Casting Processing, MH2252, 6hp

Lecture 8a+b
Solidification and cooling shrinkage of metals

Lect.8-1

Today´s topics

- Study visit at Scania AB – Yes!
  - Study visit groups
  - Seminar presentations
- Repetition
  - Precipitation of pores and slag inclusions at casting
  - Cast iron
- Solidification and cooling shrinkage of metals
  - Conditions for feeder
  - Hot top
  - Cooling shrinkage

Lect.8-2

Study Visit – Scania AB

Date: **Friday 7/10**
Time: **08.00 – 12.00**

Compulsory for all students registered to Casting Processing MH2252

Responsible
Anders Eliasson, KTH: 073-614 95 73
Isak Hollinger, Scania CV AB: 070 700 810 555

Program
08.30 - 09.30 Presentation of the new Foundry
09.30 - 11.00 Foundry tour
11.00 - 12.00 Summary and transport back to Södertälje hamn

Preparation:
Prepare yourself by repeating the pages about sand forming, solidification in sand moulds and cast irons in the text book. You can learn more about Scania at www.scania.com

Lect.8-3

Seminar Presentation- Study Visit Groups – Scania AB

The presentations of the different tasks will take place:

14/10, 13-15, Blå

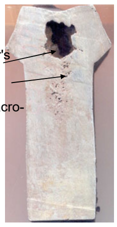
You should prepare and make a short presentation at a maximum of 10-15 minutes about your task (max 8-10 PowerPoint slides). Attendance at the presentations are mandatory!

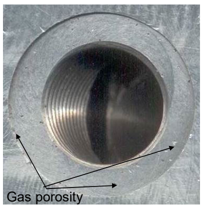
Each presentation, should be handed in in Canvas before or latest at the presentation. All students should be involved and be at the stage. The groups are (max three members) - Subscribe in Canvas!

Group 1: Moulding - Materials and methods at Scania
Group 2: Cast Iron Parts in a Scania-truck, describe the different types of cast iron alloys and where they are used and why
Group 3: The technique of additive manufacturing is a growing technology that can be applied for manufacturing of cores. Discuss when/how this is a suitable process route.

Lect.8-4

Shrinkage porosity - gas porosity

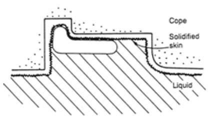




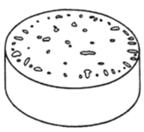
- Pores and porosity (micro / macro), cause surface defects and poor mechanical properties.
- Shrinkage porosity, arises because insufficient feeding of melt to the last solidified areas.
- Gas porosity, resulting from a high content of gas-forming substances in the melt.

Sources for Common Gases in Metals

- Entrapped Air
- From atmosphere
  - Oxygen, Nitrogen
  - Hydrogen from moisture $H_20+M=2\underline{H}+MO$ 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

Lect.8-6

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}

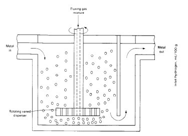
4. $k = \frac{x^s}{x^L}$

The partition coefficient

- close to 1, low enrichment, << 1 large enrichment to the liquid

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

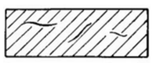


Rotating Impeller

Common gases
H_2: Hydrogen
N_2: Nitrogen
O_2: Oxygen
CO: Carbon monoxid

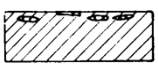
Slag Inclusions (Cinders)

- 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 $[M][O]=K_{MO}$



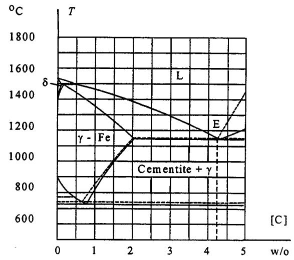
oxide skin (Al_2O_3)

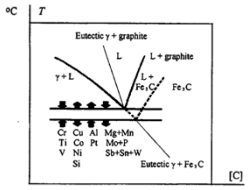
- Macroslags:
  - Visible by eye (>0.1 mm)
  - Formed in the melt before solidification
  - Reaction products from desoxidation elements
  - Refractory material from mould walls



Slag Inclusions

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





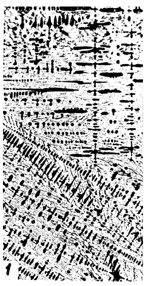
- Steel < 2% C
- Cast Iron > 2% C (2.5-4.3 %C)
- T_E= Stable (1153 °C)
- $T_{E'}$= Metastable (1147 °C)

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

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

Lect.6-10

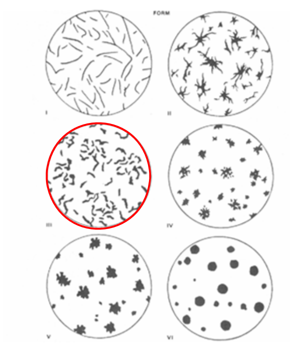
White Cast Iron



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

Lect.5-11

Different types of grey cast iron



I, II : Flake graphite

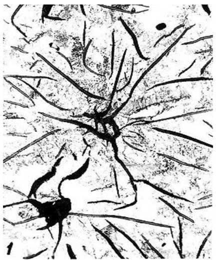
III : Compacted graphite, CGI

IV,V : Vermicular graphite

VI : Nodular graphite

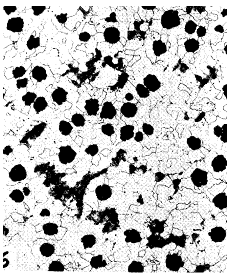
Lect.5-12

A. Flake Graphite



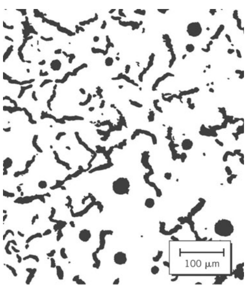
- Spherical cells
- Very good castability
- Good damping properties

B. Nodular Graphite (Ductile Iron)



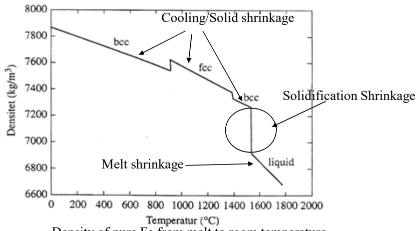
- Spheroidal graphite morphology
- By adding Cr or Mg
- More difficult to cast
- Good ductility
- High strenght

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

What happens during the casting process? Volume Change!



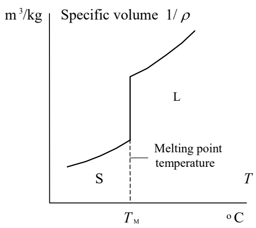
Density of pure Fe from melt to room temperature.

Melt shrinkage, cooling the melt down to temperature when solidification begins.

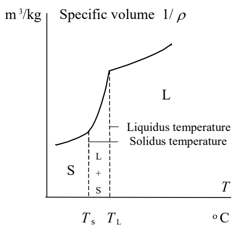
Solidification shrinkage, transition from the molten to the solid phase.

Cooling/Solid shrinkage, solid phase cooling to room temperature.

Solidification and Cooling Shrinkage of Metals



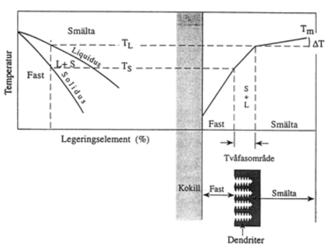
The solidification and cooling processes of a pure metal.



The solidification and cooling processes of an alloy

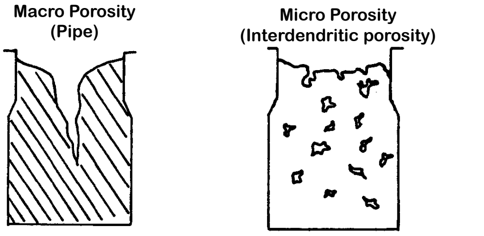
See chapter 10.2 Solidification and Cooling Shrinkage

Solidification Shrinkage in Alloys



- Dendrites form network
- The width of the channels control the melt transport
- At some point a shrinkage cavity will be formed

Shrinkage Cavities

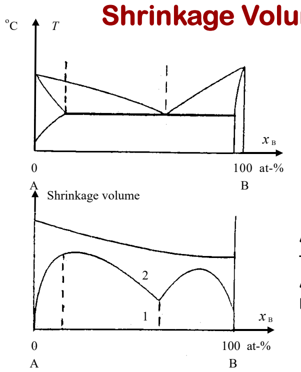


- •Strong Cooling (chill mould)
- •Small Solidification Interval
- •Weak Cooling (Sand Mould)
- •Broad Solidification Interval

Note, not the same magnification – it is only a schematic view

Lect.8-19

Shrinkage Volume



$$\beta = \frac{V_L - V_S}{V_L} = \frac{\rho_S - \rho_L}{\rho_S}$$

Area 1: Shrinkage cavities – micro porosity

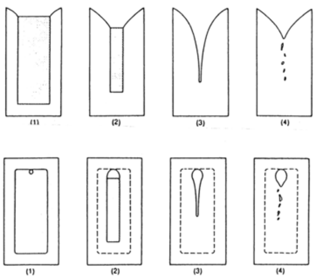
Area 2: Pipe – macro porosity

The shrinkage volume as a function of the composition of the alloy.

This is really important!

Lect.8-20

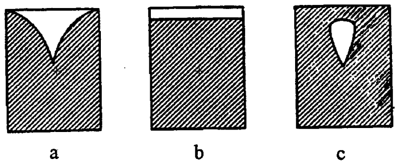
Shrinkage porosity - Micro / macro-porosity



Shrinkage porosity generally has a jagged and uneven surface

- During solidification, a volume decrease occurs since the solid metal has a higher density than the melt, (β=ρ_S-ρ_L/ρ_S).
- The shrinkage (β) is compensated for by melt flow into the two phase region.
- If this not can be compensated by new melt, shrinkage porosity occurs.

Positions of Cavities in Ingots

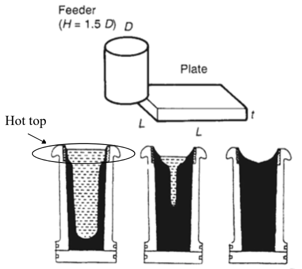


a) Cooling from sides and bottom

b) Cooling from bottom only

c) Cooling from all sides, i.e. top, sides and bottom

Feeders and Hot Top



A feeder add melt to the castings from an outside system.

A hot top is a better isolated part of an ingot and acts as a feeder for the rest of the ingot.

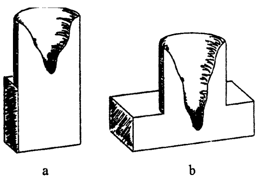
Feeding means to compensate the volume decrease of melt due to solidification shrinkage, with melt from an external system (feeder) such that the macro porosity (pipe) do not end up in the casting.

Three Conditions for Feeders

- **Solidification Time**
  - $t_{feeder} > t_{casting}$
- **Volume**
  - $V_{feeder\ total} - V_{solidified\ in\ feeder} > \beta\ (V_{feeder} + V_{casting})$

$$(1-\beta)\cdot\frac{V_f}{V_c}=\left(\frac{C_c}{C_f}\right)^{\frac{1}{2}}\cdot\frac{A_f}{A_c}+\beta$$

$$C=\frac{\pi}{4}\cdot\frac{\rho_{metal}^{2}(-\Delta H)^{2}}{(T_i-T_o)^{2}\,k_{mould}\,\rho_{mould}\,c_p^{mould}}$$

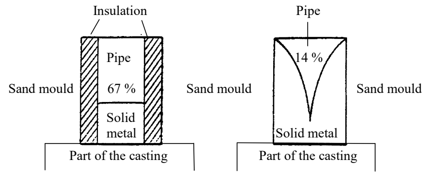


The plate and the feeder has the same solidification time but in b, the plate volume is larger

- **Placement of Feeder**

See chapter 10.4.1 Feeder System

Volume Condition of the Feeder - Efficiency of the Feeder

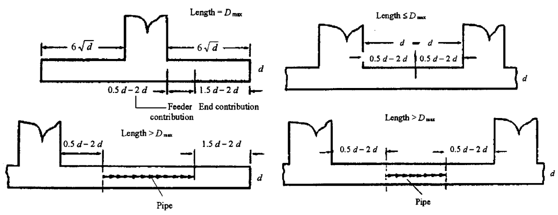


$$\varepsilon = \frac{V_f - V_{sm}}{V_f} \qquad V_f = \frac{\beta V_c}{\varepsilon - \beta} \qquad V_f - V_{sm} = \beta \left(V_f + V_c\right)$$

The efficiency of the feeder is defined as the ratio ε of the volume of melt in the feeder, which has been added to the casting, and the volume of the feeder.

Lect.8-25

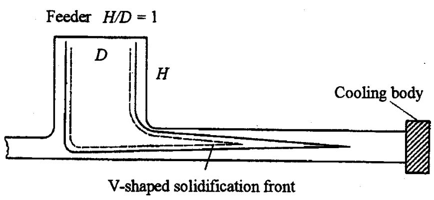
Feeder placement (open feeding ways) - Rules of Thumb (Low C Steel)



η= viscosity of the metal melt
r= radius of the channel
v= rate of flow of the melt
s= thickness of the solidifying shell

Lect.8-26

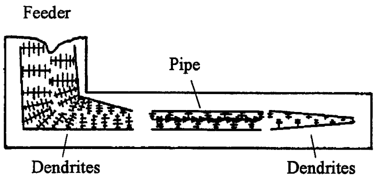
Cooling Body – affect the feeding length



Directed cooling is used to increase the effective feeding distances.

Lect.8-27

Feeding in Alloys with large Solidification Interval – CFR-value

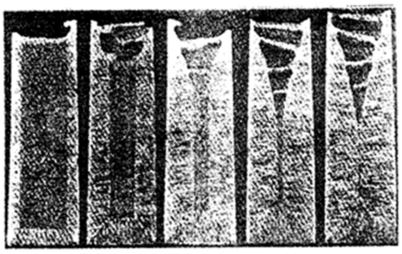


$$CFR = \frac{t_{total} - t_{initial}^{centreline}}{t_{total}}$$

CFR = measure of feeding resistance
t_{total} = total solidification time
$t_{start, centreline}$ = time when solidification starts in centreline

Lect.8-28

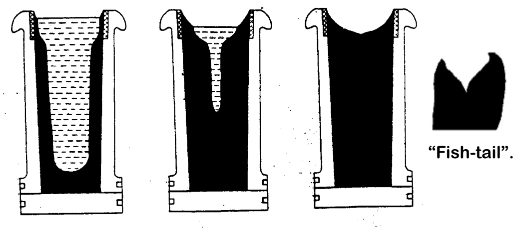
Pipe Formation in Ingots



At the beginning of the 20th century the English metallurgist Brearley used a stearin melt in his simulation experiments to study the formation of a pipe at solidification of an ingot

Lect.8-29

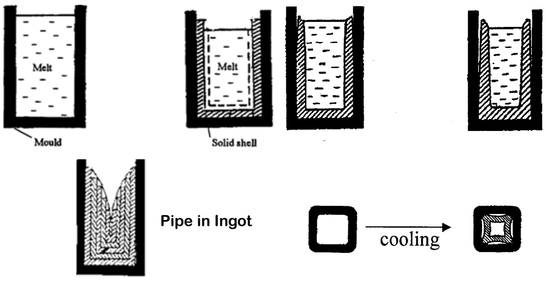
Hot Top



A hot top insulate the top of the ingot with give less pipe and higher yield

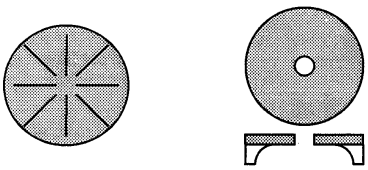
Lect.8-30

Cooling Shrinkage in Ingots



Thermal Stresses gives uneven deformation around the periphery of the ingot

Cooling Shrinkage

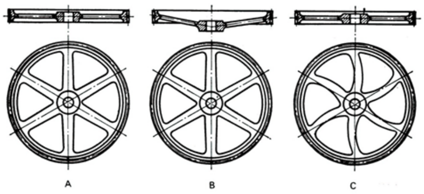


Circular plate casting with uniform thickness

Ring-shaped casting which is thicker at the periphery

Design to have a uniform temperature in casting

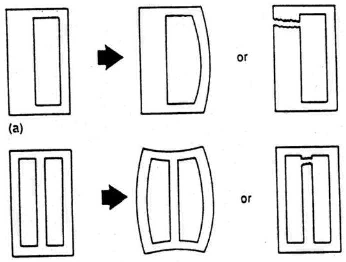
Cooling shrinkage - tensions and cracks

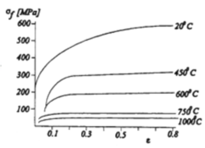


If the hub, rim and spokes have very different cooling rate, cooling cracks can occur at the inelastic configuration in (A). Both (B) and (C) provide possibilities for elasticity and stress relaxation during shrinkage

- Design the goods to avoid local stress concentrations
- Design as far as possible with constant wall thickness

The Shrinkage Harp





A thicker/more isolated part will take longer time to cool down but at the same time have a lower TS and might then be deformed. At low temperature stresses will occur och cracking

Lect.9-34

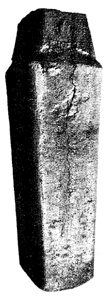
Hot Cracking

Hot Crack

Hot cracks are formed when the first formed metal shell cracks /separates due to tensile stresses in the shell and the interior of the cast piece is still molten.

The Hot crack might as well be a concentration of brittle phases in the last solidified region

Stresses and Cracking!!!



Local stress concentrations cause the ingot to crack

After solidification cooling continues;

- Plastic deformation
- Tensions/stresses
- Cracking

$$\sigma = E \cdot \varepsilon$$

$$\sigma = -E \alpha \Delta T$$

Lect.8-36

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

Chapter:

- 10.1 – 10.7

Lect.8-37