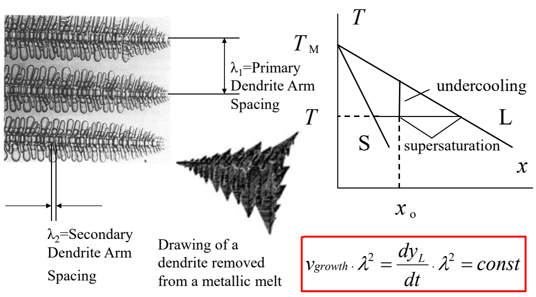
Lect.7-1

Today´s topics

- Repetition
  - Structure formation in cast materials
  - Microsegregation
  - Macrosegregation
- Precipitation of pores and slag inclusions at casting processes
  - Precipitation of pores
  - Gas reactions during casting
  - Pore morphology
  - Gases in steels and iron alloys/Aluminium
  - Slag inclusions
  - Cast iron

Lect.7-2

Characterisation of Dendrites - Dendrite Arm Distance and Growth Rate

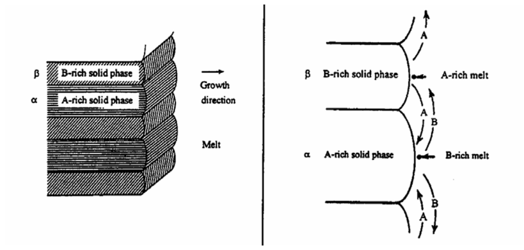


$$v_{growth} \cdot \lambda^2 = \frac{dy_L}{dt} \cdot \lambda^2 = const$$

$$v_{growth} = \mu \cdot (T_L - T)^n$$

Lect.5-3

Lamellar Eutectic Growth

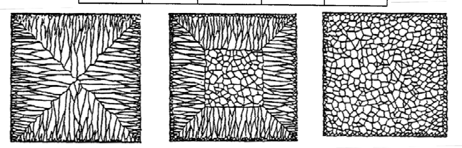


$$v_{growth} \cdot \lambda^2 = \frac{dy_L}{dt} \cdot \lambda^2 = const$$

Lect.5-4

Macrostructure - Different Cooling Conditions

Casting method	Cooling Rate	Growth Rate	Columnar Zone	Macro-structure
Continuous casting	very strong	high	long	Figure 37 a
Ingot casting	strong	medium	short	Figure 37 b
Sand mould	weak	slow	absent	Figure 37 c



A: Strong cooling. High casting temperature

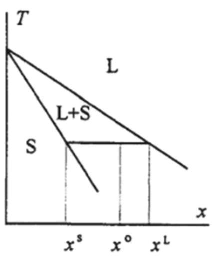
B: Medium cooling. Medium casting temperature

C: Weak cooling. Low casting temperature.

Lect.6-5

The Lever Rule: Equilibrium Solidification

- <u>High</u> **diffusion rates: *Lever rule* valid**



$$x^L = \frac{x^S}{k} = \frac{x^0}{1 - f(1-k)}$$

$x^0 =$ initial concentration of the alloying element

$f =$ fraction solid

$k =$ partition coefficient (x^S/x^L) of the alloying element

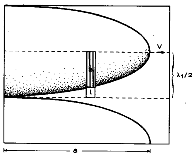
$D^S > 10^{-10}$ m²/sek

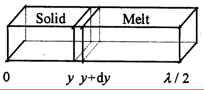
See chapter 7.3.2 The Lever rule

Lect.6-6

Scheil's Model

- f < 0.9 and low diffusion rate: *Scheil's model* valid
- There is an even composition in the melt at every moment
- The diffusion in the solid phase is neglectable
- There exists local equilibrium between solid and liquid phase can be described by the partition constant





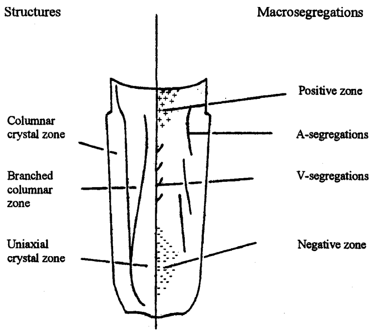
$$x^L = \frac{x^S}{k} = x^0 \cdot (1-f)^{-(1-k)}$$

$k = \frac{x^S}{x^L}$ the partition constant

$f = f_s$ = fraction solid

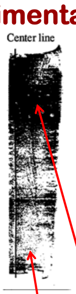
See chapter 7.3.1 Scheil´s Model for Microsegregation

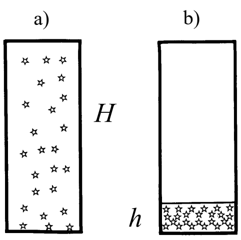
Macrosegregations in Ingots



See chapter 11.9 Macrosegregations in Steel Ingots

Sedimentation Segregation - +/- Segregation

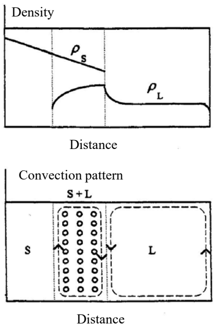




a) Equiaxed crystals in the melt before sedimentation.
b) Equiaxed crystals, including their associated melt, after sedimentation

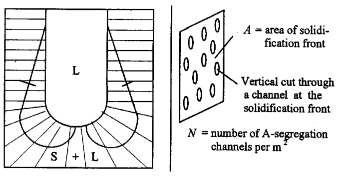
Positive segregation (+): the concentration of the alloying element exceeds the average concentration.
Negative segregation : there is instead a lack of the alloying element (lower than average concentration)

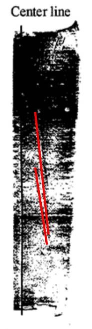
A-segregations – Ghost lines!



- The density of the melt increases linearly with decreasing temperature.
- The density of the melt within the two-phase region **decreases** due to **microsegregation of lighter alloy elements**.
- Natural convection in the melt and an **opposite convection pattern** in the two-phase region.
- Higher concentration of alloy elements will lower the liquidus temperature and cause **re-melting of solid structure**.
- Ghost-lines!

A-segregations - Freckles



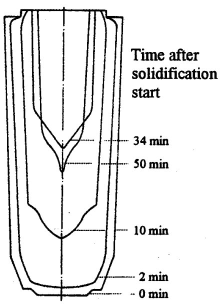


Channels (ghost lines/freckles) in castings are caused by natural convection due to concentration gradients in the two-phase region during the solidification process of an ingot.

The channels are created in the partly solidified two-phase region S+L.

V-segregation

- Vacuum, caused by the solidification shrinkage in the lower parts of the ingot.
- Cannot be filled by melt from above because the distance is long and the resistance from the dendrite arms is great.
- The pressure difference, which arises between the different parts of the ingot results in a general settling of the crystals in the middle zone.

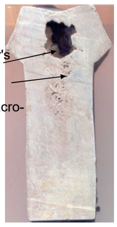


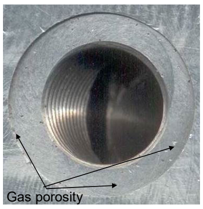
Porosity in castings

- Deteriorate quality of a casting
- Lower mechanical properties
  - Reduced elasticity
  - Decreased impact resistance
- Risk for crack formation
- Reduced surface quality during machining

- Gas Porosity
  - Gas entrapped during casting
  - Precipitation of dissolved gas
  - Smooth surface of porosity
- Shrinkage Porosity
  - Solidification shrinkage
  - Uneven surface of porosity

Shrinkage porosity - gas porosity

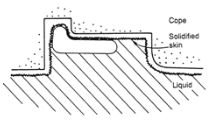




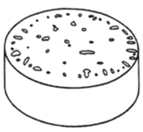
- Pores and porosity (micro / macro) cause surface defects and poor mechanical properties.
- Shrinkage porosity, arises because insufficient feeding of melt to the last solidified areas.
- Gas porosity, resulting from a high content of gas-forming substances in the melt.

Sources for Common Gases in Metals

- Entrapped Air
- From atmosphere
  - Oxygen, Nitrogen
  - Hydrogen from moisture $H_2O+M=2\underline{H}+MO$ and $2\underline{H}=H_2(g)$
- In Steels and Iron
  - Carbon monoxide, $\underline{C}+O_2=2CO(g)$
- Reaction with mould materials
  - H_2 (moisture in sand), O_2, CO, CO_2, SO_2

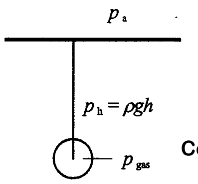


Entrapped Air



Precipitated gas porosity

Condition for pore precipitation (Pressure in a Gas Bubble)



$$p_{gas} = p_{atm} + p_h + \frac{2\sigma}{r}$$

$$p_{gas} > p_{atm}$$

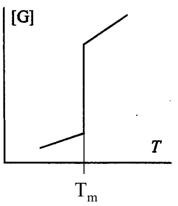
Condition for pore precipitation (simplified)

Note: the lower surface tension – the easier it is to form bubbles (gas pores)

See chapter 9.3.1 Gas Reactions and Gas Precipitation in Metal Melts

Lect.7-16

Gas Solubility in Metal Melts



Sievert's Law

$$[G] = const\sqrt{p_{G_2}}$$

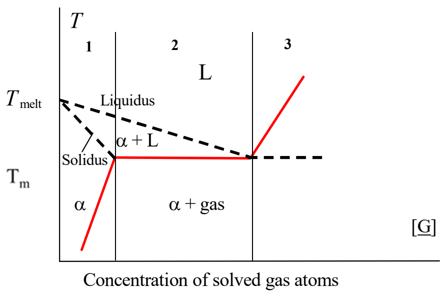
Note: You find the constant by finding the solubility in liquid in a phase diagram/gas solubility diagram at 1 atm

The concentration of the dissolved gas atoms in the melt or in the solid phase is proportional to the square root of the partial pressure of the gas in the surrounding atmosphere

See chapter 9.7.1 Hydrogen in Steel and Iron Alloys

Lect.7-17

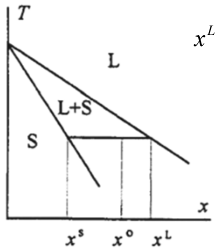
Gas Solubility and the Phase diagram



Region 1: Gas content totally dissolved in solid.
Region 2: Precipitation of gas porosity during solidification
Region 3: Precipitation of gas porosity during melt cooling followed by gas porosity during solidification

Lect.7-18

The Lever Rule



$$x^L = \frac{x^S}{k} = \frac{x^0}{1 - f(1-k)}$$

$x^0 =$ initial concentration of the alloying element

$f =$ fraction solid

$k =$ partition coefficient (x^S/x^L) of the alloying element

Valid: $D^S > 10^{-10}$ m²/sek

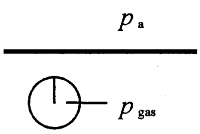
Lect.7-19

Pore precipitation in solidifying melts

1. $x^L = (\frac{x^S}{k}) = \frac{x^0}{1 - f(1-k)}$ — **The Lever Rule.**
   - **Always valid for gaseous elements**
   - **f^S in relation to x^L**
2. $[G] = const \sqrt{p_{G_2}}$ — **Sievert's Law**
   - **Valid for two atomic gas molecules**
   - **x^L in relation to P_G^2**
3. $p_{gas} > p_{atm}$ — **Condition for pore precipitation**
   - **Simplified, close to the melt surface**
   - **P_G^2 in relation to P_{atm}**
4. $k = \frac{x^s}{x^L}$ — **The partition coefficient**
   - **close to 1, low enrichment, << 1 large enrichment to the liquid**

Lect.8-20

Rounded Pores (Region 3)



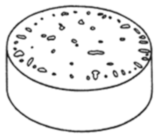
Precipitated in melt

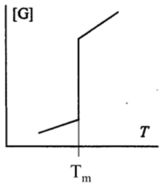
Composition in melt $x^0 > x^L$

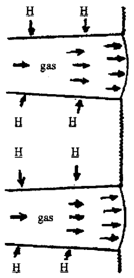
Lect.7-21

Elongated Pores (Region 2)

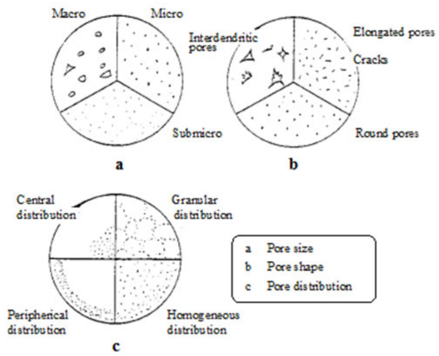
- Nucleated in the two phase region - between the dendrites
- Formed when the initial gas composition not is initially saturated
  $x^S < x^0 < x^L$





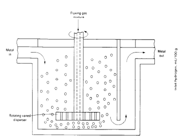


Different types of pore structures



Methods of lowering the dissolved gas content in metal melts

- Solidification – re-melting
- Stirring
  - Subsonic stirring
- Lowering the partial pressure
  - Vacuum treatment
  - Inert gas bubbling
  - Active gas bubbling
- Desoxidation - precipitation of secondary phases



Rotating Impeller

Common gases

H_2: Hydrogen

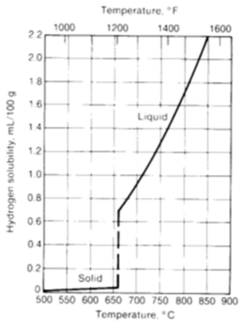
N_2: Nitrogen

O_2: Oxygen

CO: Carbon monoxid

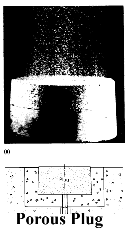
Hydrogen Pick-Up in Aluminium

$2Al+3H_20 = Al_2O_3+6\underline{H}$



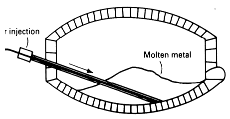
Lect.7-25

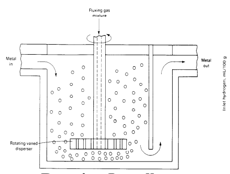
Degassing of Aluminium Melts



Porous Plug

Lance Injection





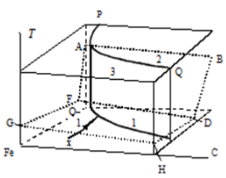
Rotating Impeller

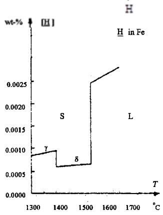
- Inert gas (Nitrogen or Argon)
- Reactive gases (Chlorine)

Lect.7-26

Gases in Steels and Iron

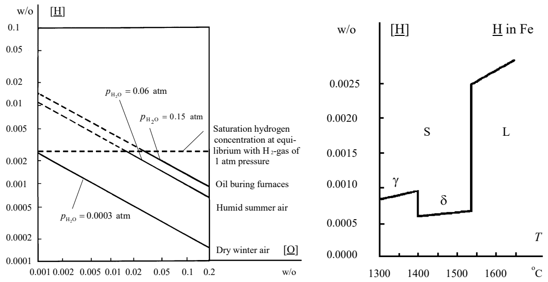
- Carbon monoxide
  - $\underline{C} + \underline{O} = CO\ (g)$
- Oxygen
  - From oxygen in atmosphere
  - Remove by addition of desoxidant
    - $\underline{M} + \underline{O} = MO$
    - Al, Si, Mg
- Hydrogen
  - $2H_20 = 2H_2 + O_2$
  - $\underline{C} + O_2 = CO + H_2$
  - $H_2 = 2\underline{H}$
  - Avoid moisture, bubble with inert gas





Lect.7-27

Hydrogen concentration in a steel melt



- Hydrogen pick up
  - $2H_20 = 2H_2 + O_2$

[H] ^{2}.[O] = const

Note: a decrease of the oxygen concentration leads to an increased hydrogen concentration as a consequence of the solubility product of water

Lect.7-28

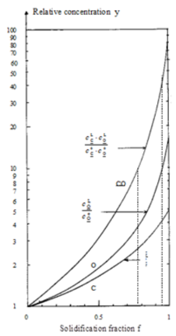
Oxygen and Carbon Monoxide in a Steel melt

$$c_C^L \cdot c_O^L = 0.0019 \cdot p_{CO}$$ (w/o and atm)

$$y_O = c_O^L / c_O^o = \frac{1}{1 - f \cdot (1 - 0.054)}$$

$$y_C = c_C^L / c_C^o = \frac{1}{1 - f \cdot (1 - 0.020)}$$

$$y_{CO} = y_C \cdot y_O = \frac{c_C^L \cdot c_O^L}{c_C^o \cdot c_O^o}$$



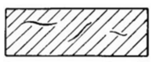
Both C and O are present in all steel and iron melts. When the steel solidifies both C and O concentrate in the melt and the saturation limit may be exceeded

See chapter 9.7.3 Oxygen and Carbon Monoxide in Steel and Iron Alloys

Lect.7-29

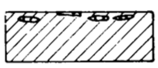
Slag Inclusions (Cinders)

- Slag:
  - Non-Metallic Inclusions in Metals
- Microslags:
  - Not detectable by naked eye (<0.1 mm)
  - Most often formed interdendritic during solidification
  - M+O = MO where M = desoxidation element (Si, Al etc.) Solubility Product [M][O]= K_{MO}



oxide skin (Al_2O_3)

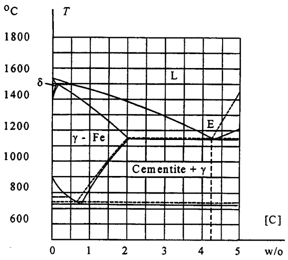
- Macroslags:
  - Visible by eye (>0.1 mm)
  - Formed in the melt before solidification
  - Reaction products from desoxidation elements
  - Refractory material from mould walls



Slag Inclusions

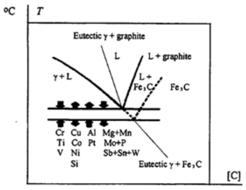
Lect.8-30

Cast Iron - Fe-C alloys with carbon content > 2.1 w/o C



- Steel < 2% C
- Cast Iron > 2% C (2.5-4.3 %C)

- T_E= Stable (1153 °C)
- $T_{E'}$= Metastable (1147 °C)

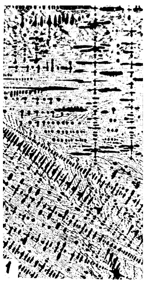


Promotes Grey Iron
- Si - Important
- Ni, Cu, Co
- Slow Cooling Rate
- Inoculation

Promotes White Iron
- Cr, V, Ti
- High Cooling Rate

Lect.6-31

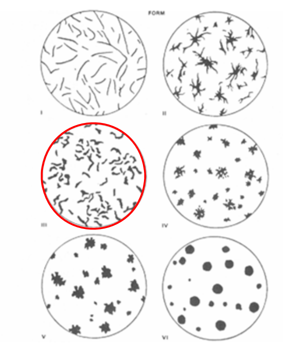
White Cast Iron



- Mixture of cementite and austenite
- Eutectic is called ledeburite
- Very hard
- Very low ductility = fragile
- High wear resistance
- Friction material

Lect.5-32

Different types of grey cast iron



I, II : Flake graphite

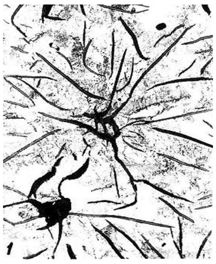
III : Compacted graphite, CGI

IV,V : Vermicular graphite

VI : Nodular graphite

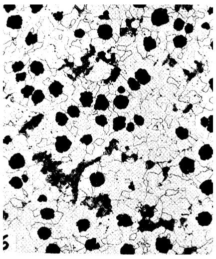
Lect.5-33

A. Flake Graphite



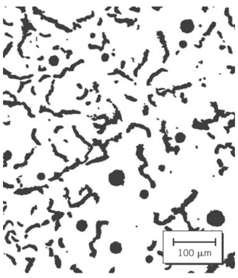
- **Spherical cells**
- **Very good castability**
- **Good damping properties**

B. Nodular Graphite (Ductile Iron)



- Spheroidal graphite morphology
- By adding Cr or Mg
- More difficult to cast
- Good ductility
- High strenght

C. Compact Graphite Iron (CGI)



- Intermediate between flake and spheriodal graphite - with respect to structure castability and strength
- By adding small amounts of Cr or Mg
- Difficult to control microstructure

Recommended reading in
"Materials Processing during Casting", by Hasse Fredriksson and Ulla Åkerlind

Chapter: ❑ 9.1 – 9.9

Lect.7-37