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TenarisUniversity

Instructor Presentation – Steelmaking for Non-Specialist

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Agenda

Steelmaking Overview

Raw Materials

Electric Arc Furnace Steelmaking

Secondary Steelmaking

Continuous Casting of Round Bars

Agenda

Steelmaking Overview

Raw Materials

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Continuous Casting of Round Bars

Steelmaking Overview

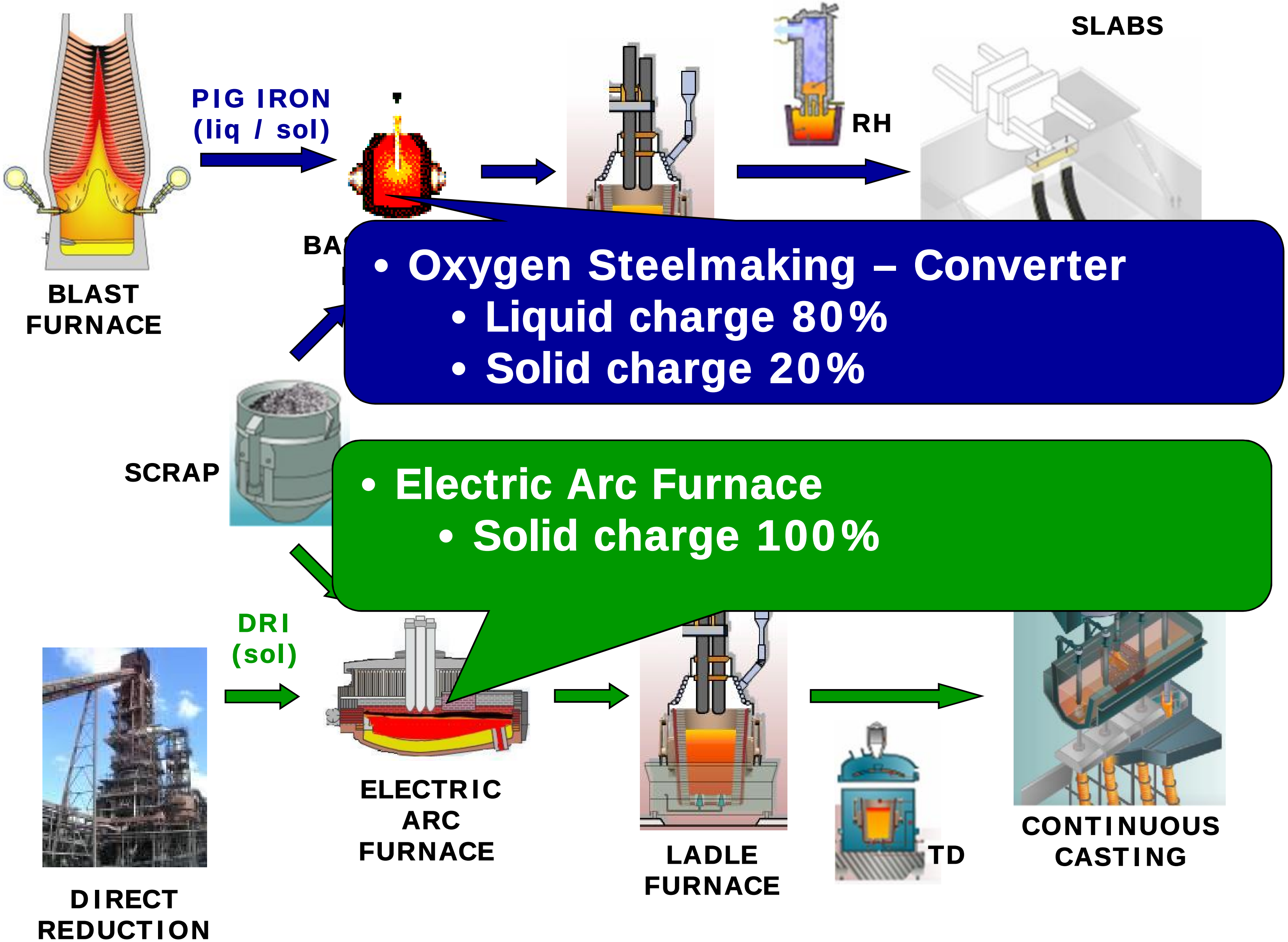
Example of Chemical Composition
Steel Grade API N80

	C	Mn	Si	S	P	Ni	Cr	Mo	V	Nb	Ti
max	0.27	1.30	0.35	0.010	0.025	0.15	0.20	0.080	0.010	0.005	0.035
aim	0.26	1.25	0.30								0.022
min	0.24	1.15	0.25								0.015

	Al	B	N	Cu	Cu+8Sn
max	0.035	0.0025	0.009	0.250	0.380
aim	0.018	0.0020			
min	0.010	0.0015			

Main elements ***Deoxidants*** ***Residual*** ***Alloys*** ***Microalloys Grain refiners***

Steelmaking Overview



- **Oxygen Steelmaking – Converter**
  - **Liquid charge 80%**
  - **Solid charge 20%**

- **Electric Arc Furnace**
  - **Solid charge 100%**

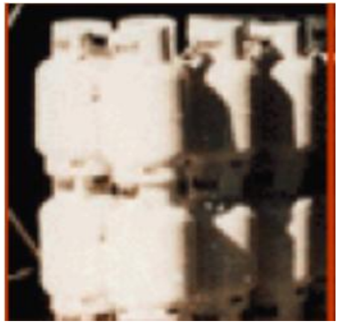
Steelmaking Overview

SLABS

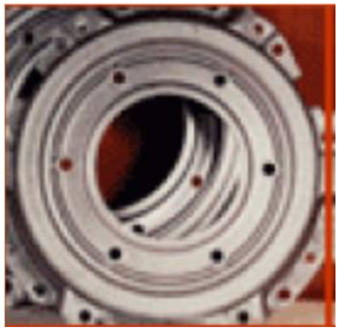
Steelmaking Overview

Flat products

- Tin plate
- Galvanized
- Car body (electrogalvanized)
- Steel drums
- Structural
- Welded pipes





Steelmaking Overview

ROUND BARS

Steelmaking Overview

Round bars products

Agenda

Steelmaking Overview

Raw Materials

Electric Arc Furnace Steelmaking

Secondary Steelmaking

Continuous Casting of Round Bars

Raw Materials

Scrap

Virgin Iron Units

Slag Formers

Ferroalloys

Scrap

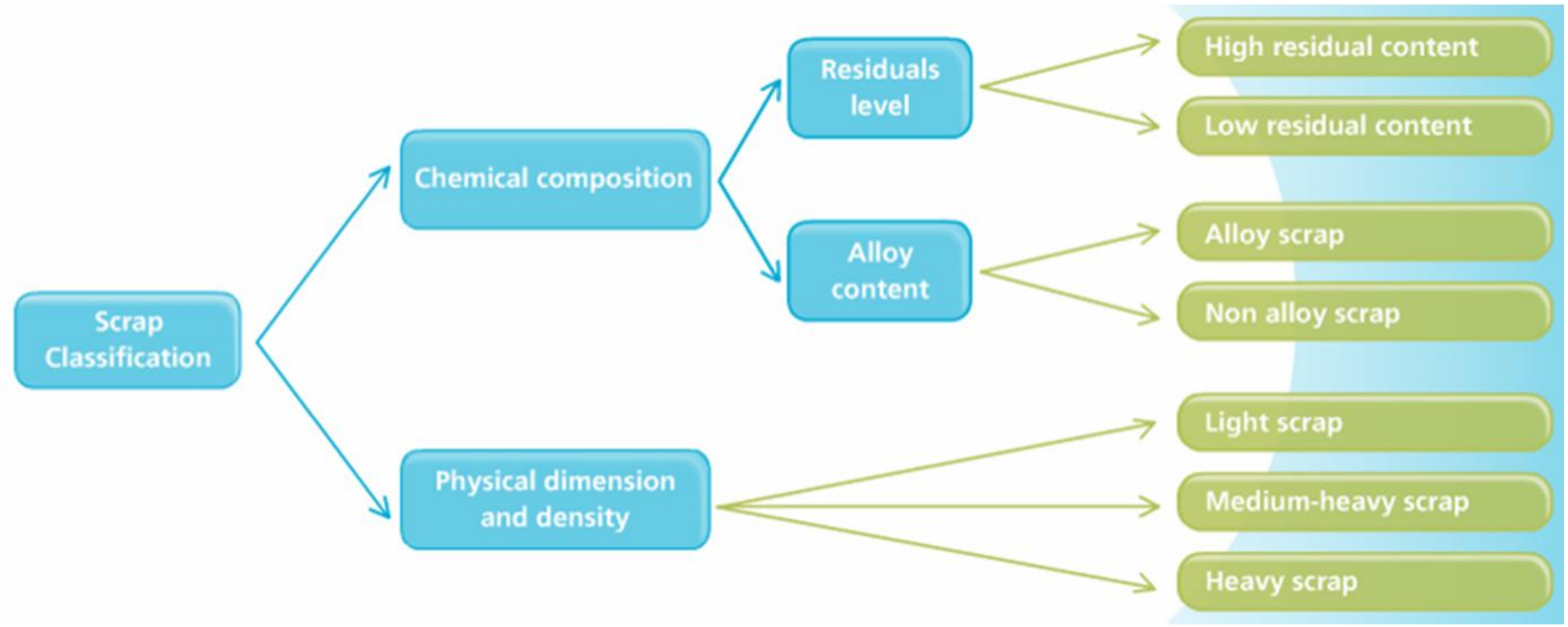
Virgin Iron Units

Slag Formers

Ferroalloys

Scrap

Classification



Scrap

Sources

Obsolete scrap	Prompt scrap	Revert scrap
Obtained from steel products beyond the end of their useful life (e.g. demolished buildings and ships, discarded machinery, cars and domestic objects)	New scrap coming from other industries which process steel products (e.g. cuttings, turnings, crops)	Internal recycled scrap from within the steelmaking and forming process (e.g. ladle and tundish skull, crop ends from continuous casting or rolling operations)

Scrap

Scrap: Heavy

Scrap

Scrap: Light

Scrap

Scrap: Bundles

Scrap

Scrap: Turnings

Raw Materials

Scrap

Virgin Iron Units

- **Sponge Iron**
- **Pig Iron**

Slag Formers

Ferroalloys

Raw Materials

Scrap

Virgin Iron Units

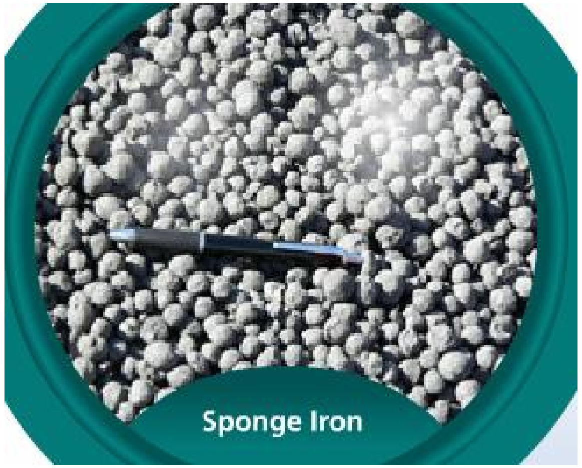
- **Sponge Iron**
- **Pig Iron**

Slag Formers

Ferroalloys

Virgin Iron Units

Sponge Iron (DRI)

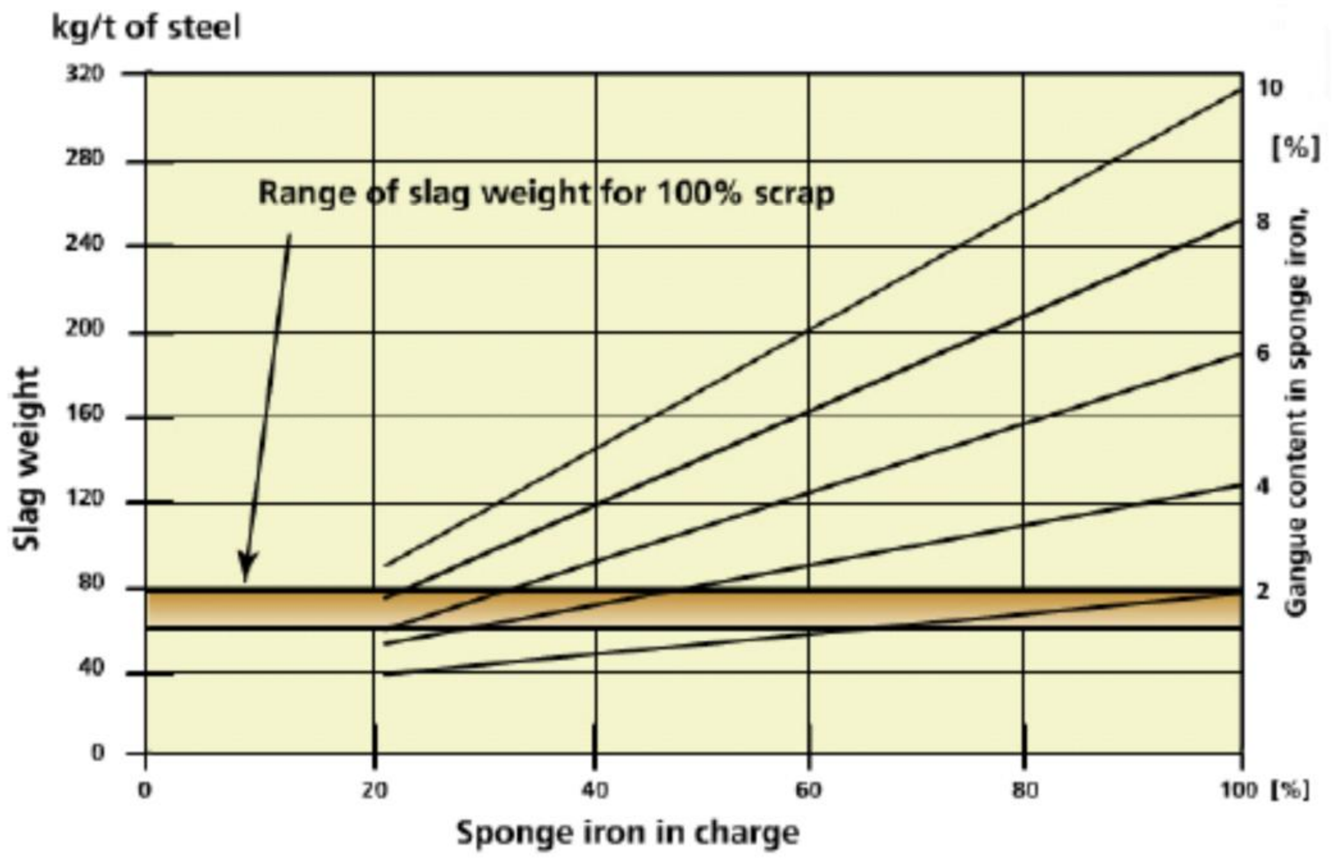


The typical chemical composition of sponge iron is:

- Metallic Iron: 87 to 88.5%
- Metallization (%metallic iron / %total iron): 93.5 to 95.5%
- Carbon: 1.9% to 2.5%
- Equivalent Carbon (Ctotal-Cnecessary for FeO reduction): 0.9 to 1.3%
- Others ⇒ non metallic gangue: 3,5%; SiO_2: 1.5% to 2%; Al_2O_3: 0.7%; P: 0,05%; S: 0,003%.

Virgin Iron Units

Effect of the gangue in sponge iron and slag weight



Raw Materials

Scrap

Virgin Iron Units

- **Sponge Iron**
- **Pig Iron**

Slag Formers

Ferroalloys

Virgin Iron Units

Pig Iron

The typical composition of the pig iron produced in Siderar is:
C: 3 to 5% Si: 0.10 to 0.50% Mn: 0.20% P: 0.08%
S:0.045% Rest: Fe

Raw Materials

Bucket charge

ON TOP: **Light Scrap. This layer has the purpose of protecting the roof from the electric arc (light scrap quickly melts allowing the electrodes to descend faster and prevent the roof from long time exposure to the arc)**

IN THE MIDDLE: **Heavy scrap should be placed in this area. This prevents the electrodes from breaking due to heavy-scrap falls, which might happen if it were charged at the top position. Mixed scrap is also charged in the middle section, above heavy scrap.**

AT THE BOTTOM: **Light scrap, in order to soften the fall of heavy scrap that might damage the furnace. It also helps a better closing of the bucket preventing the material from falling out of it when moving.**

Raw Materials

Main operative parameters affected by metallic charge

- Chemistry of liquid heel at melt-down stage
- Metallic yield – losses to the slag and fumes
- Tap-to-tap time
- Electric energy consumption
- Electrode consumption
- Slag formers consumption
- Maintenance costs (panels, roof, etc)
- De-oxidant and ferroalloys consumption

Raw Materials

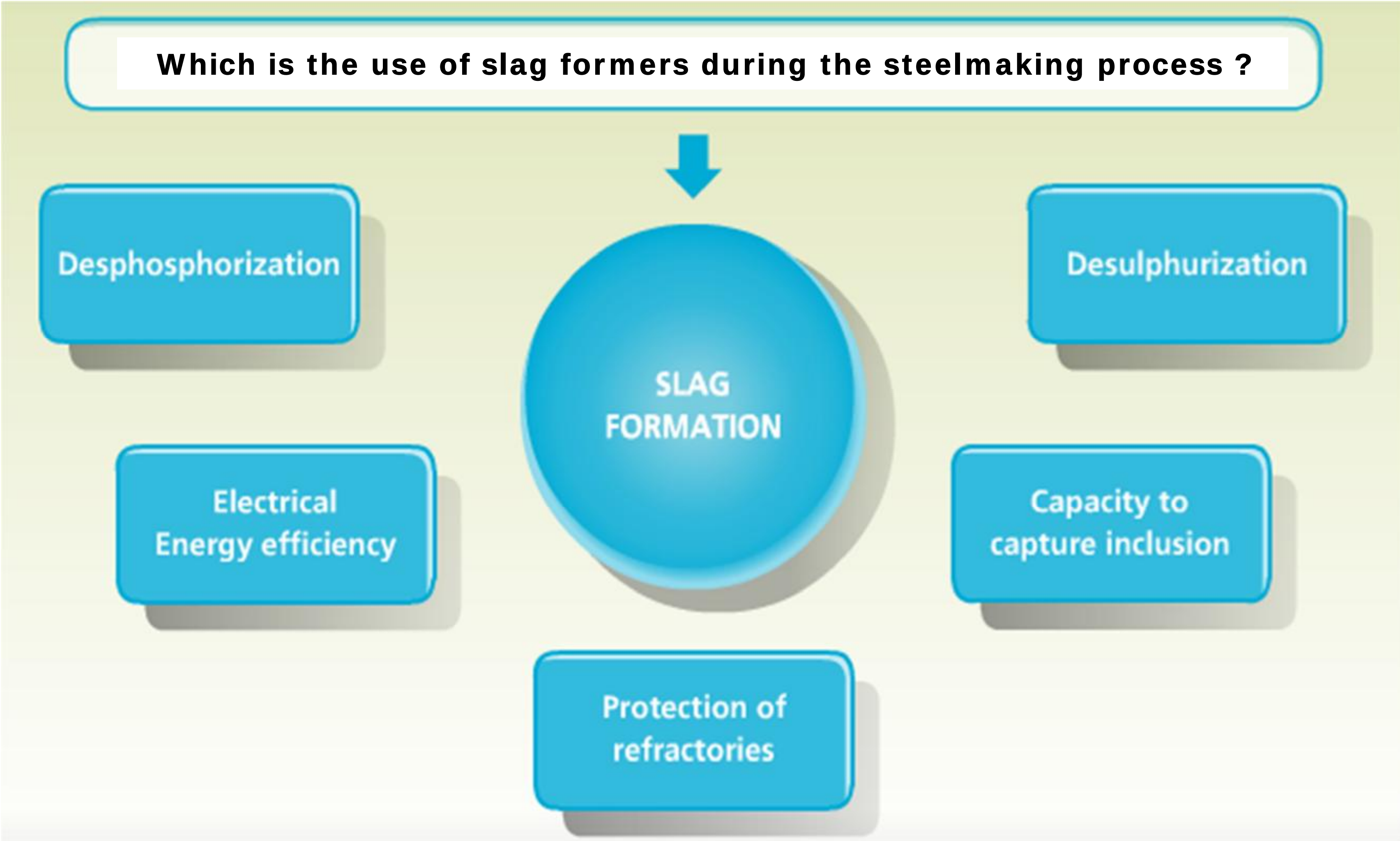
Scrap

Virgin Iron Units

Slag Formers

Ferroalloys

Slag Formers



Slag Formers

Main slag formers used in EAF and/or LF

FLUXES		CaO	SiO_2	AL_2O_3	MgO	Fe_xO_y
Limestone	$CaCO_3$	~ 55	< 5	< 2	< 5	< 2
Lime	CaO	~ 92	< 2	< 3	< 3	< 2
Magnesite	MgO	< 2	< 5	< 5	~ 90	< 10
Dolomitic lime	CaO-MgO	~ 60	< 1	< 1	~ 40	< 2
Ca-aluminate	$CaO-Al_2O_3$	~ 50	< 5	~ 40	< 2	< 2
Alumina	Al_2O_3 chemically produced	< 1	< 5	~ 95	< 1	< 1
Bauxite	Al_2O_3 Calcinated	< 2	< 15	~ 70	~ 0	~ 15
Fluorspar	CaF_2	~ 65 CaF_2	< 15	< 15	< 5	< 1

Slag Formers

Lime

Raw Materials

Scrap

Virgin Iron Units

Slag Formers

Ferroalloys

Ferroalloys

How to evaluate a ferroalloy ?

- **Alloy content (single / complex)**
- **Carbon content**
- **Residual elemnts: Cu – Sn – Al – Si**
- **Granulometry**
- **Melting point**
- **Density**
- **Cost per point**

Ferroalloys

Ferroalloy	Metallic content	yield	Kg/meter
FeMn	0.754	0.95	
FeMn (refined)	0.84	0.95	
Fe Si Mn (Mn)	0.65	0.95	
Fe Si Mn (Si)	0.16	0.85	
Fe Si	0.753	0.85	
Fe Mo	0.68	0.92	
Ni (electrolitic)	0.999	0.99	
Cu (electrolitic)	0.999	0.99	
Fe Cr (high carbon)	0.665	0.93	
Fe Cr afinado	0.70	0.93	
Fe Ti Cored-wire	0.702	0.82	0.360
Fe V	0.79	0.90	
Nv (V)	0.795	0.90	
Nv (N)	0.085	0.49	
Fe Nb	0.658	0.90	
S Cored-wire	0.999	0.75	0.168
Si Ca (Si)	0.60	0.90	0.213
Ca Si (Si)	0.30	0.90	0.160
Si Ca (Ca)	0.30	0.15	0.213
Ca SI (Ca)	0.60	0.15	0.160
$CaCN_2$	0.25	0.60	0.160
Fe B Cored-wire	0.0625	0.93	0.452
Al in wire	0.995	0.74	0.307
Al in bars	0.98	0.30	
Carbons			
Carbon wire	0.96	0.99	0.125
Carbon	0.95	1.00	
Fe Mn (c)	0.065	1.00	
Fe Mn afinado	0.010	1.00	
Fe Cr (c)	0.065	1.00	
Fe Cr afinado	0.010	1.00	
Fe Si Mn (c)	0.020	1.00	

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Metallurgical operations

Equipment Description

Sequence of Operation

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Metallurgical operations

Equipment Description

Sequence of Operation

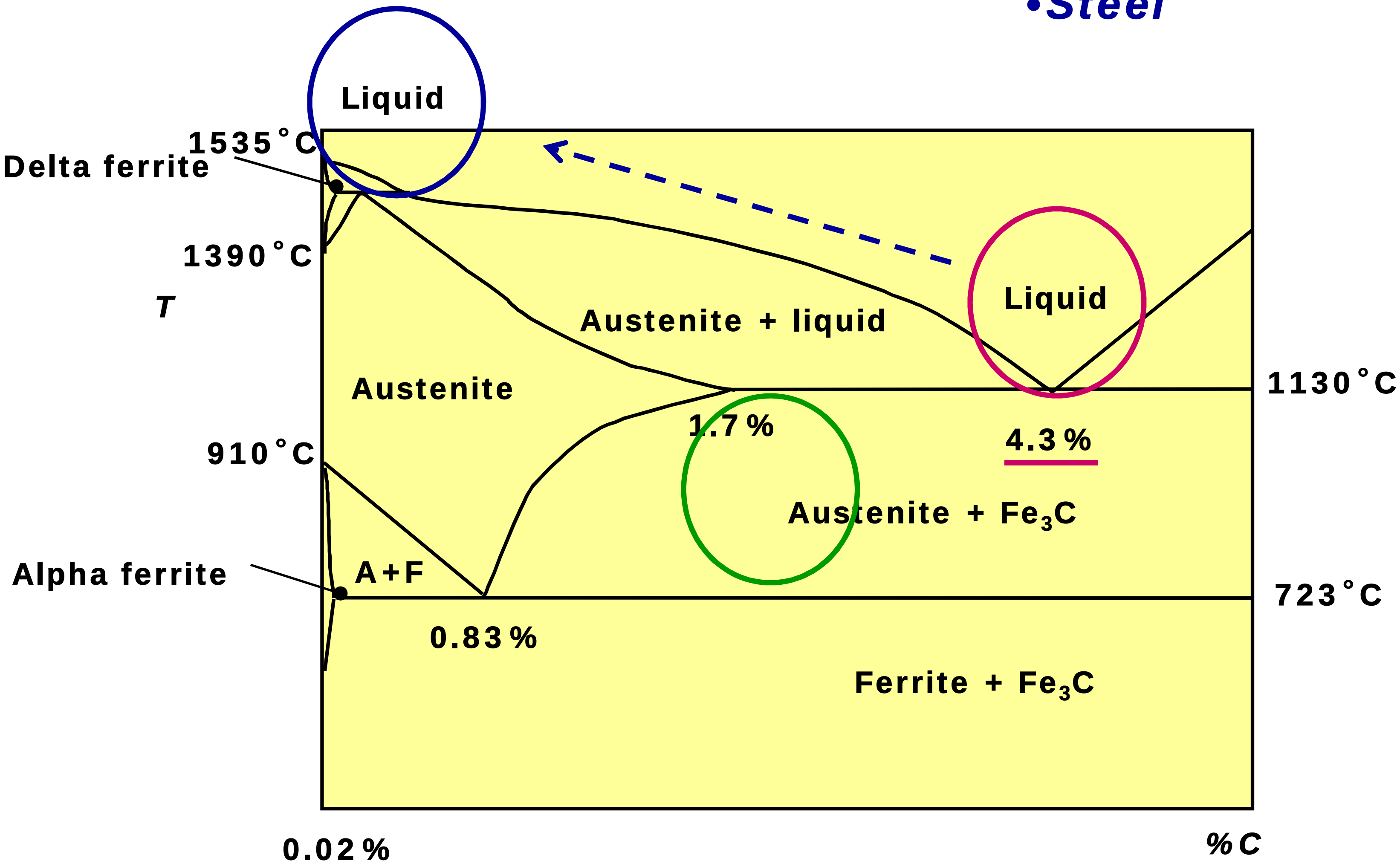
Metallurgical Operations

- **Oxidation (Si – Mn - Cr)**
- **Slag formation**
- **C-O reaction**
- **Heating up of the liquid steel**
- **Dephosphorization**
- **Homogenization**

Metallurgical Operations

Fe-C Diagram

- *Pig iron*
- *DRI*
- *Steel*



Slag formation

The slag affect the following parameters

- **Thermal and chemical insulation of the bath**
- **Dephosphorization**
- **Pick-up of oxides from the bath**
- **Electric arc coverage (foamy slag)**
- **Protection of water cooled panels**
- **Reduction of the arc ´noise´**

Slag formation

Typical chemical composition of the EAF slag

Chemical composition	Reference mean; St.dev.	Source of the chemical compounds in the slag
CaO	33,5%; 3,9	Melting of lime (calcium and dolomitic lime) and sponge iron gangue
FeO	29,0%; 5,4	Oxidation of Fe during oxygen injection and FeO contained in the sponge iron
SiO_2	15,1%; 1,5	Oxidation of Silicon contained in the scrap and sponge iron gangue
MgO	11,6%; 2,4	Melting of dolomitic lime and refractories erosion
MnO	1,9%; 0,5	Oxidation of Manganese contained in the scrap
Al_2O_3	5,1%; 0,6	Oxidation of Aluminium contained in the scrap
P_2O_5	0,9%; 0,1	Oxidation of Phosphorous contained in the load
Binary Basicity index = [CaO/SiO_2] from 2 to 2,5 approximately		
Ternary Basicity index = [$CaO/(SiO_2+Al_2O_3)$] from 1,7 to 1,9 approximately		

Slag formation

Slag quality and characteristics

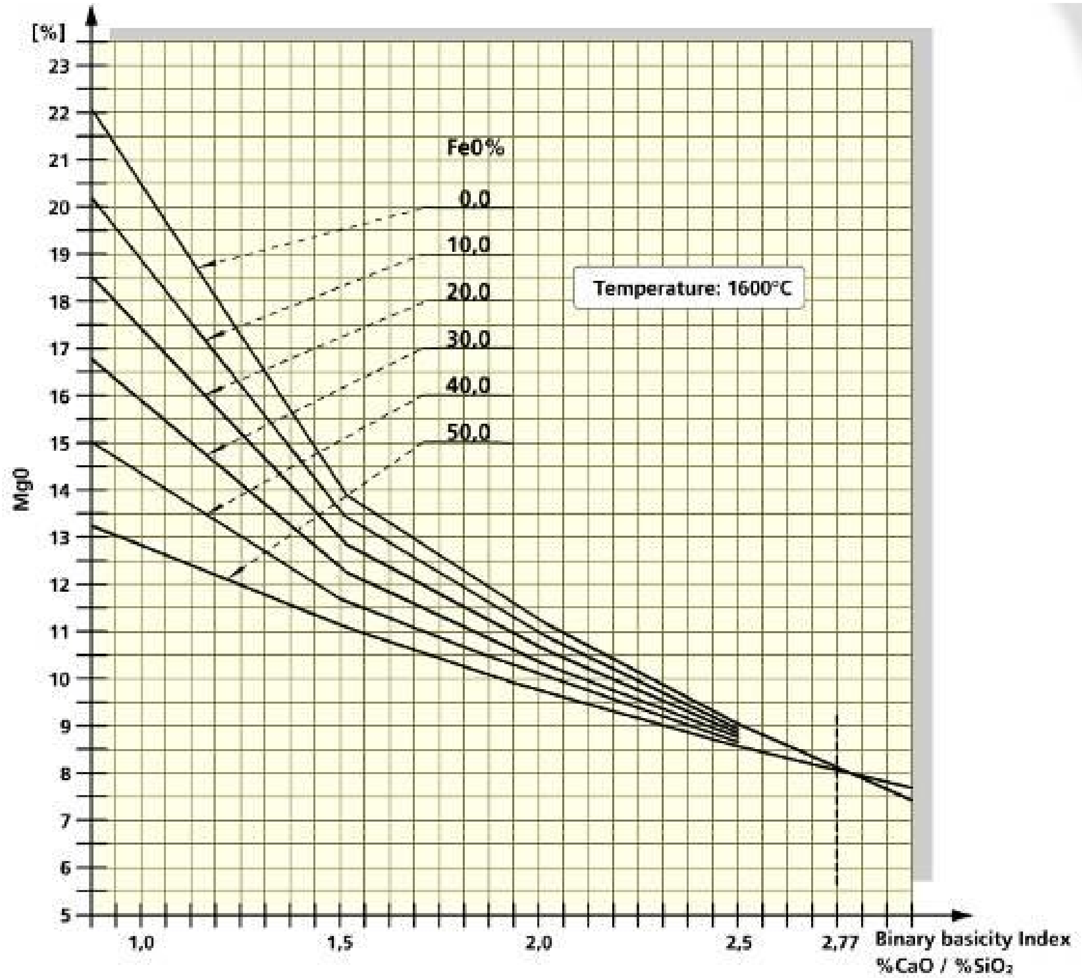
During normal operation, the amount of slag can be between 8 and 10% of the bath weight according to the metallic charge.

- **Viscosity**
- **MgO solubilit**
- **Oxidation Power**
- **Dephosphorizati**
- ***Liquidus* tempe**

•CaO / SiO2 - Þ Viscosity ¯
•CaO / MgO - Þ Viscosity ¯
•CaF2 - Þ Viscosity ¯
•Temperature - Þ Viscosity ¯

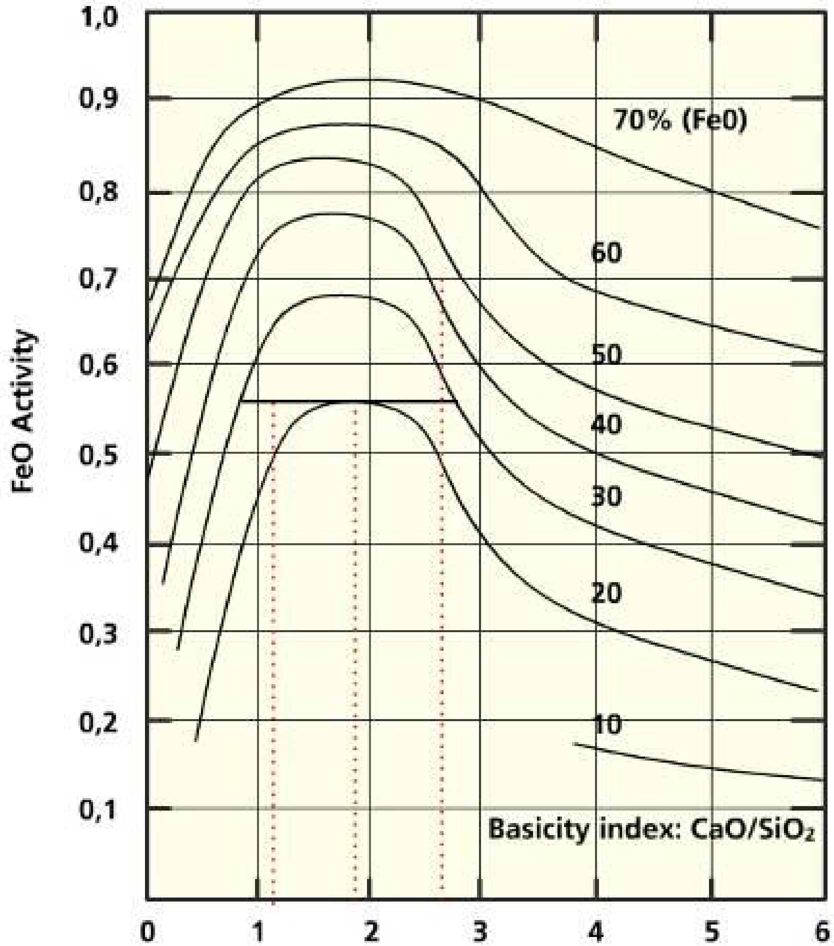
Slag formation

MgO saturation for slag of low basicity index with FeO as a parameter



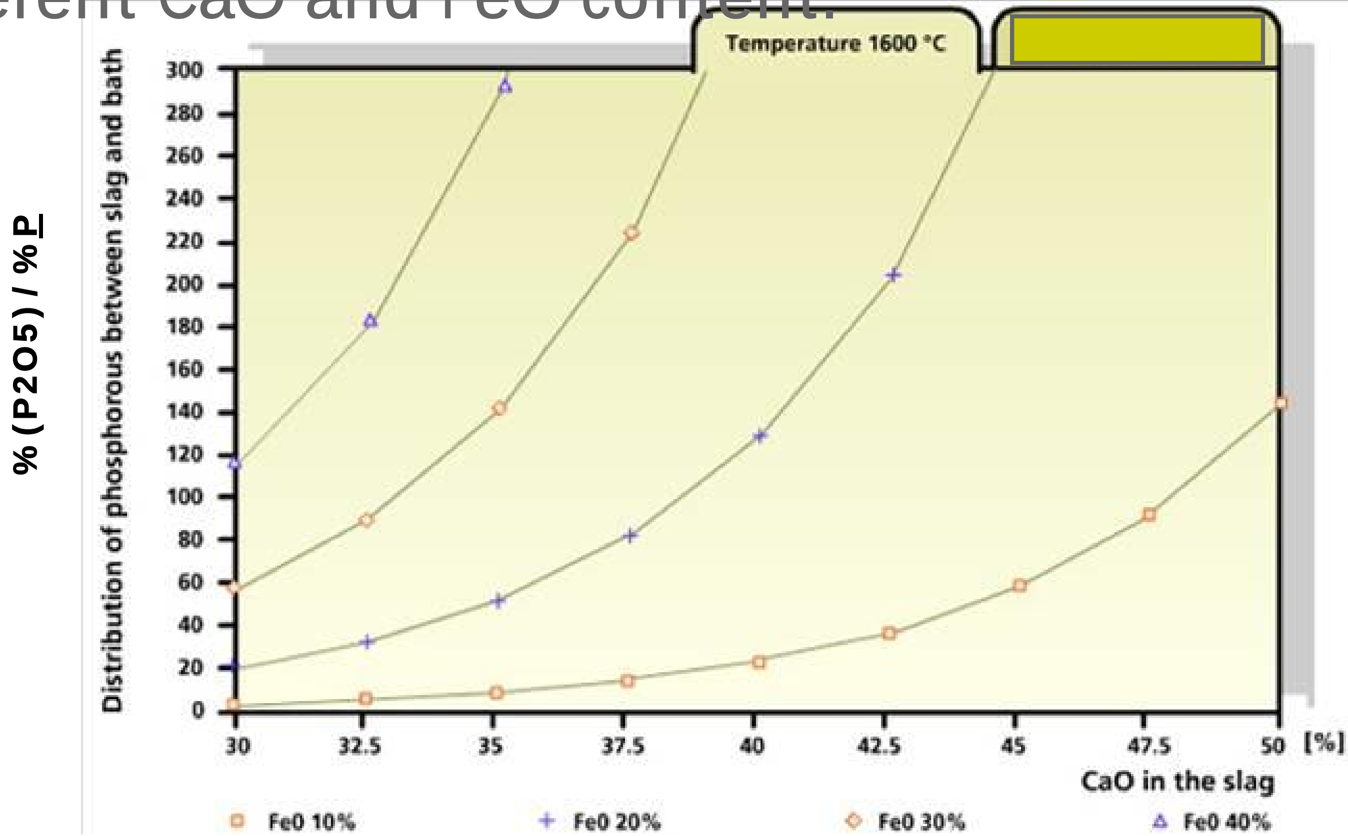
Slag formation

Influence of the binary basicity index and FeO content in the slag on the FeO activity



Slag formation

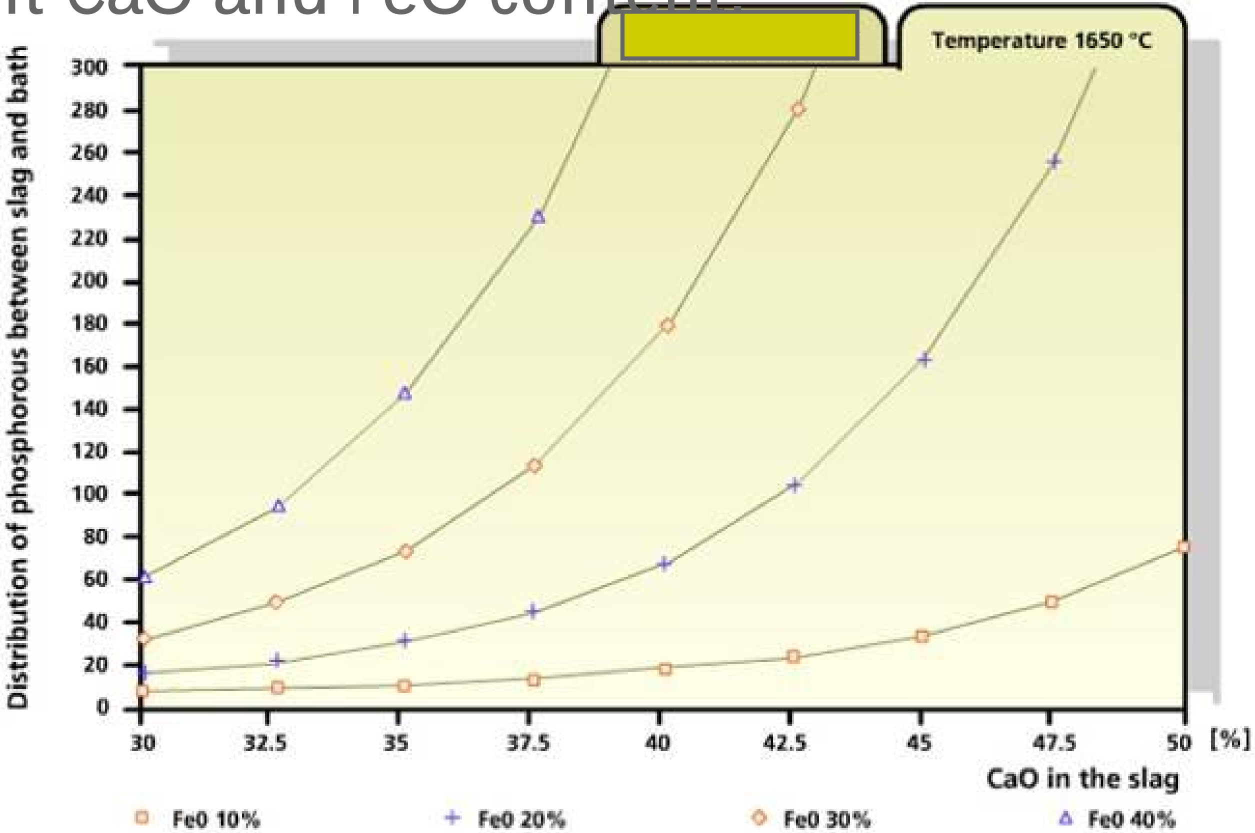
Distribution of P between the slag and metal bath given different CaO and FeO content.



Slag formation

Distribution of P between the slag and metal bath given different CaO and FeO content

% (P2O5) / % P



C-O reaction

Decarburization.

Chemical energy input.

Phosphorus removal.

Oxidation of other elements.

Thermal and chemical homogeneity.

Foamy slag formation.

Removal of Hydrogen and Nitrogen.

Total Oxygen needed for a Heat.

Sources of Carbon.

Decarburization

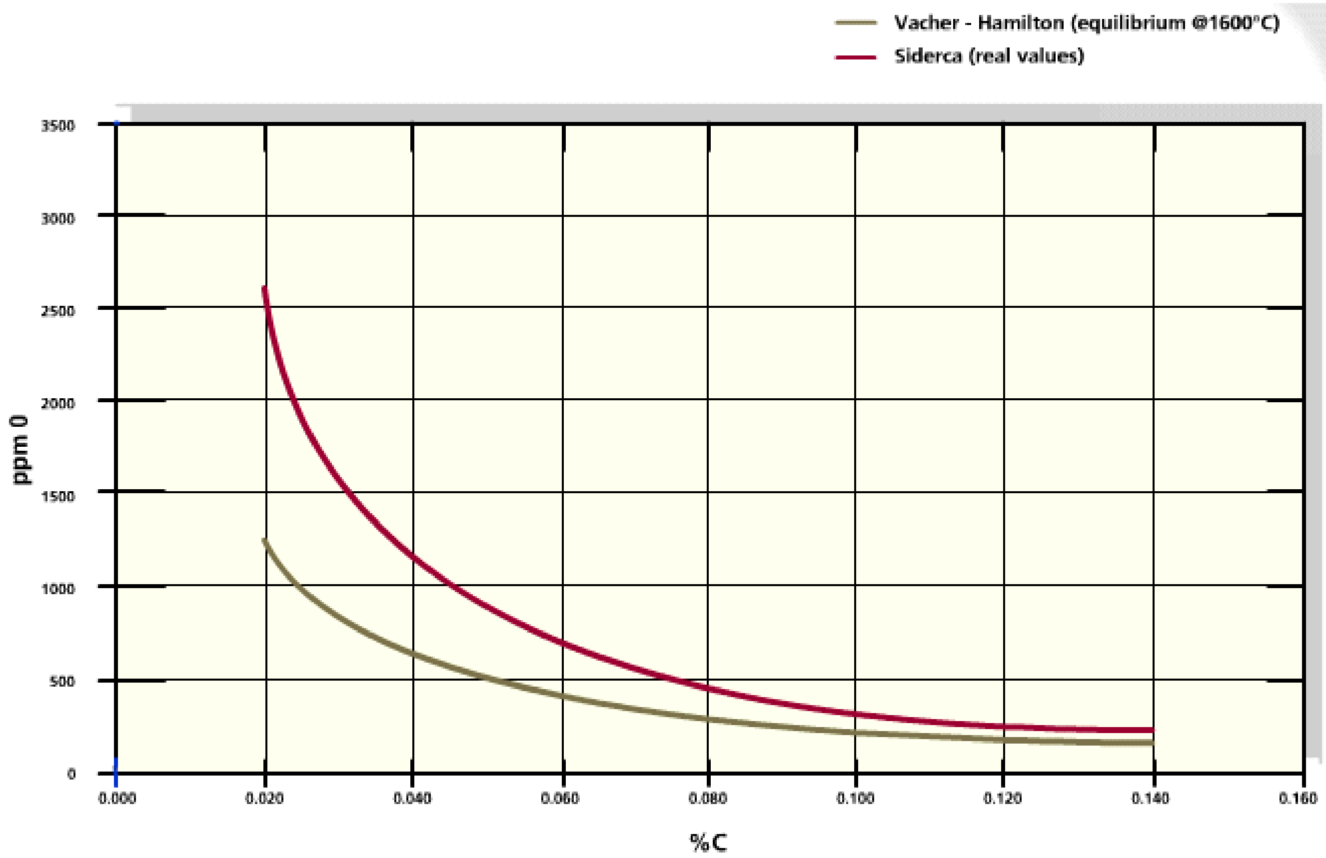
Consists in the carbon removal contained in the metallic charge.

$$C + \frac{1}{2} O_2 \leftrightarrow CO$$

The amount of carbon and oxygen to be added into the EAF should be carefully calculated, controlled and balanced.

Decarburization

C-O Equilibrium Relationship:



Chemical energy input

Oxygen and methane gas react generating an important amount of energy (exothermic reactions)

$C + \frac{1}{2} O_2 \leftrightarrow CO + 1.5\ kWh/Nm^3\ of\ O_2$

$CO + \frac{1}{2} O_2 \leftrightarrow CO_2 + 4.8\ kWh/Nm^3$

$CH_4 + 2\ O_2 \leftrightarrow CO_2 + 2H_2O + 8.9\ kWh/Nm^3\ of\ CH_4$

Phosphorus removal

- **Oxygen reacts with phosphorus present in the bath**
- **Phosphorus pentoxide reacts with CaO present in the slag**

$$2P + 5FeO \leftrightarrow P_2O_5 + 5Fe + heat$$

$$P_2O_5 + 3CaO \leftrightarrow 2(PO_4)^{3-} + 3Ca^{2+} \text{ in the slag/metal interface}$$

The P removal is temperature dependant, the lower the temperature the higher the removal.

Oxidation of other elements

The oxidation process generates oxides that can be removed through the slag

$$Si + O_2 \leftrightarrow SiO_2 \text{ (slag)}$$

$$Mn + \tfrac{1}{2} O_2 \leftrightarrow MnO \text{ (slag)}$$

$$2\,Cr + \tfrac{1}{2} O_2 \leftrightarrow Cr_2O_3 \text{ (slag)}$$

Unfortunately O_2 also reacts with Fe forming different iron oxides that are eliminated in the slag affecting the metallic yield performance.

Thermal and chemical homogeneity

The C-O reaction produces gases which generate an upward stirring movement allowing the thermal transfer and improving the chemical kinetics.

Foamy slag formation

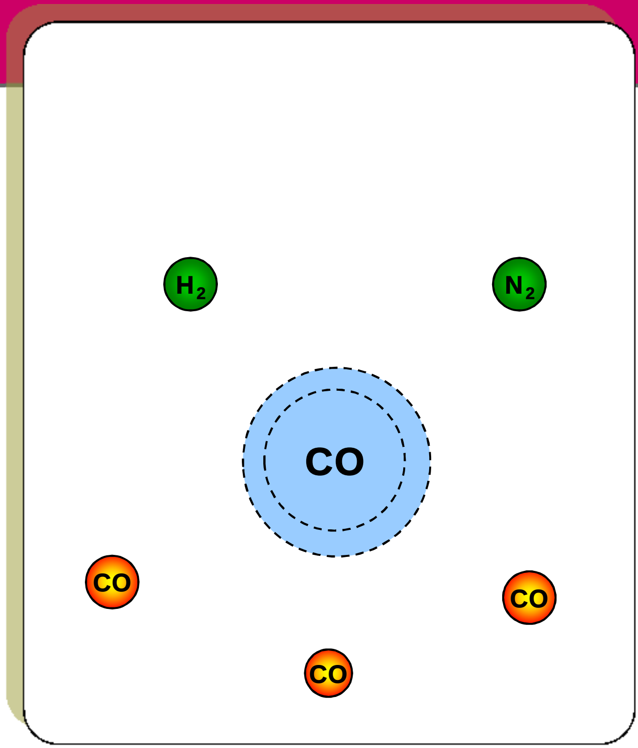
The bubbling gases encourage the "foaming" of the slag necessary for the protection of the wall refractories and the slag line.

$$C + \frac{1}{2} O_2 \leftrightarrow CO$$

$$FeO + C \leftrightarrow CO + Fe \text{ in the slag}$$

Removal of Hydrogen and Nitrogen

The CO bubbles produce both a pick-up and drag effect on the H2 and N2 dissolved in steel.



Total Oxygen needed for a heat

The following factors must be taken into account:

Dissolved oxygen in the bath

+ Oxygen present in FeO contained in the slag

+ Oxygen needed to burn carbon and oxidize other elements

+ Oxygen needed for methane combustion

Total Oxygen [m^3]

Sources of Carbon

The most common Carbon sources are:

- **Cast iron and/or pig iron**
- **Sponge iron equivalent carbon**
- **Scrap's average carbon content**
- **Coke loaded in the scrap bucket**
- **Coke pneumatically injected**

Electric Arc Furnace Steelmaking

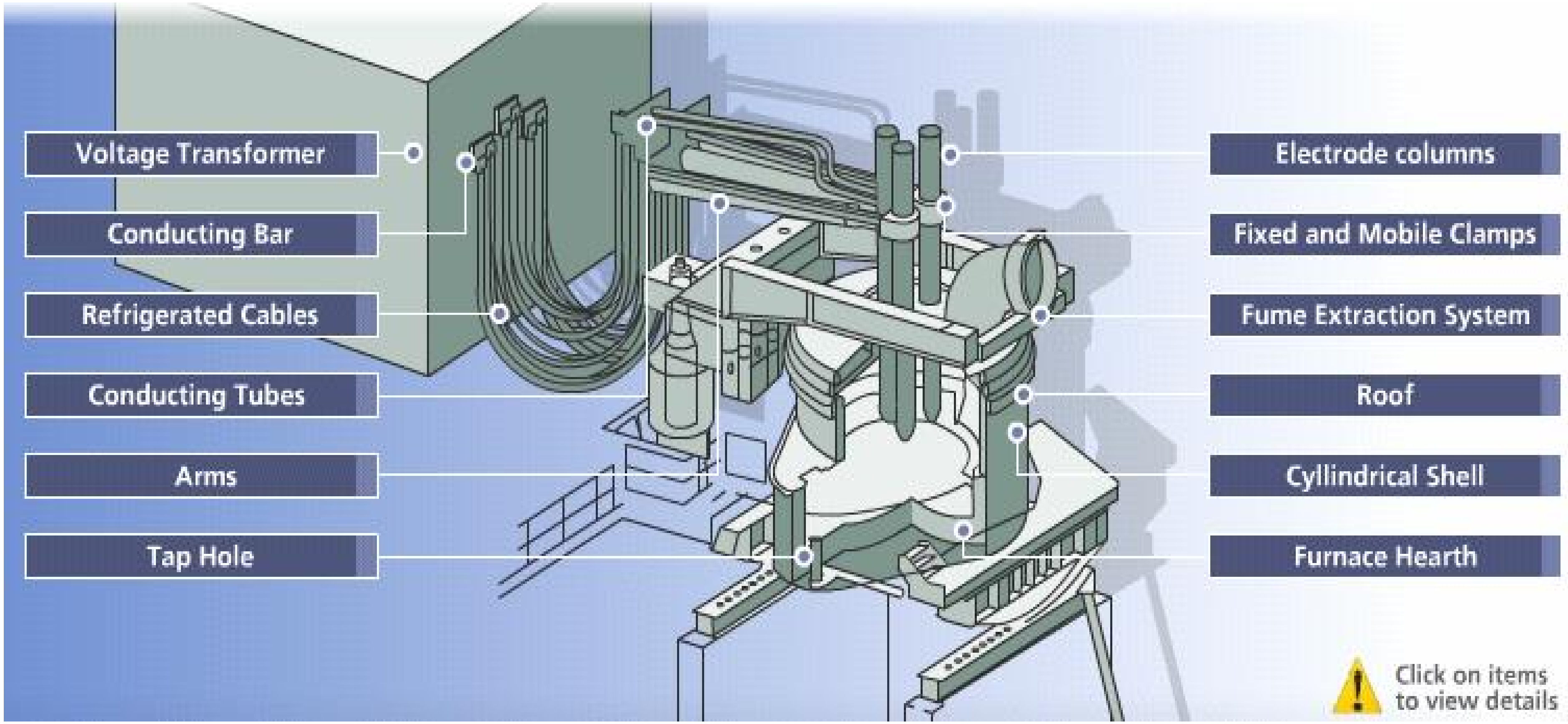
Metallurgical operations

Equipment Description

Sequence of Operation

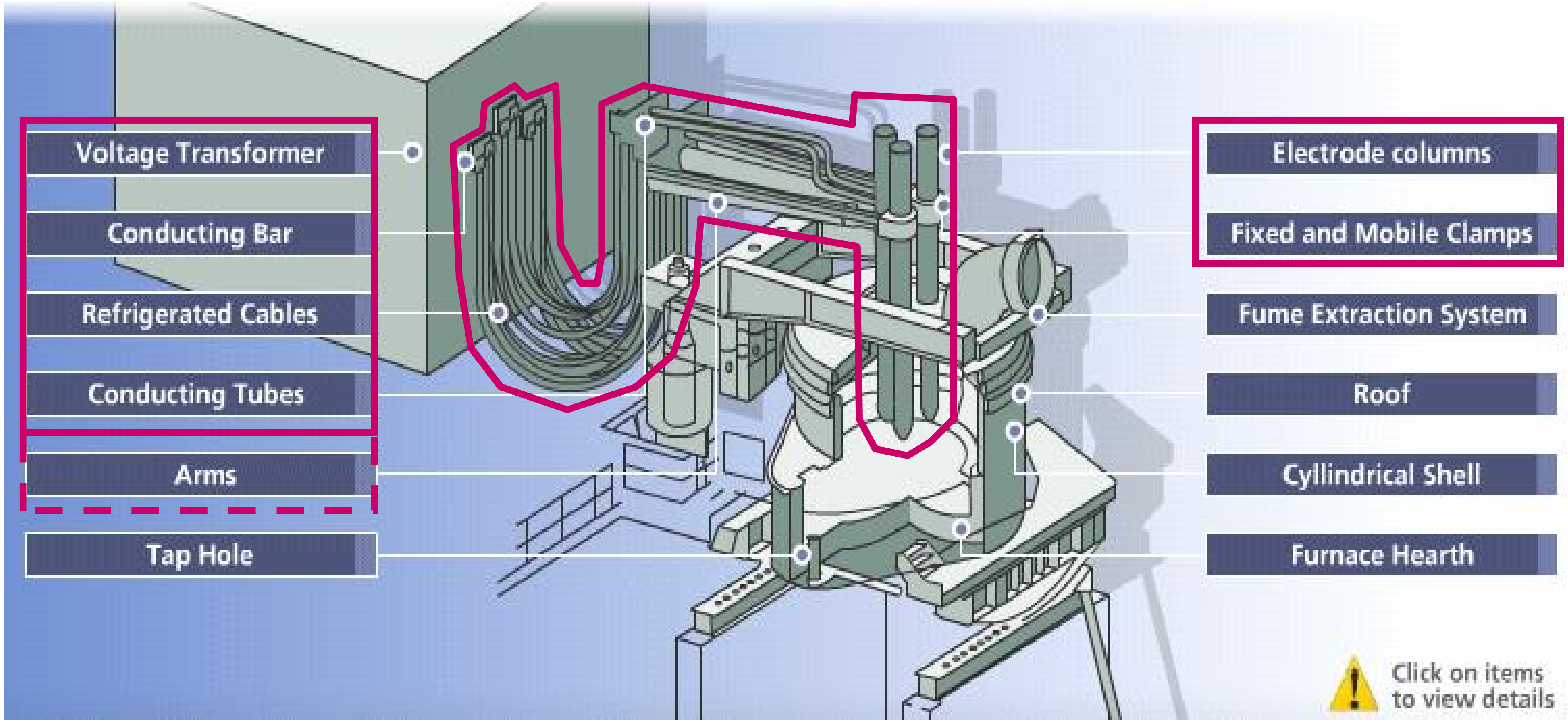
EAF description

Main parts



EAF description

Electric conducting and regulation system



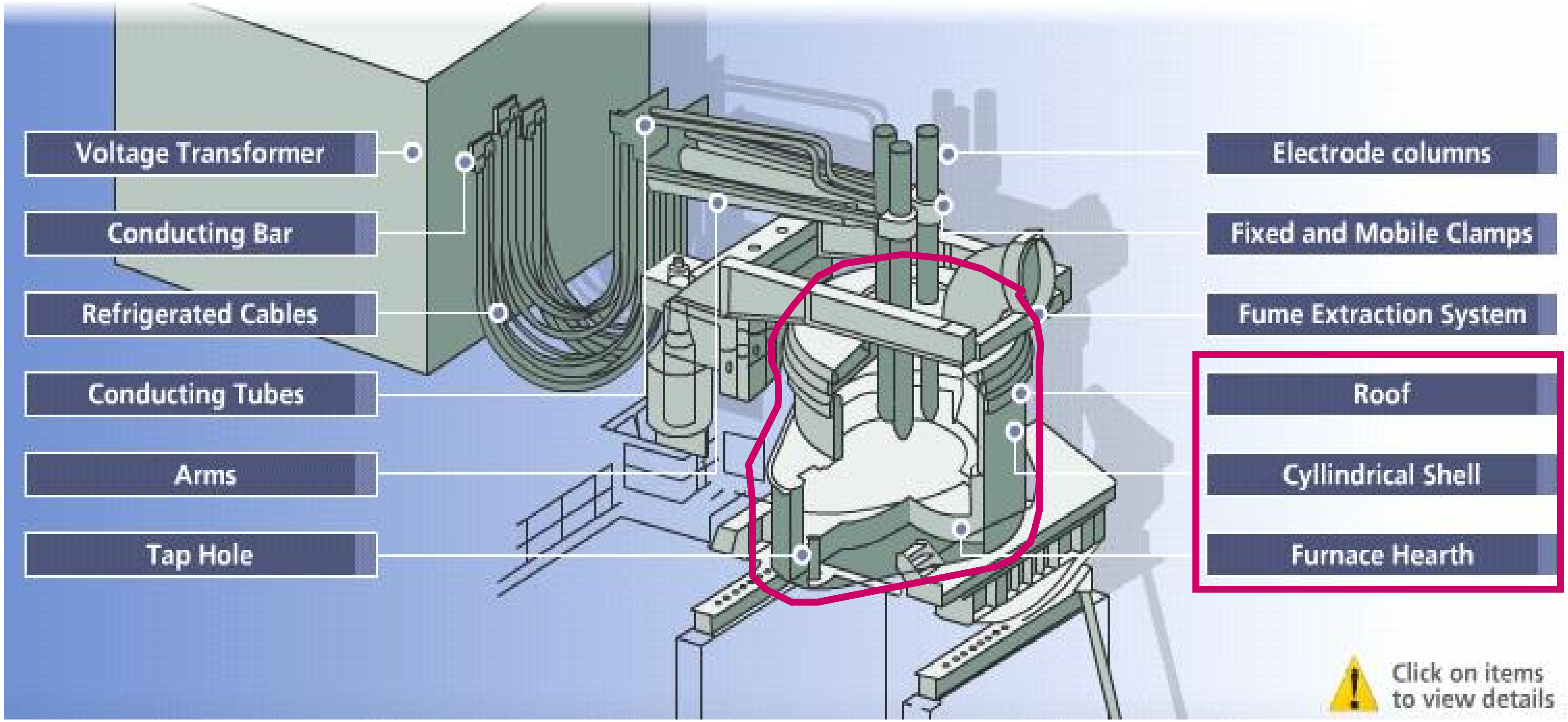
EAF description

Electric conducting and regulation system

- **Electric conducting system is designed using a minimum power loss criteria. This implies:**
    - **Minimum conductor length**
    - **Use materials with maximum electric conductivity**
    - **Avoid operation with high electric density**
- **Electric regulation system must control:**
    - **Arc stability**
    - **Arc power input**
    - **Electric efficiency**

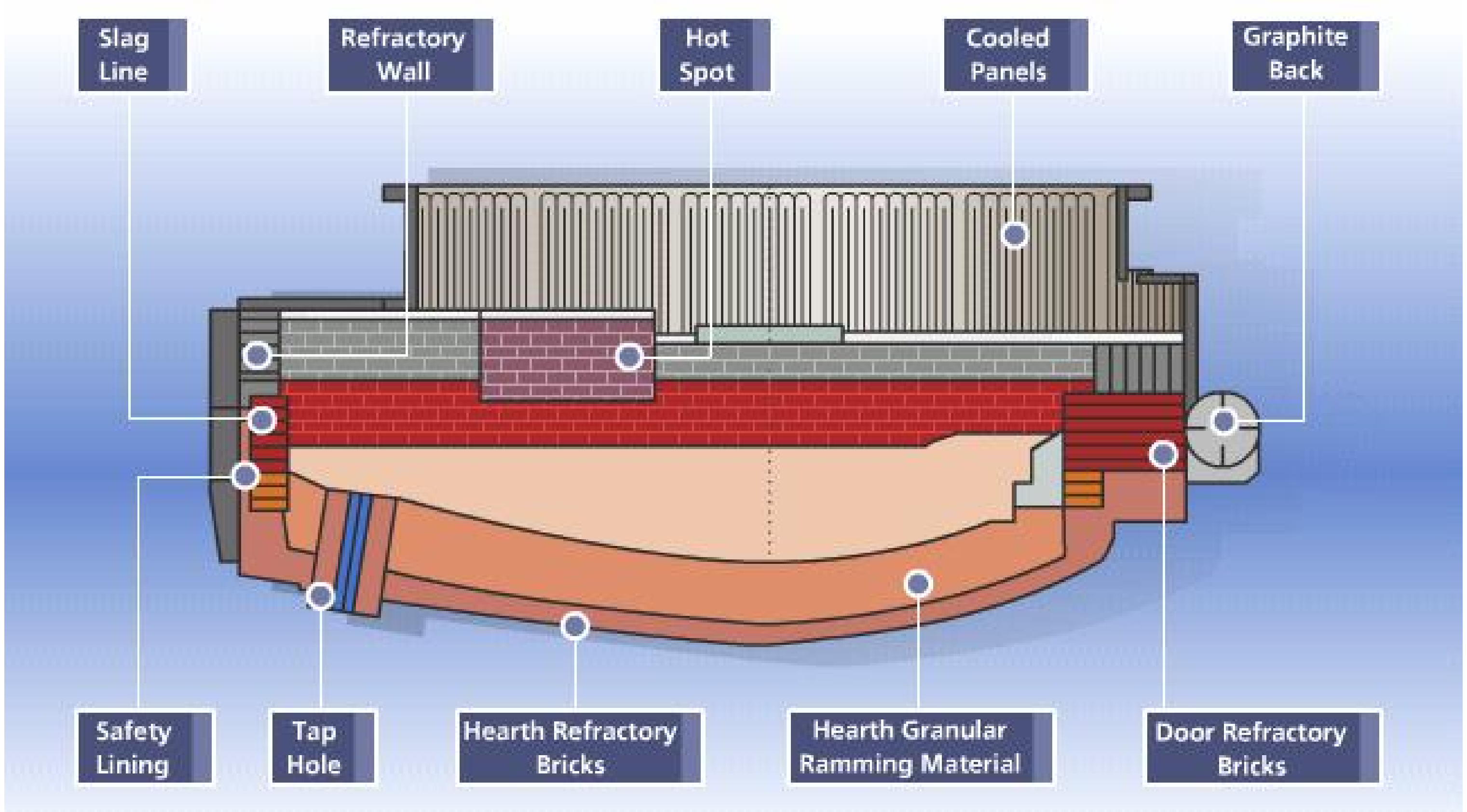
EAF description

EAF body



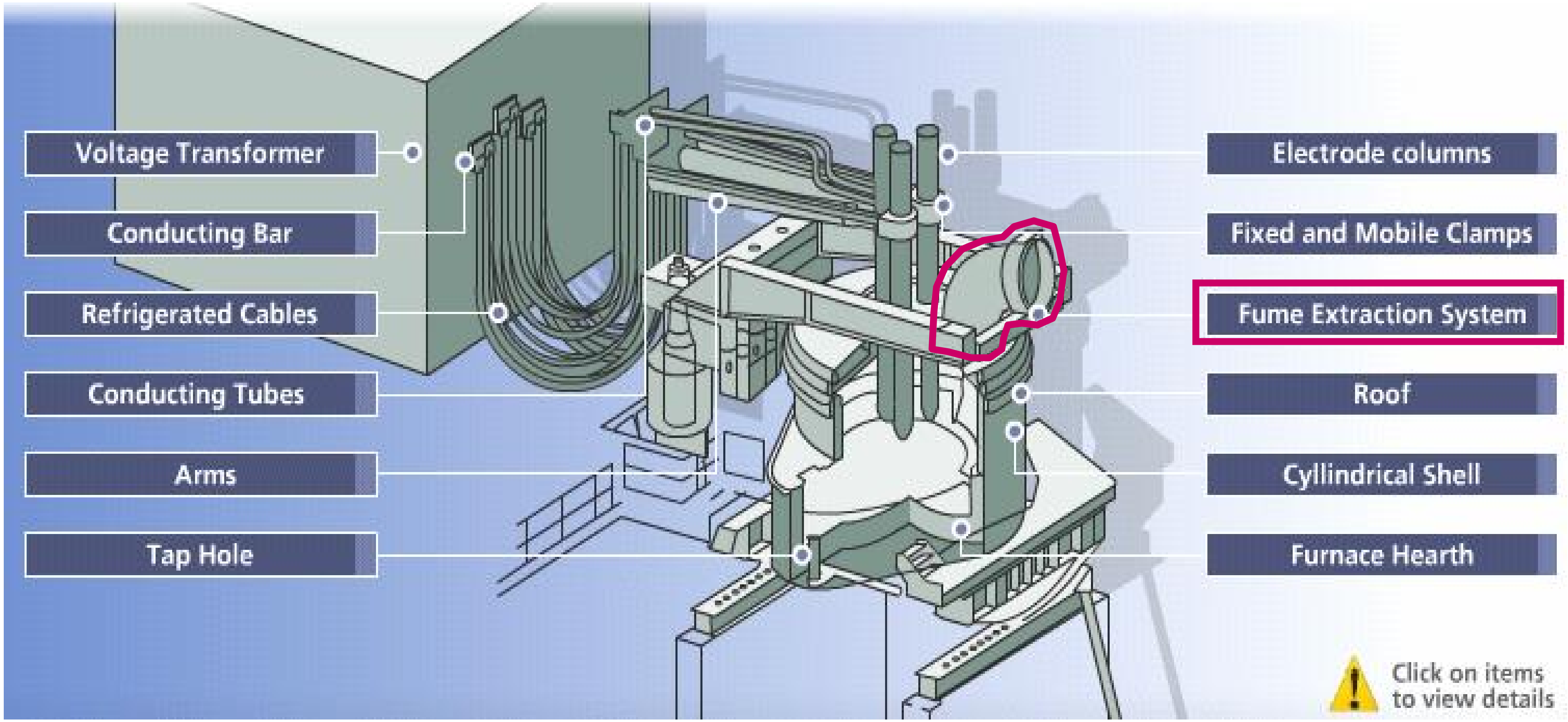
EAF description

Furnace hearth refractory and cylindrical shell



EAF description

Fume extraction system



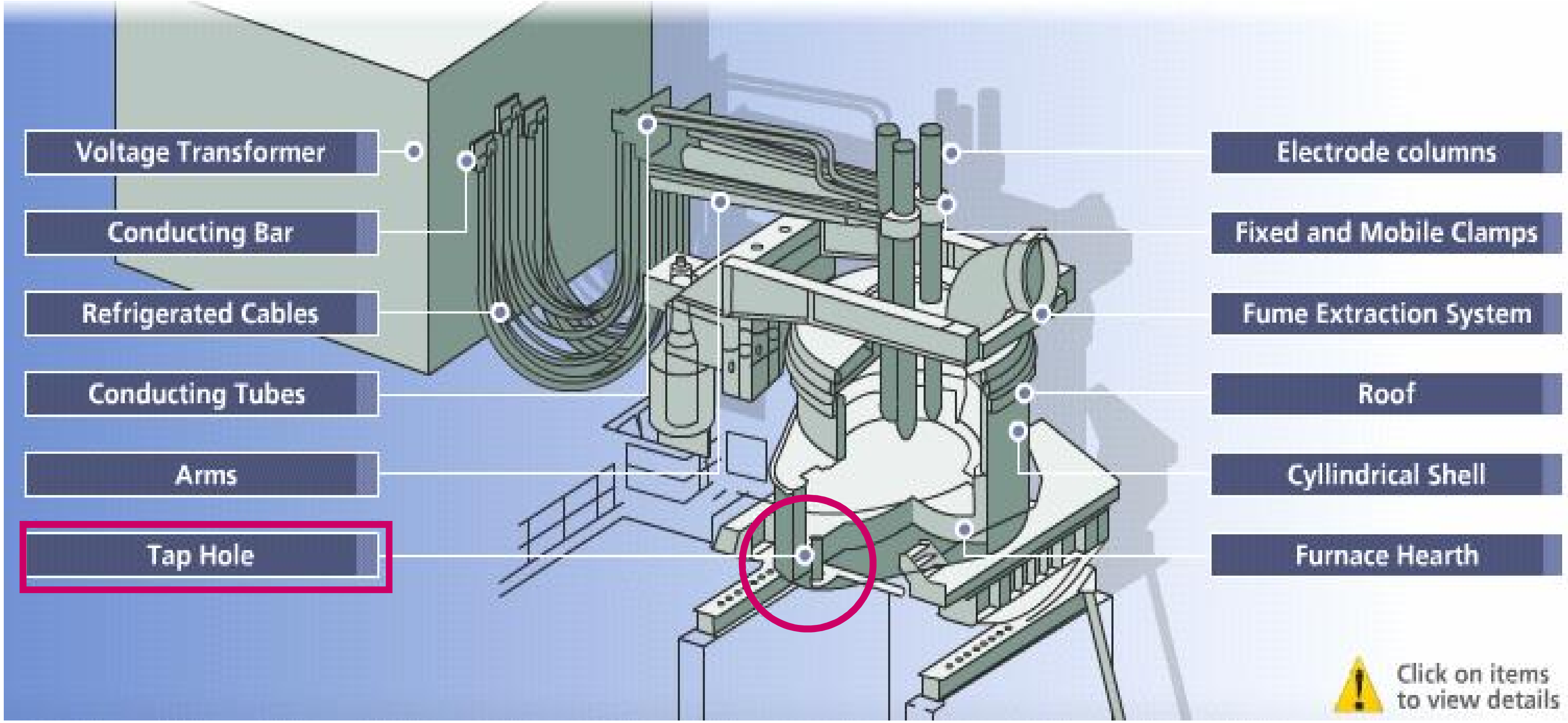
EAF description

Fume extraction system

- **Collect the fumes and hot gases from the furnace**
- **Transport them to a cooling and cleaning system before being released to the atmosphere.**

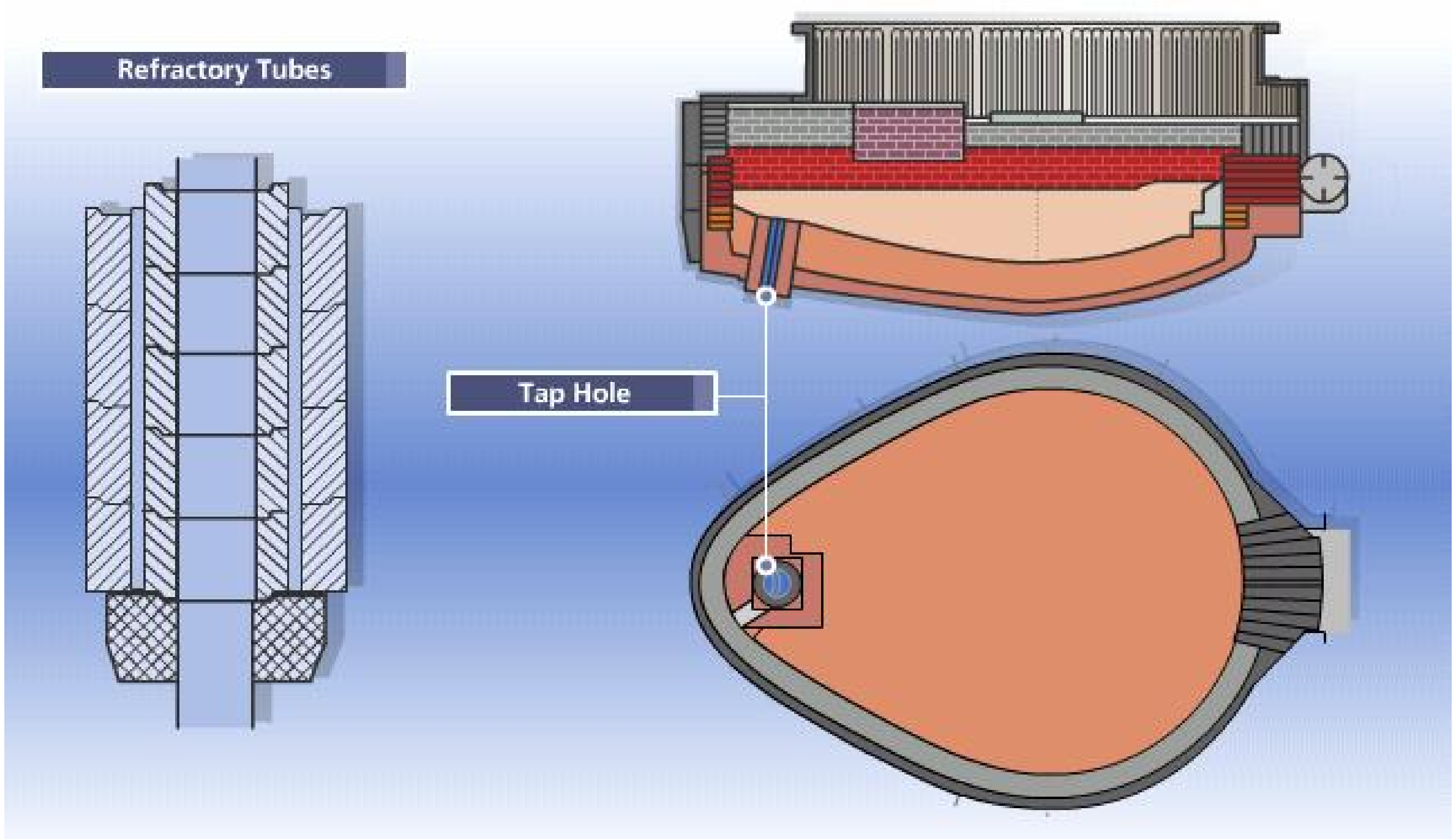
EAF description

EBT system



EAF description

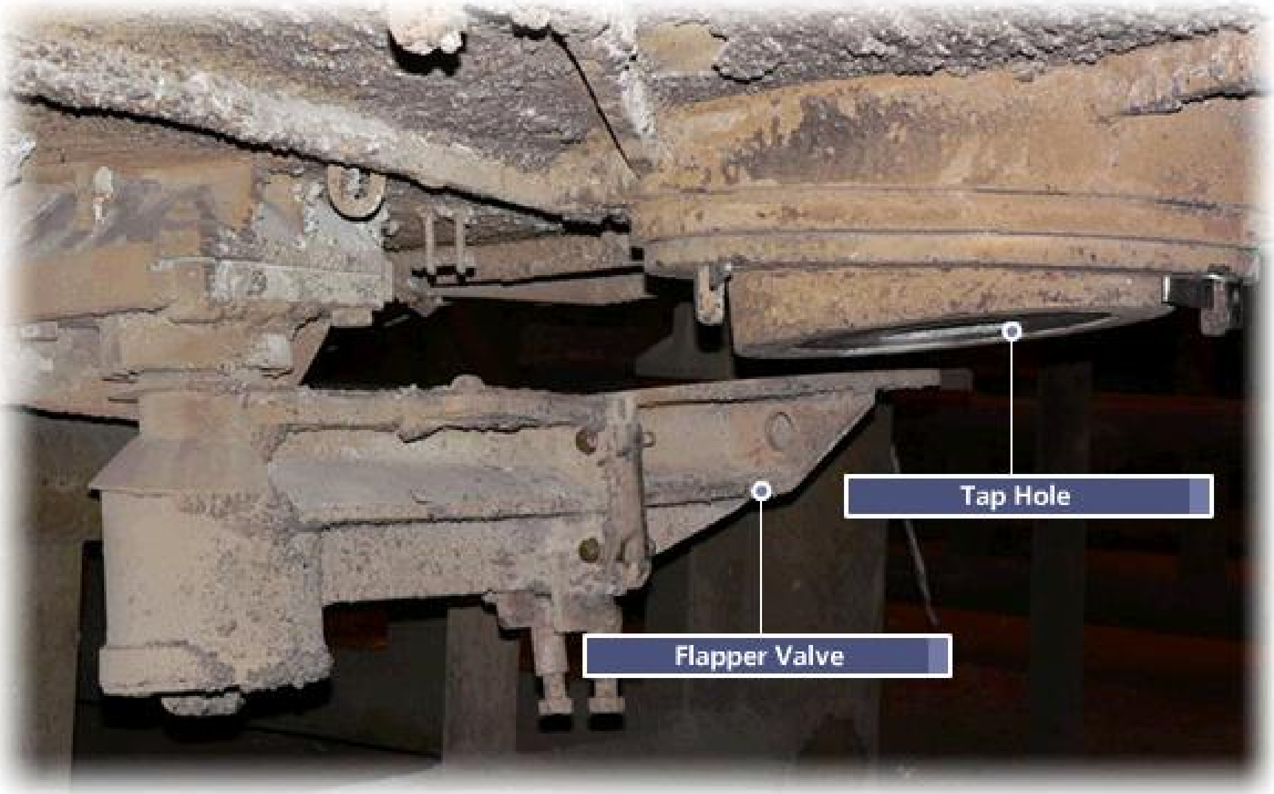
Tap hole



EAF description

EBT system

- **Allows the transference of the liquid bath from the EAF to the ladle for further processing**



EAF description

EAF movements

- **Tilting: de-slagging and tapping**
- **Clamp/unclamp to adjust the working length of the electrode**
- **Electrodes up and down movements for arc length regulation**
- **Roof lower/raise/swing to allow scrap charging**
- **Opening/closing of the working door**
- **Slide of the EBT flapper valve**

EAF description

Auxiliary equipments

- **Mechanic arc system for sampling (steel) and measuring (O_2 and temperature)**
- **Equipment to prolong the electrode columns**
- **Oxy-gas burners**
- **Oxygen injection lances**
- **Carbon injection lances**

Electric Arc Furnace Steelmaking

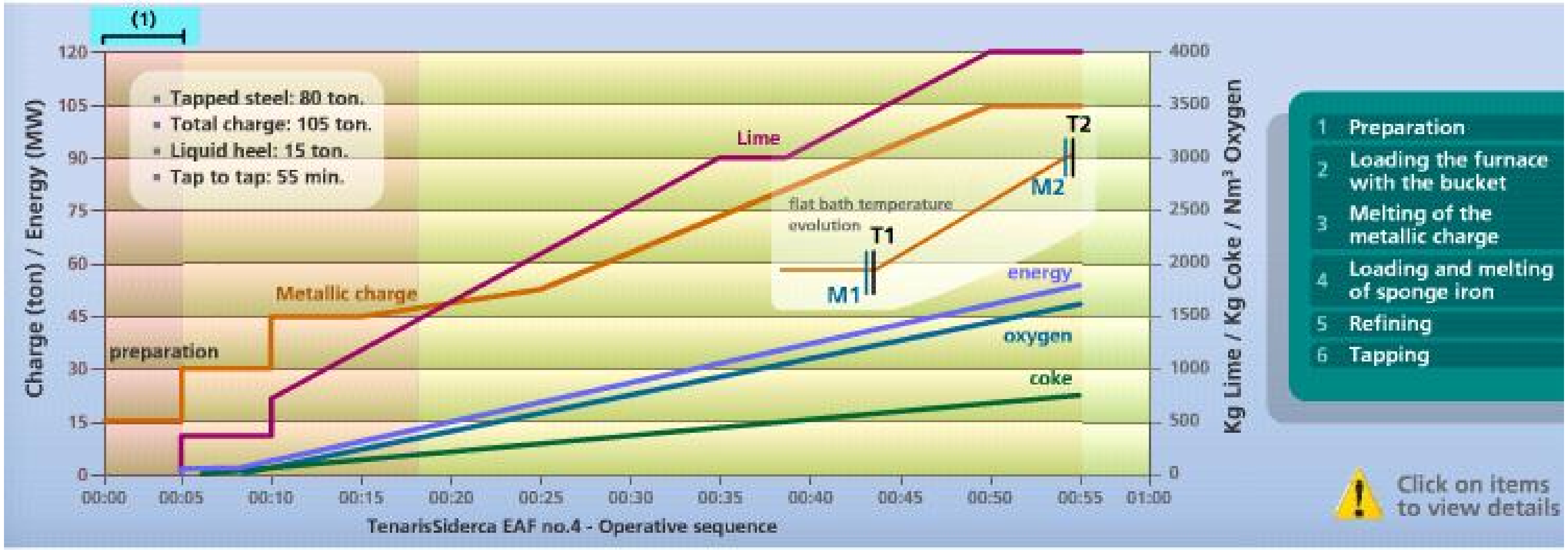
Metallurgical operations

Equipment Description

Sequence of Operation

Sequence of Operation

Preparation



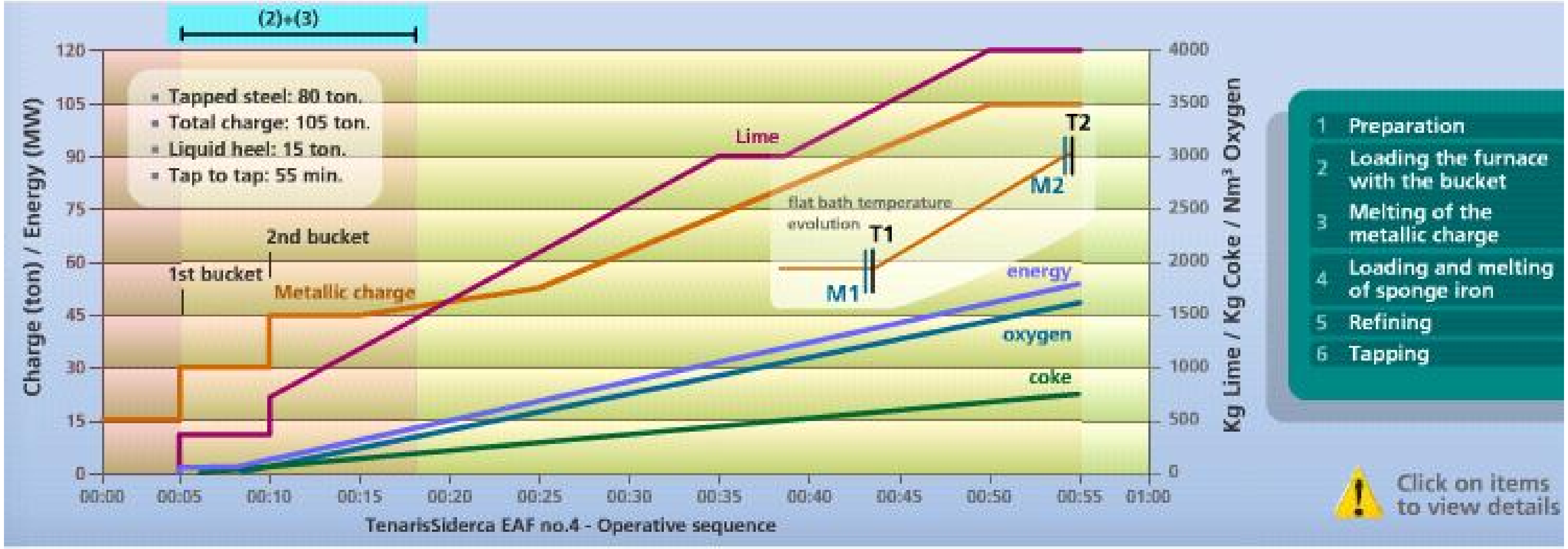
Sequence of Operation

Preparation

- **After tapping the previous heat**
- **Visual inspection to evaluate refractory state**
- **Slag line repaired by gunning basic material (MgO)**
- **EBT is cleaned and sealed with refractory sand**

Sequence of Operation

Loading and melting the metallic charge



Sequence of Operation

Loading the metallic charge

- **More than 1 bucket can be loaded to the furnace.**
- **When more than 1 bucket is used, special attention must be taken:**
  - **Avoid over-melting the metallic charge.**
  - **Have enough available volume.**
- **Energy losses due to radiation when the roof is opened.**

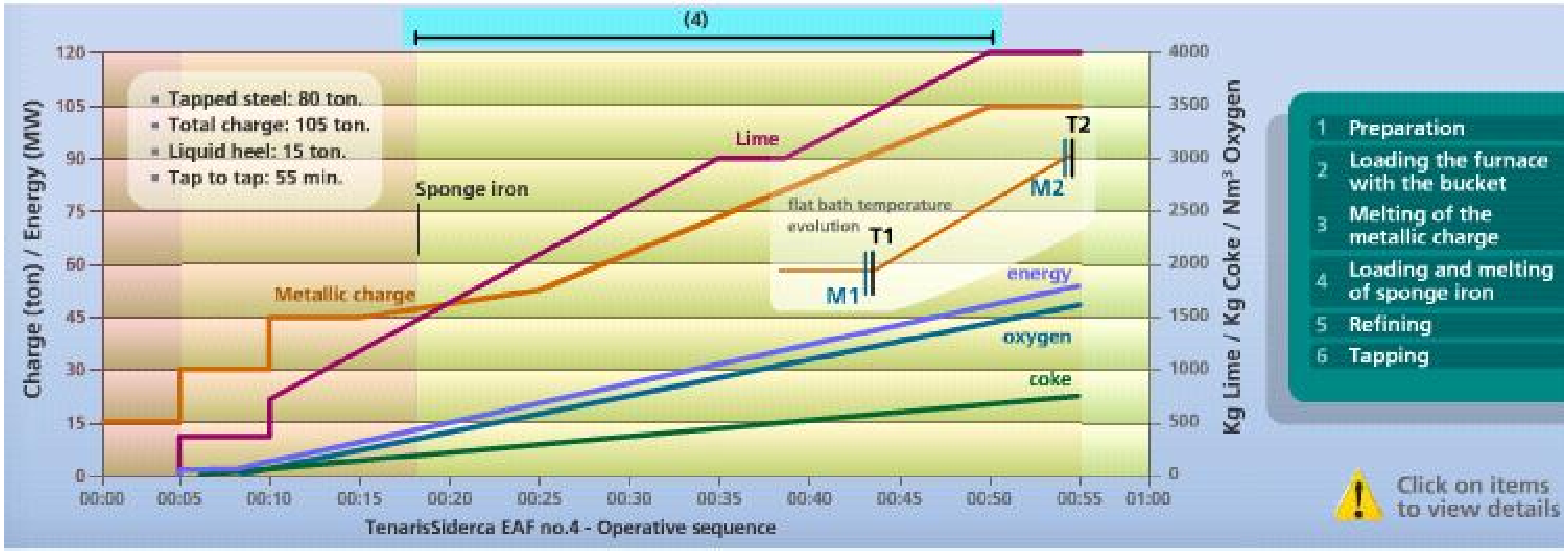
Sequence of Operation

Melting the metallic charge

- **Special attention must be paid to preserve the electrodes and have a stable arc.**
- **Oxygen is injected from the beginning to speed up the process**
- **When continuous charging system is available sponge iron can be loaded during this stage**

Sequence of Operation

Loading and melting of Sponge Iron



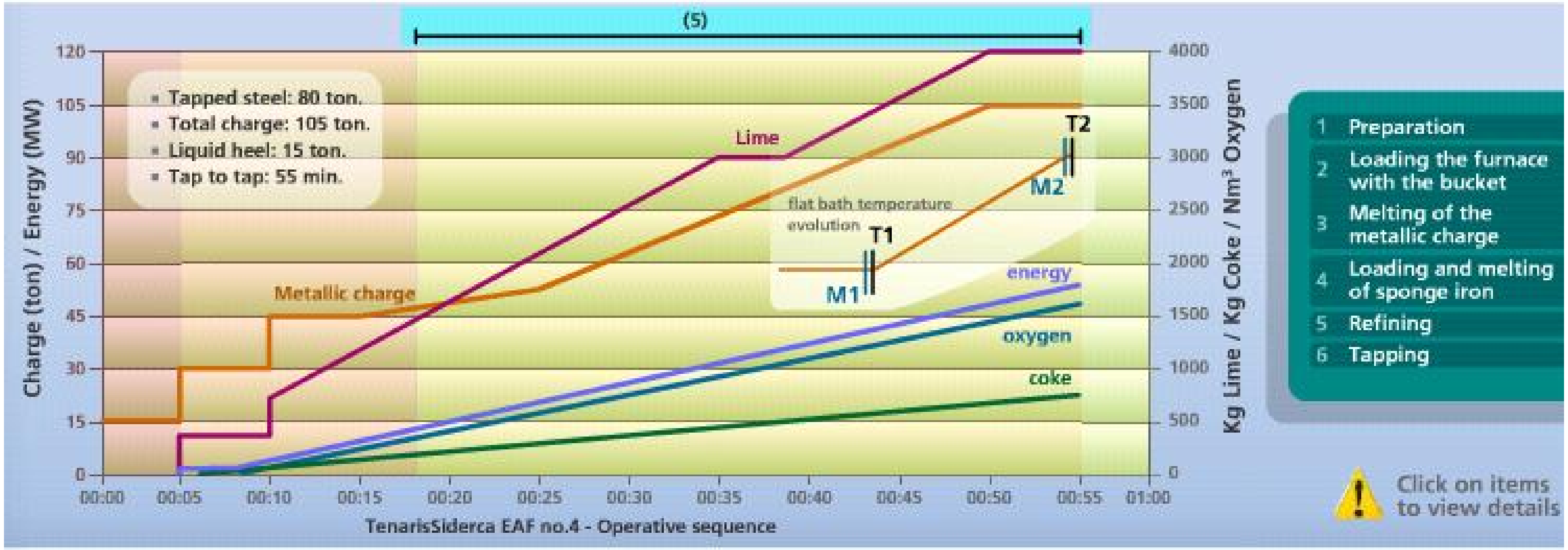
Sequence of Operation

Loading and melting of Sponge Iron

- **According to plant technology**
- **Part of total sponge iron can be charged in the buckets together with scrap**
- **The rest is charge using a continuous charging system**

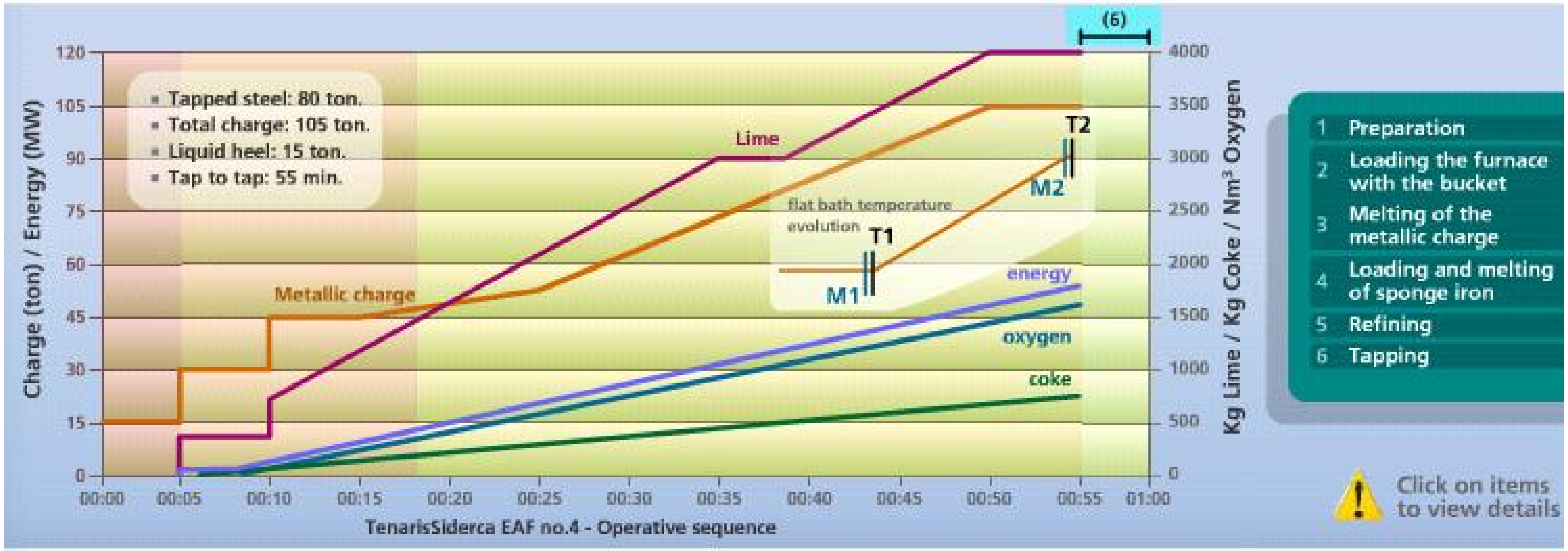
Sequence of Operation

Refining



Sequence of Operation

Tapping



Sequence of Operation

Tapping - Ferroalloy additions

- **Bulk addition @ tapping.**
  - **High temperature**
  - **Strong stirring**

- **Trimming addition @ ladle (secondary Steelmaking)**
  - **Controlled operation**
  - **Small additions**
  - **Stirring (double Argon plug)**
  - **Temperature (Heating)**
  - **More time required**

Sequence of Operation

Tapping – Sequence of additions

For example: tapping 80 tons of liquid steel (tal)

- **@ 5 tons: synthetic slag is added**
  - **Protect the steel from re-oxidation and nitrogen pick-up**
- **@ 10 tons: aluminum addition**
  - **For steel deoxidation**
  - **Helps to obtain a fully melted homogeneous slag.**
- **@ 30 tons: ferroalloys and carbon addition.**
  - **Pointing 0.020/0.030 below minimum specification preventing any error in the weight of the additions.**

Sequence of Operation

Tapping – Sequence of additions

For example: tapping 80 tons of liquid steel (tal)

	C	Mn	Yield at tapping (%)	
	%	%	C	Mn
FeMn High C	6.5	75.4	100	92

	% C	% Mn
Last Furnace Sample	0,050	0,20
First LF Sample (aim)	0,125	1,00
Added with Ferroalloys	0,075	0,80

$$kgFeMn = \frac{\%Mn \cdot tn_{liq\ steel} \cdot 10}{Mn_{content}/100 \cdot Mn_{yield}/100}$$

$$kgFeMn = \frac{0.80 \cdot 80tn \cdot 10}{75.4/100 \cdot 92/100} = 923kg$$

$$\%C_{added} = \frac{923kg \cdot 6.5/100 \cdot 100/100}{80tn \cdot 10} = 0.075\%$$

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Continuous Casting of Round Bars

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Plant Lay Out

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Ferroalloy Additions

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Plant Lay Out

Equipment Description

Sequence of Operation

Ferroalloy Additions

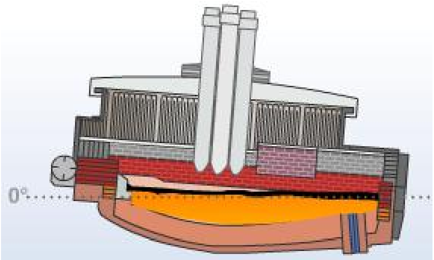
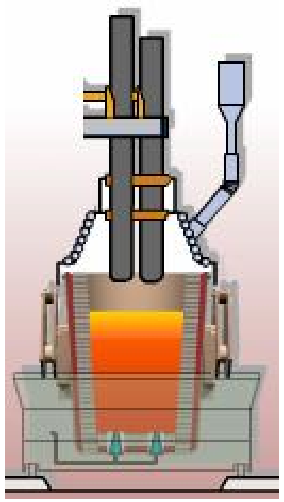
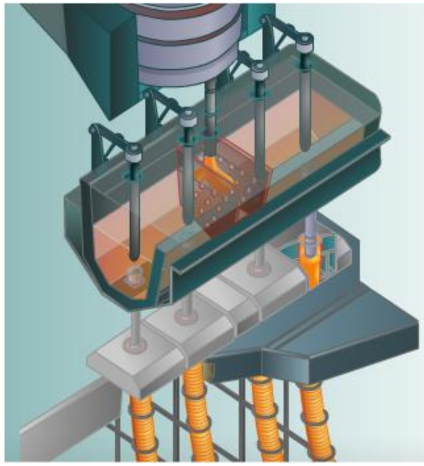
Metallurgical Operations

Involves all the process and operations since the EAF tapping until the start of the casting.

- **Chemical composition of the steel grade being manufactured**
- **Steel cleanliness in accordance to the final application**
- **Control the contents of N, O and H**
- **Maximize the productivity and avoid quality problems associated with bad castability.**

Metallurgical Operations

Main reactions

Primary Steelmaking EAF	**Sec. Steelmaking LF - VD**	**Continuous Casting**
		

Oxidizing ← | → **Reducing**

Deoxidation

Carbon-oxygen reaction
Dephosphorization

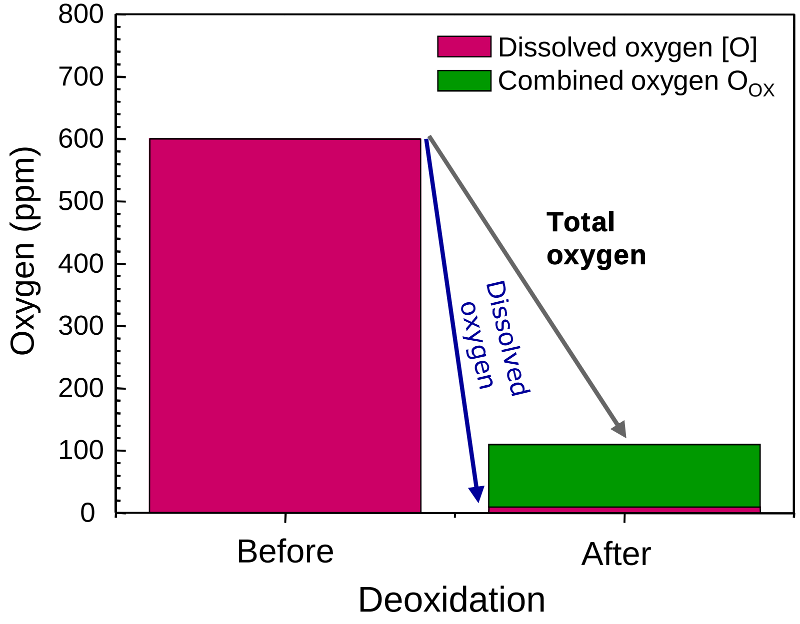
Desulphurization
Inclusion modification

} **Cleanliness / Castability**
Argon bubbling

Metallurgical Operations

Deoxidation

Oxygen content (dissolved or forming oxides) in the liquid steel must be minimized.



Metallurgical Operations

Deoxidation

Deoxidants are chemical elements capable of capturing oxygen dissolved or as an oxide, to transform it into a more stable oxide which migrates and dissolves into the slag.

Strong deoxidants	**Are the first to react, capturing the free oxygen or oxygen contained in weak oxides. e.g. strong deoxidants are calcium, aluminium, titanium**
Weak deoxidants	**They have less oxidation power. They can be reduced by a strong deoxidant. e.g. wear deoxidants are manganese, silicon, carbon**

Metallurgical Operations

Deoxidation with Aluminum

Aluminium reduces nearly all oxides present in the steel and slag (except CaO at any temperature and MgO below 1550°C).

1. $2\ Al + 3\ FeO \leftrightarrow (Al_2O_3) + 3\ [Fe]$
2. $4\ Al + 3\ O_2 \leftrightarrow 2\ (Al_2O_3)$
3. $4\ Al + 3\ SiO_2 \leftrightarrow 2\ (Al_2O_3) + 3\ [Si]$
4. $2\ Al + 3\ MnO \leftrightarrow (Al_2O_3) + 3\ [Mn]$
5. $10\ Al + 3\ (P_2O_5) \leftrightarrow 5\ (Al_2O_3) + 6\ [P]$

[ ] in the liquid steel

( ) in the slag

Metallurgical Operations

Deoxidation with Carbon

Carbon reacts with iron oxide and dissolved O. Both reaction are affected by the atmospheric pressure.

1. **C + FeO ↔ {CO} + [Fe]**
2. **C + [O] ↔ {CO}**

[ ] in the liquid steel

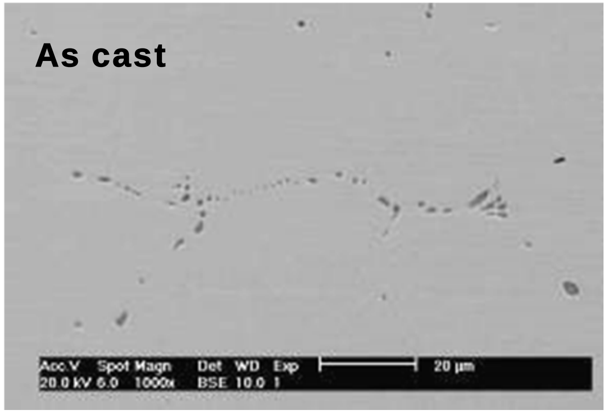
( ) in the slag

{ } gas

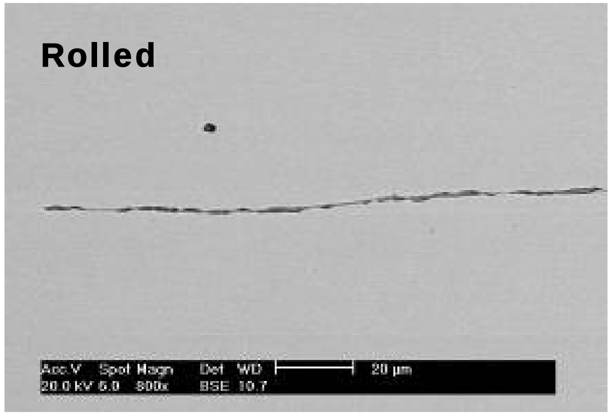
Metallurgical Operations

Desulphurization – Why should we remove sulphur?

During solidification, Mn and S combine in the interdendritic liquid forming MnS inclusions. These inclusions can be easily deformed during hot rolling.



MnS segregated at grain boundaries

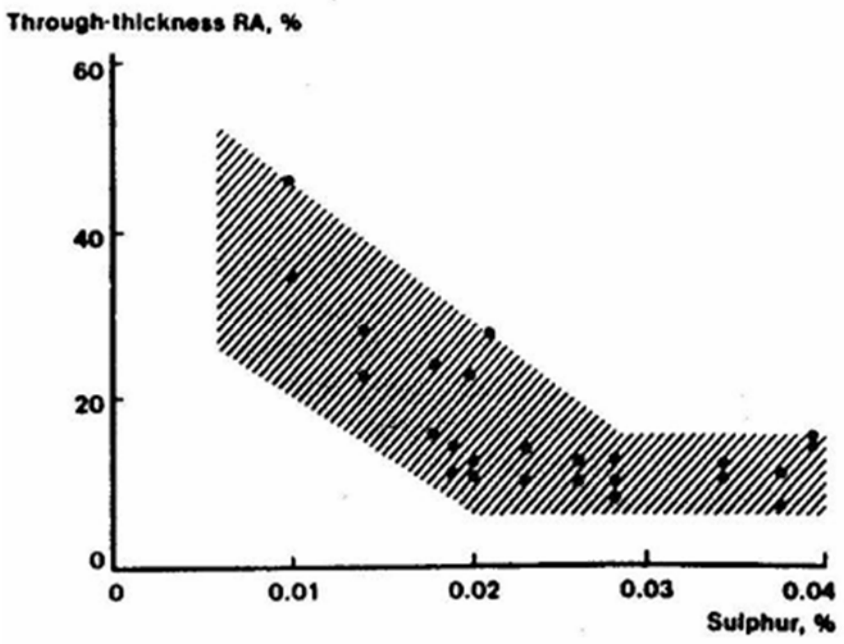


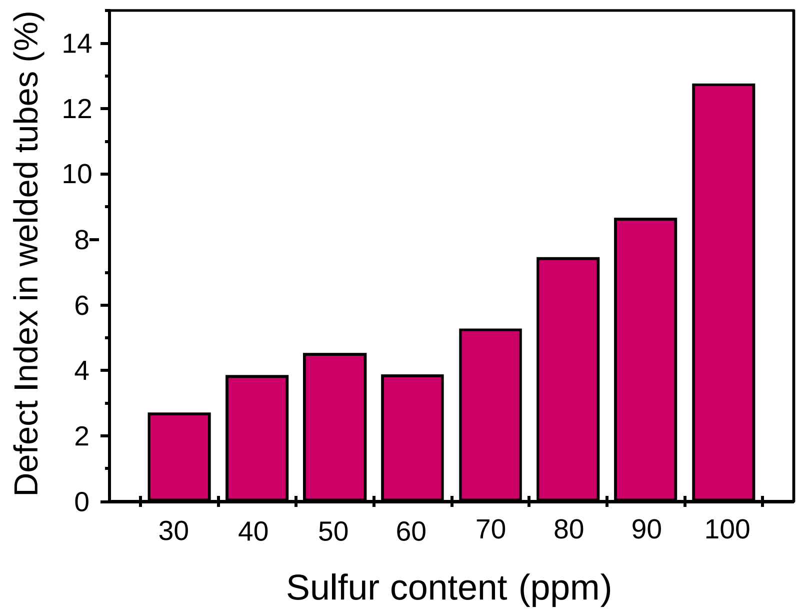
MnS stringer in the rolling direction

Metallurgical Operations

Desulphurization – Why should we remove sulphur?

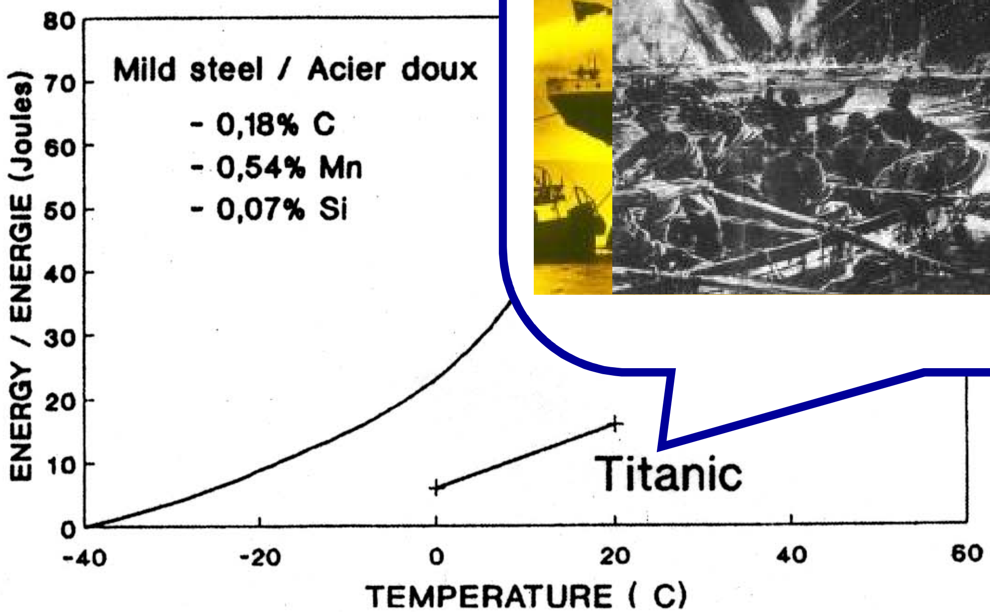
Elongated inclusions may impair the mechanical properties and affect the quality of the final product.

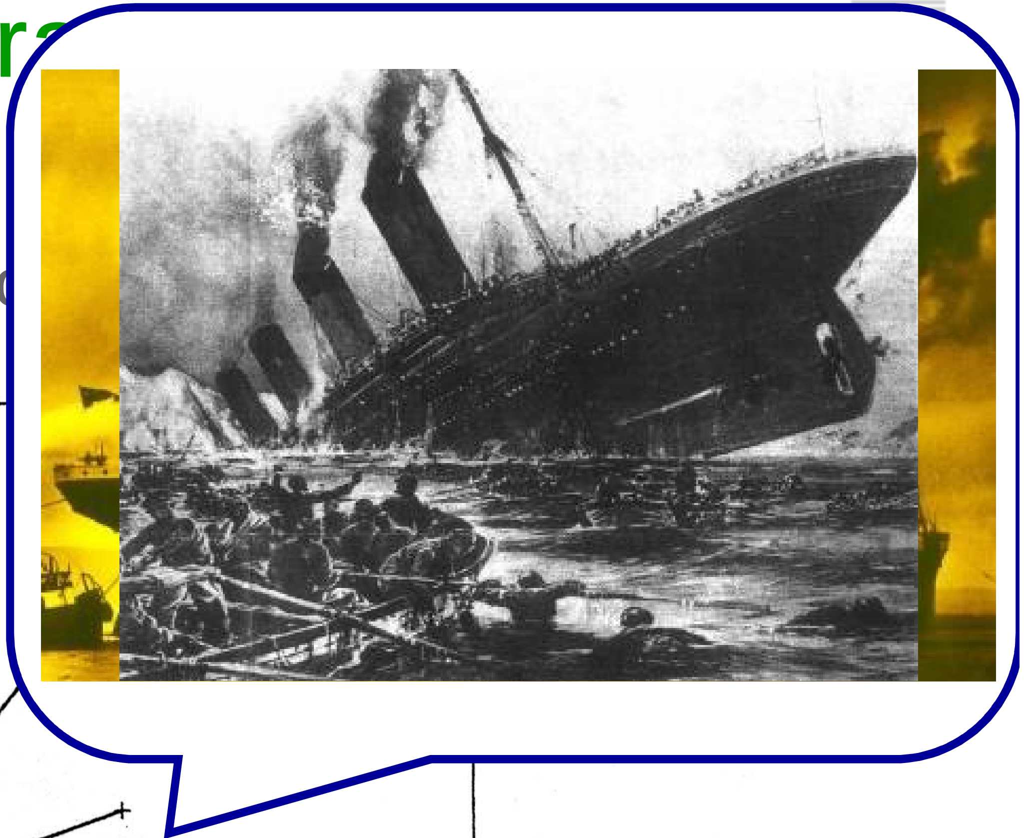




Metallurgical Opera

Desulphurization – Why sh





A comparison of the results of Charpy tests on specimens of plate steel from the Titanic with a similar steel produced in the early 1950's.

Metallurgical Operations

Desulphurization reaction

In practice, the reaction that control desulphurization is:

- $3\ [S] + 3\ (CaO) + 2\ [Al] \leftrightarrow 3\ (CaS) + (Al_2O_3)$

It is the result of two reactions:

- $2\ [S] + 2\ (CaO) \leftrightarrow 2\ (CaS) + 2\ [O]$
- $3\ [O] + 2\ [Al] \leftrightarrow (Al_2O_3)$

[ ] in the liquid steel

( ) in the slag

Metallurgical Operations

Argon bubbling

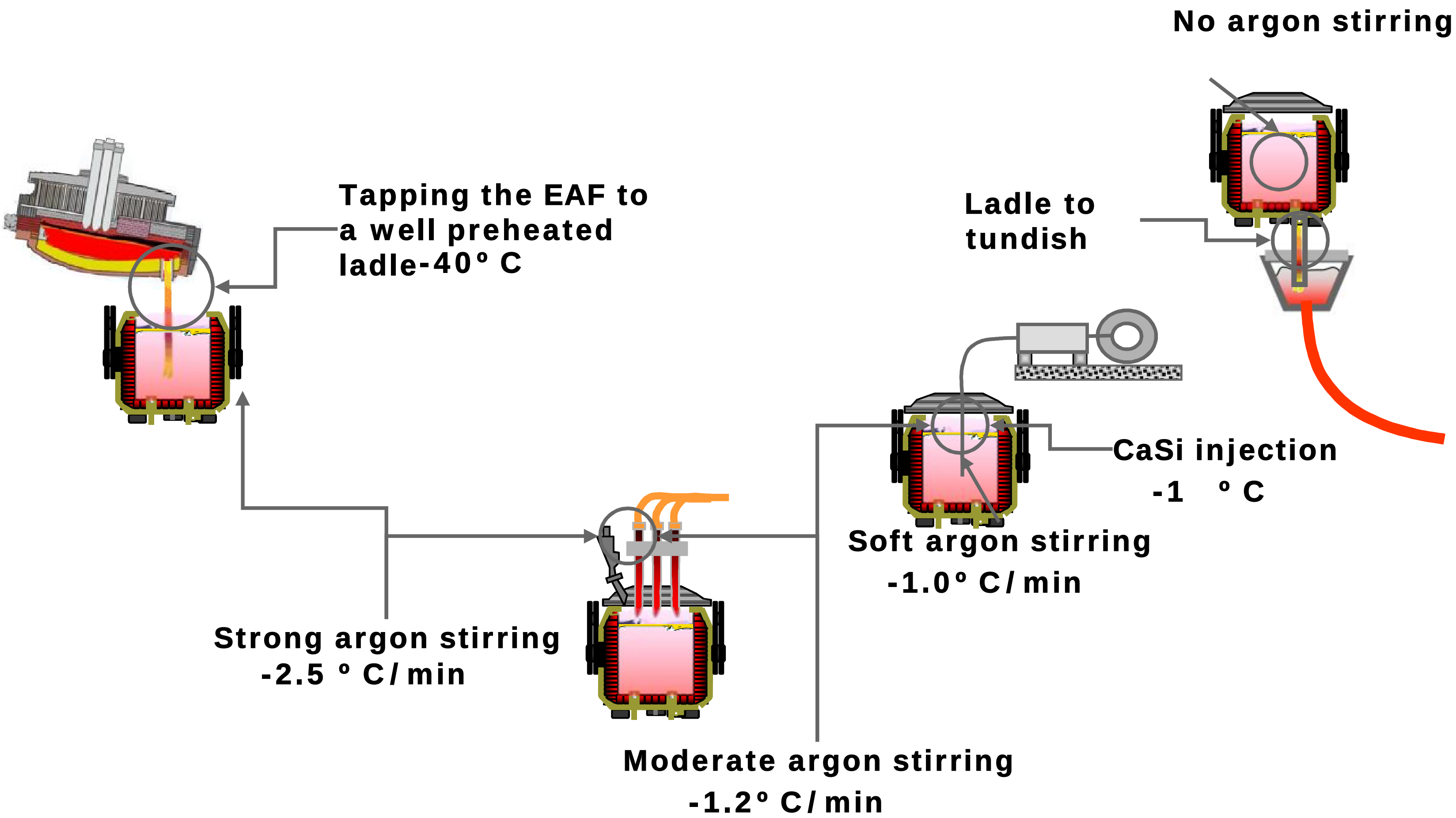
The effectiveness of the secondary steelmaking process is mainly based on the stirring of the liquid steel in the ladle.

Stirring is used in the different stages of the process.

- **Thermal and chemical homogenization**
- **Heating**
- **Flotation of inclusions**
- **Slag / Metal reactions**

Metallurgical Operations

Thermal losses



Secondary Steelmaking

Metallurgical operations

Plant Lay Out

Equipment Description

Sequence of Operation

Ferroalloy Additions

Plant Lay Out

Standard Practice and Vacuum Practice

Each of Tenaris plants have different equipment and layout. However, their operational practices can be grouped as follows:

Standard Practice	**LF → CC** **LF → TS → CC**
Vacuum Practice	**LF → VD → CC**

Secondary Steelmaking

Metallurgical operations

Plant Lay Out

Equipment Description

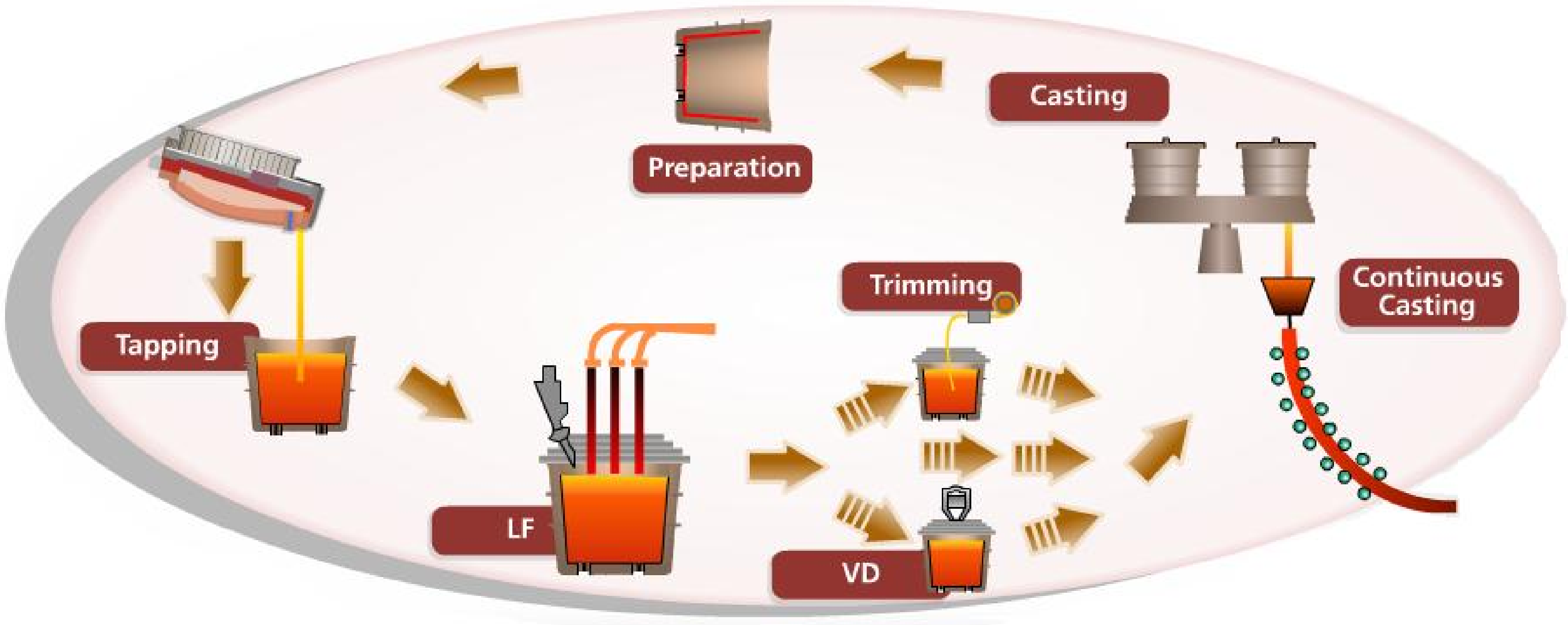
Sequence of Operation

Ferroalloy Additions

Equipment Description

The ladle

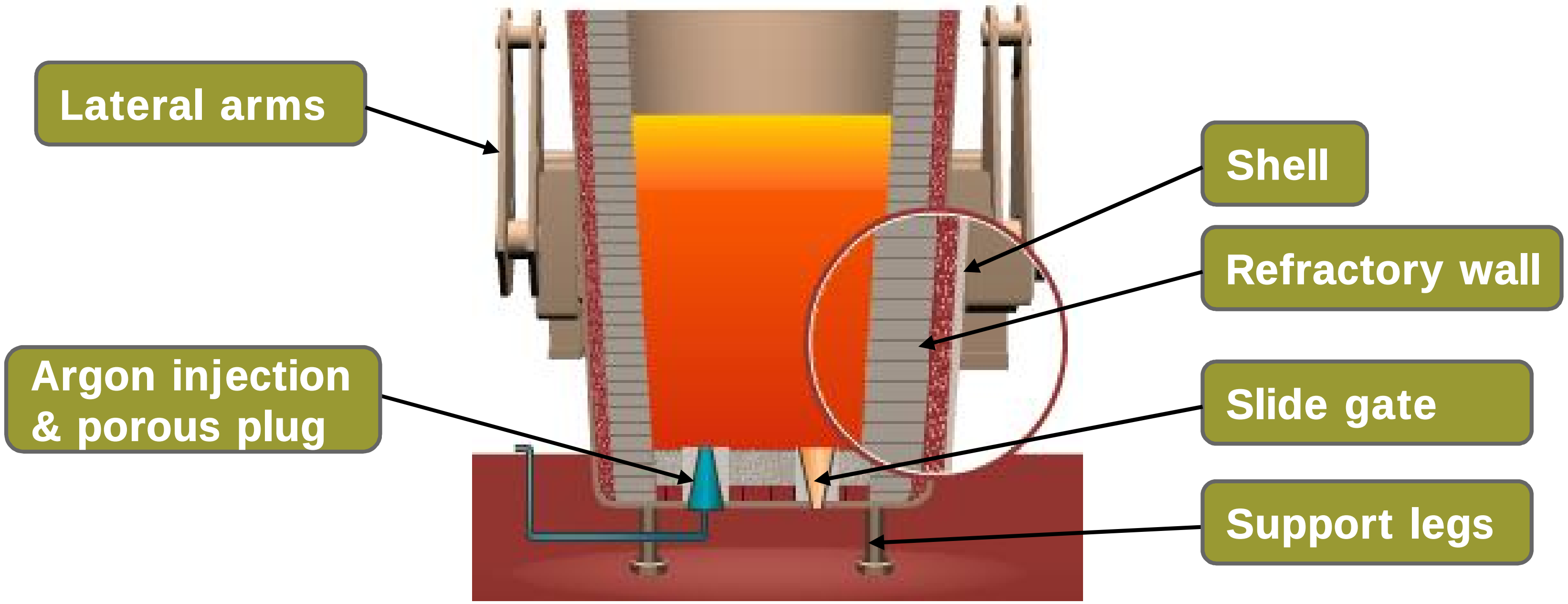
The ladle is used to performed all of the metallurgical operations in secondary steelmaking, improving quality and productivity.



Equipment Description

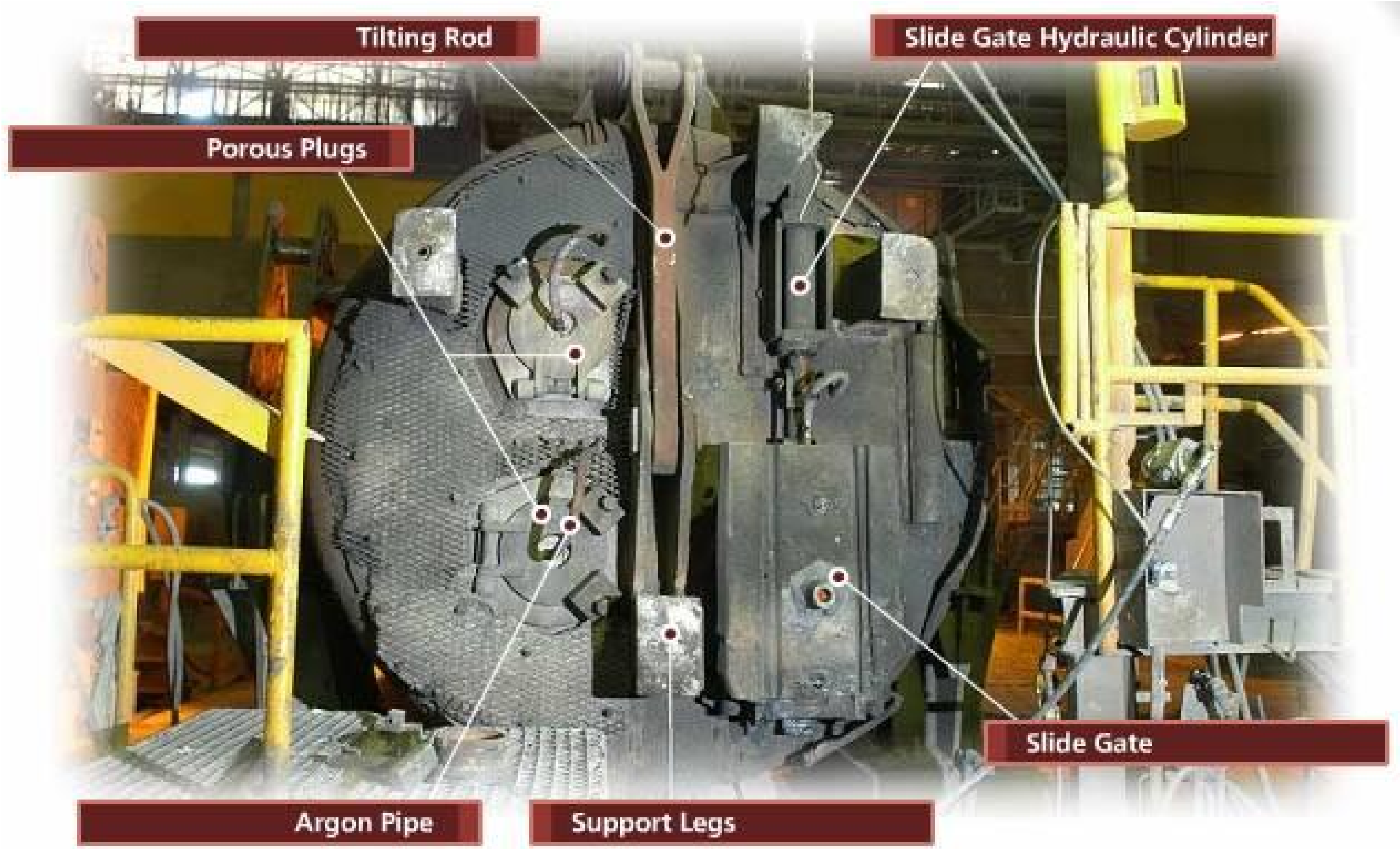
The ladle

The inner part of the ladle is refractory lined. The refractory must withstand the contact with the liquid steel and the slag during the process (@ 1550/1680°C)



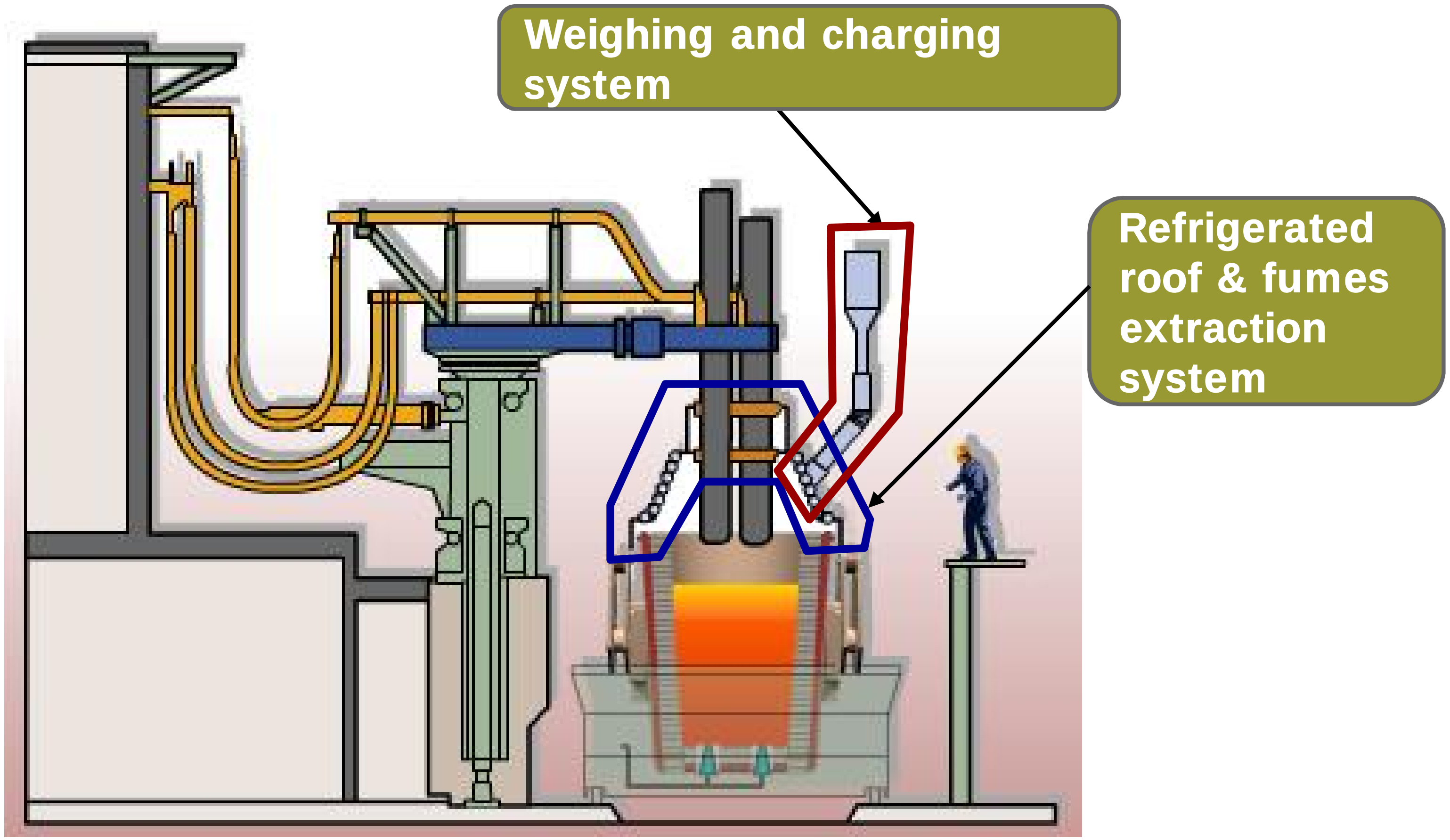
Equipment Description

The ladle



Equipment Description

The ladle furnace (LF)



Equipment Description

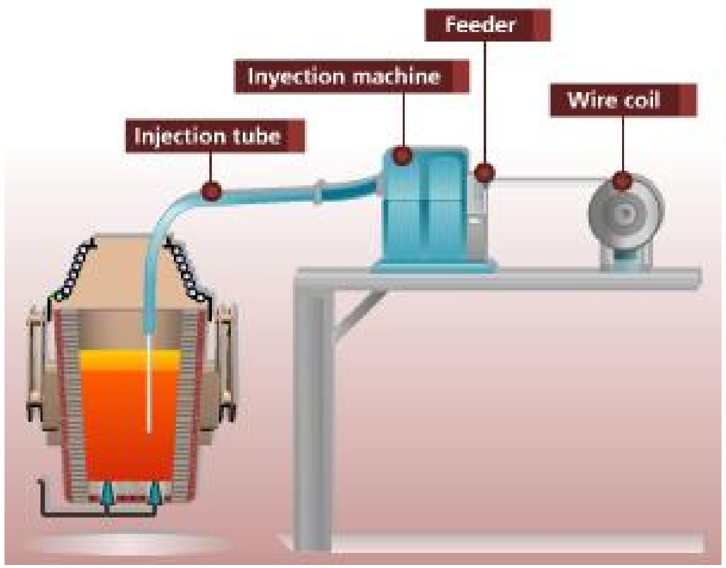
The ladle furnace (LF)

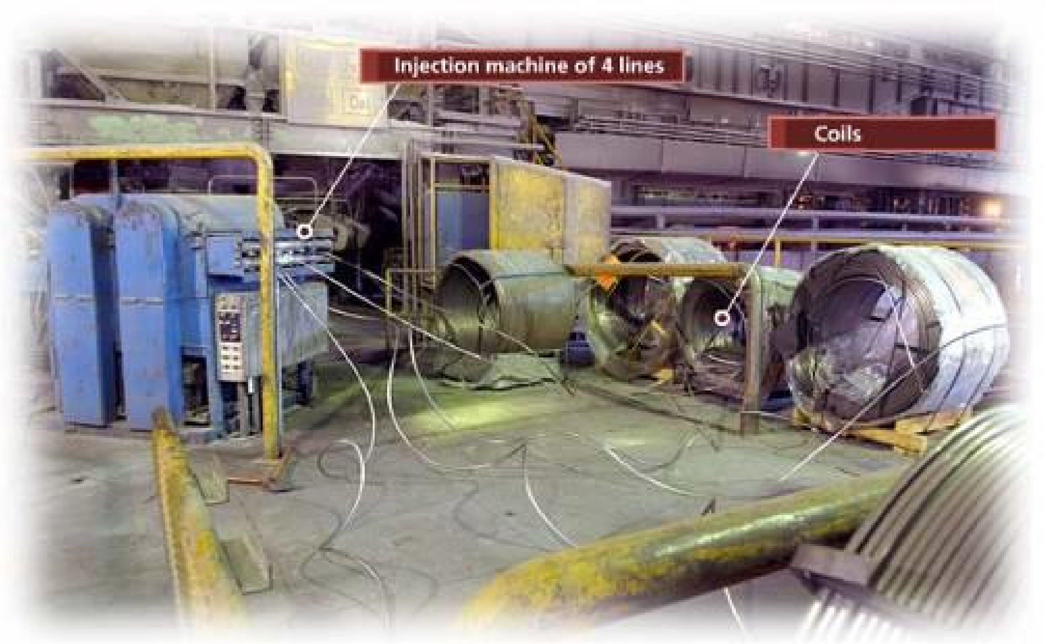
It works as a buffer station between the EAF and CC improving line flexibility and global productivity of the steelmaking process.

Equipment Description

The ladle furnace (LF)

Cored-wire is a hollow tube filled with different powder/granular materials such as CaSi (calcium silicide), ferroalloys (FeB, FeTi) or other elements (Al, C)

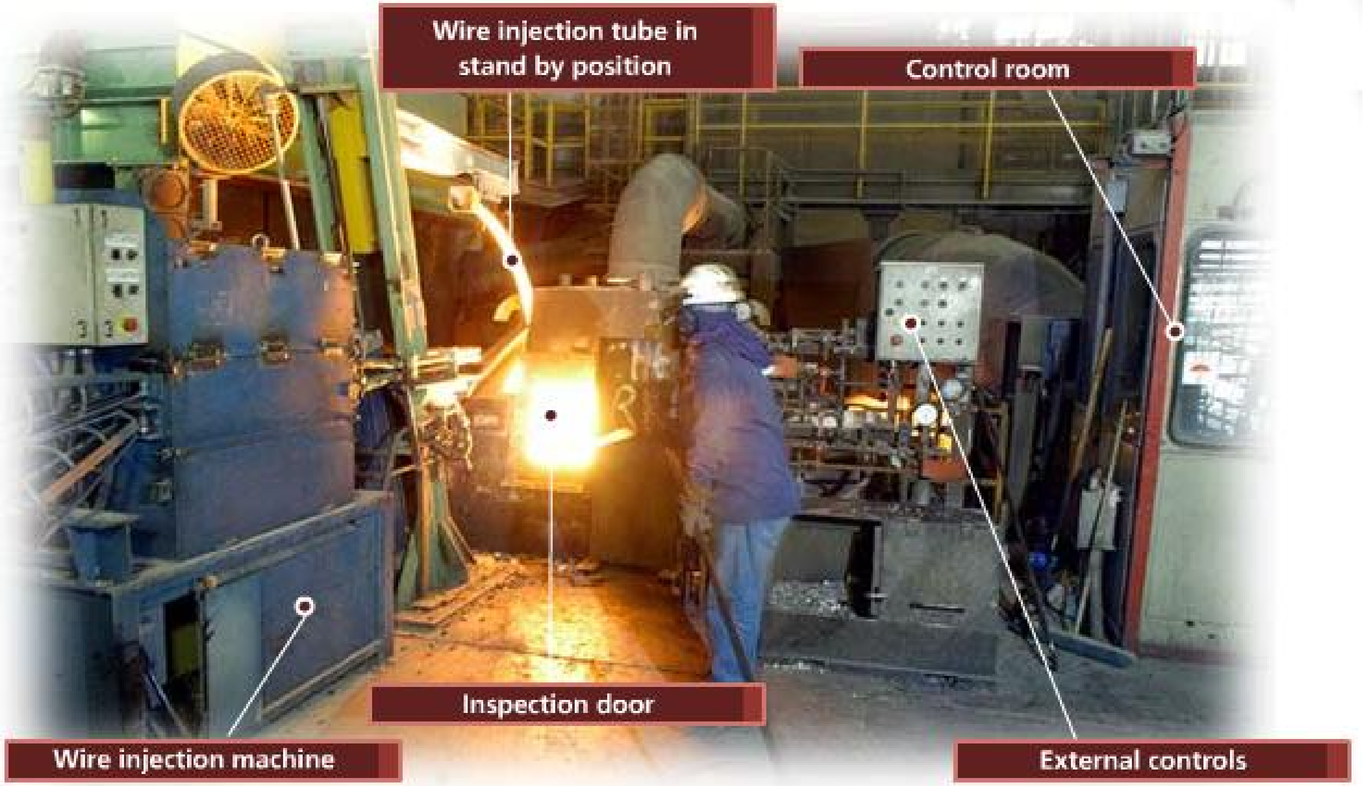




Equipment Description

The trimming station (TS)

It is a further stage of the LF where the final adjustments of the liquid bath are performed.



Equipment Description

The trimming station (TS)

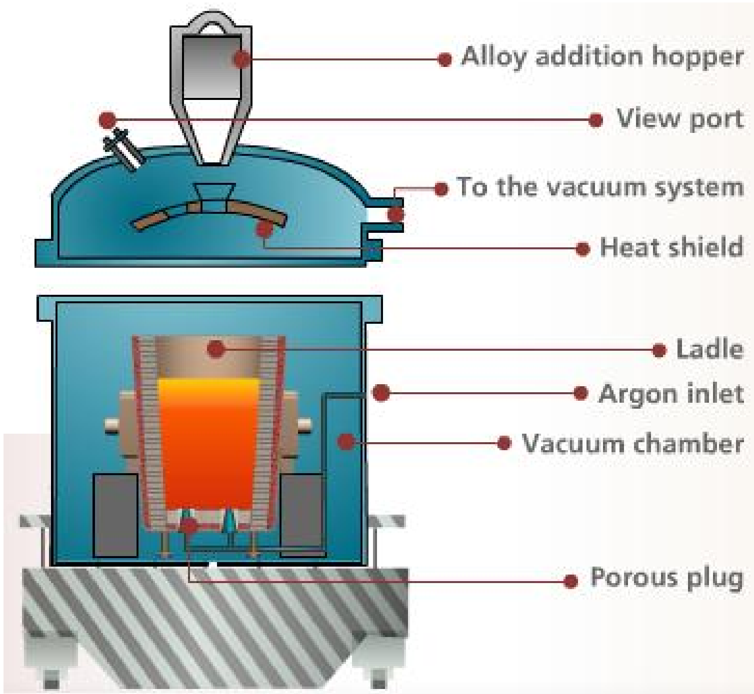
The operation performed in TS are:

- **Stirring of the liquid steel with argon injection**
- **Temperature measurements and sampling of steel and slag**
- **De-oxidation of the slag**
- **Small additions (adjustments) of materials: manually or by cored-wire injection.**

Equipment Description

The vacuum degasser (VD)

Consist in placing the ladle in a very low-pressure atmosphere while bubbling argon through its bottom.



Equipment Description

The vacuum degasser (VD)

- **Strong mixing action between the slag and steel, accelerating slag-metal reactions: de-oxidation and desulphurization**

- **Agglomeration of inclusions of alumina and aluminates which improves steel cleanliness**

- **Facilitates the elimination of gases dissolved in the steel (Nitrogen, hydrogen and oxygen)**

Secondary Steelmaking

Metallurgical operations

Plant Lay Out

Equipment Description

Sequence of Operation

Ferroalloy Additions

Sequence of Operation

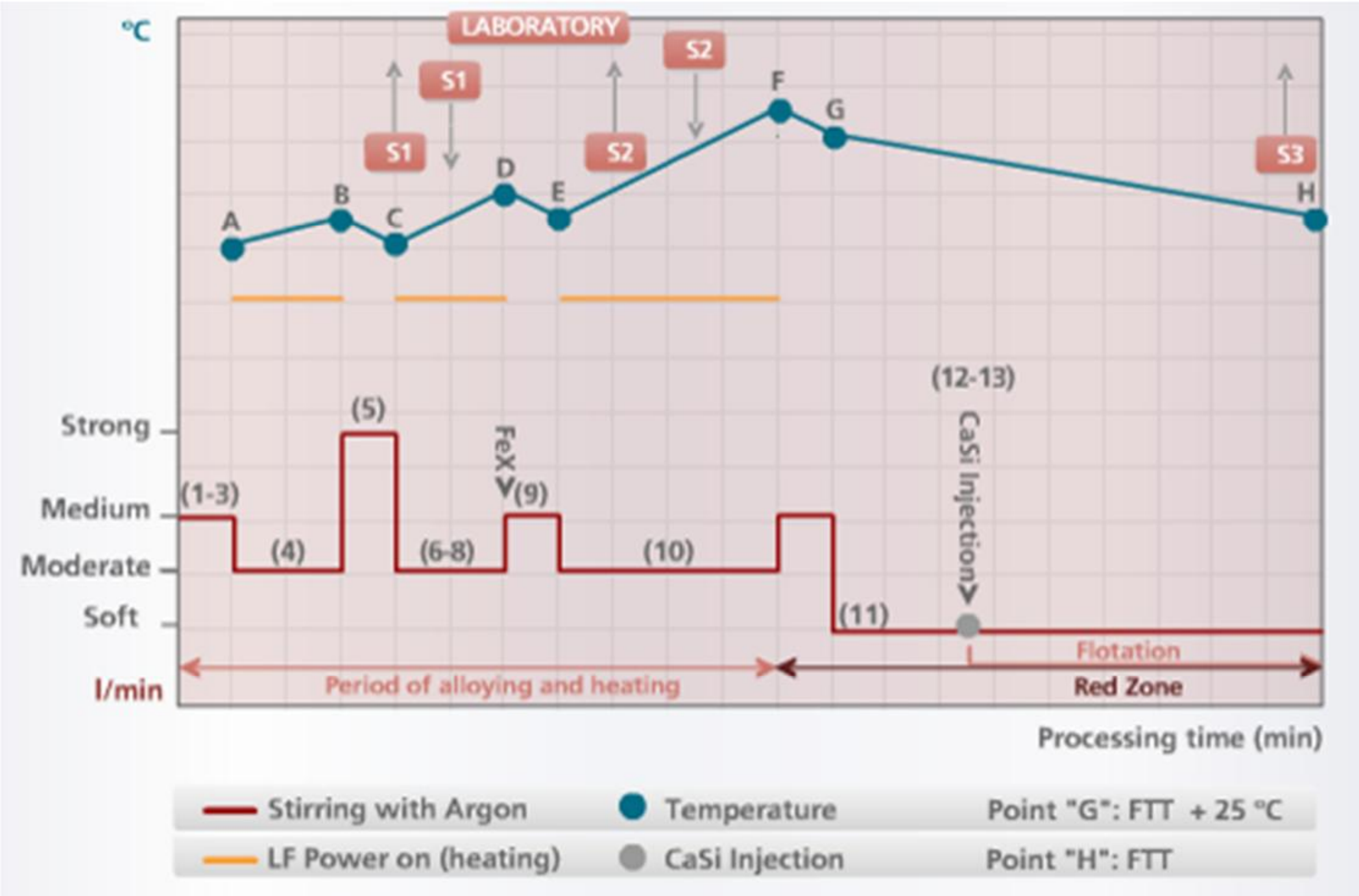
Tapping – Sequence of additions

For example: tapping 80 liquid tons (tal)

- **@ 5 tons: synthetic slag is added**
  - **Protect the steel from re-oxidation and nitrogen pick-up**
- **@ 10 tons: aluminum addition**
  - **For steel deoxidation**
  - **Helps to obtain a fully melted homogeneous slag.**
- **@ 30 tons: ferroalloys and carbon addition.**
  - **Pointing 0.020/0.030 below minimum specification preventing any error in the weight of the additions.**

Sequence of Operation

LF treatment



FTT: final treatment temperature

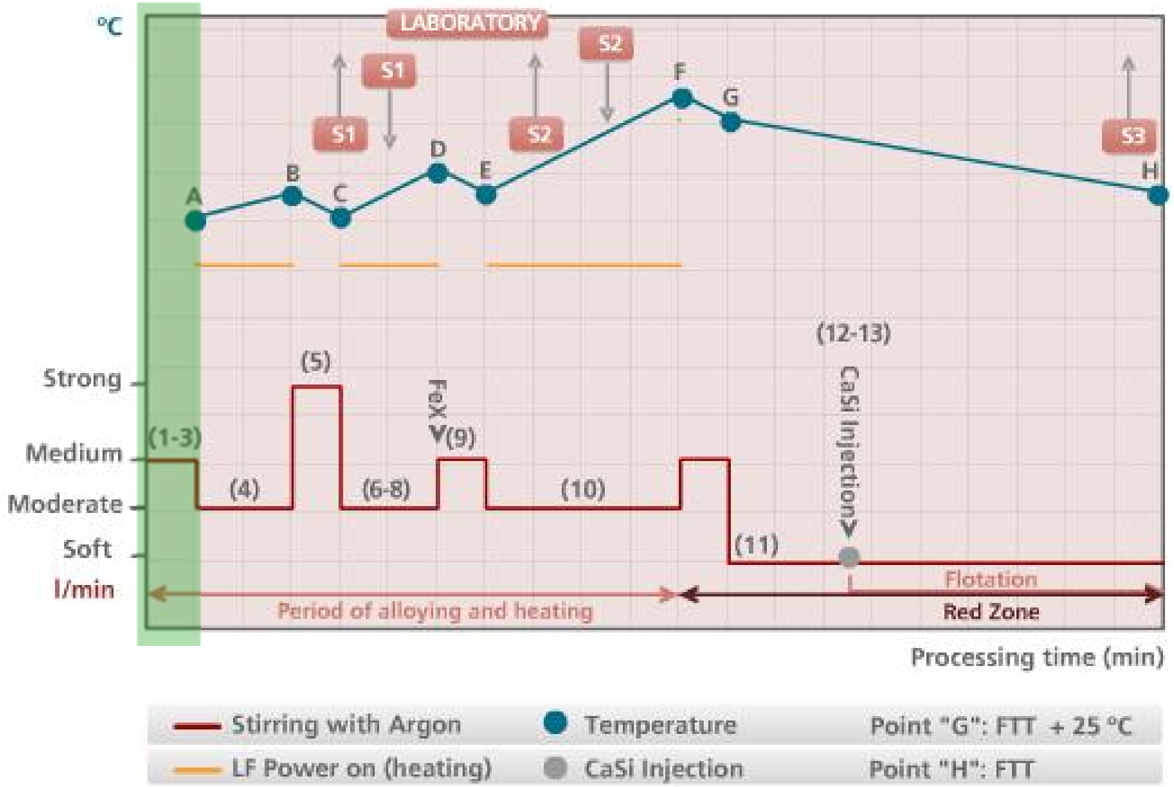
Sequence of Operation

LF treatment

1. Ladle positioning below the roof and argon system connection

2. Visual inspection and slag sampling. Evaluation of freeboard

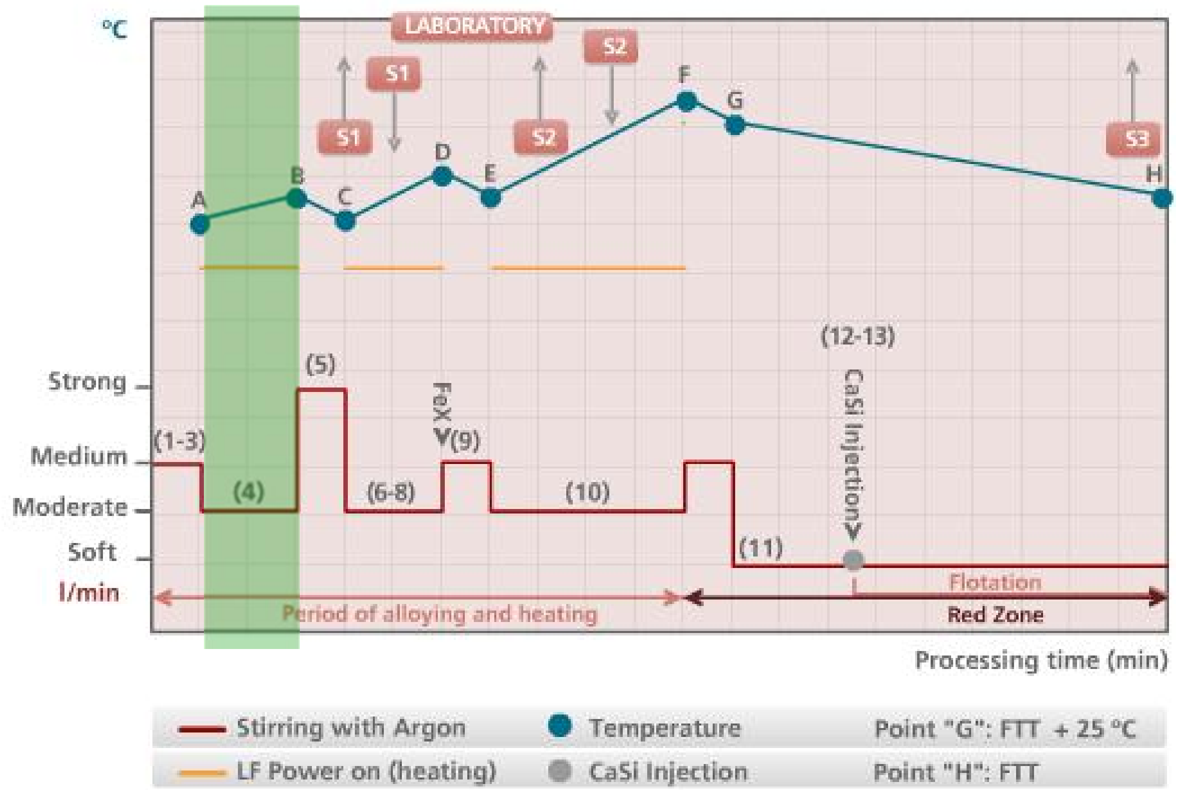
3. Start of stirring



Sequence of Operation

LF treatment

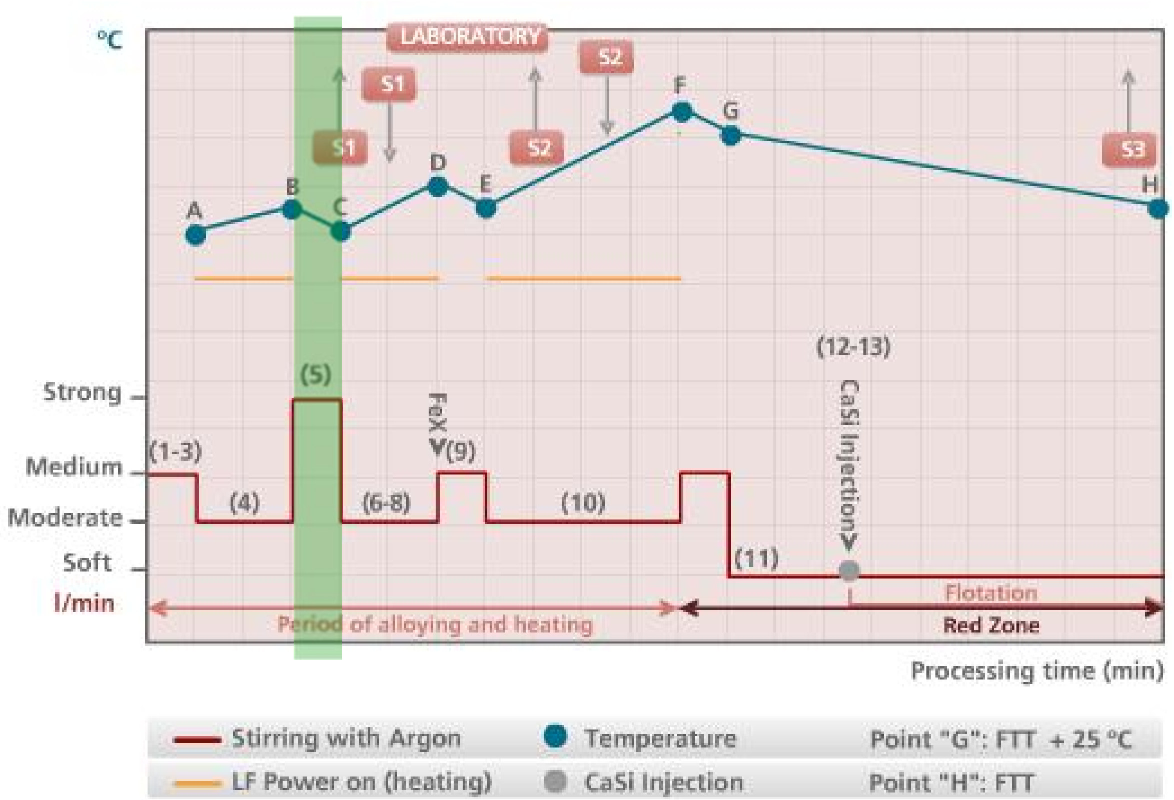
4. First heating and deoxidizing mix addition to the slag



Sequence of Operation

LF treatment

5. Temperature measurement and steel sampling for chemical analysis



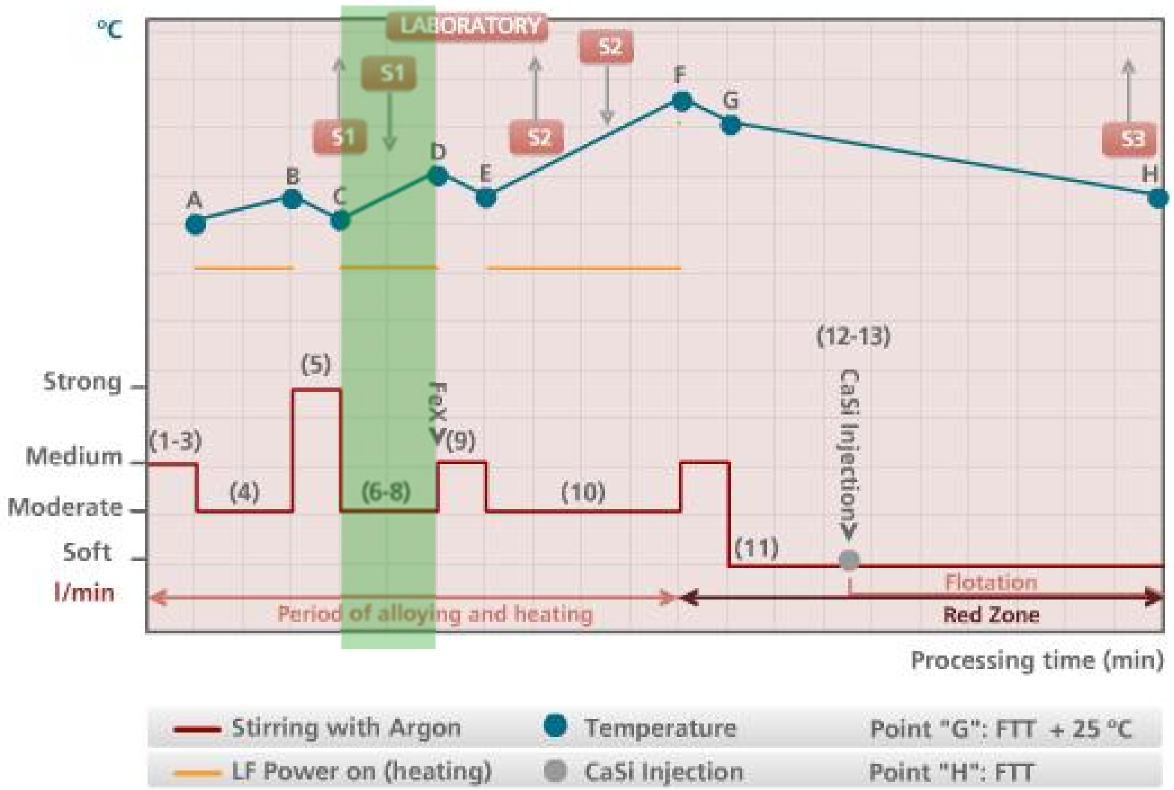
Sequence of Operation

LF treatment

6. Main Heating

7. Addition of deoxidizing mix to the slag

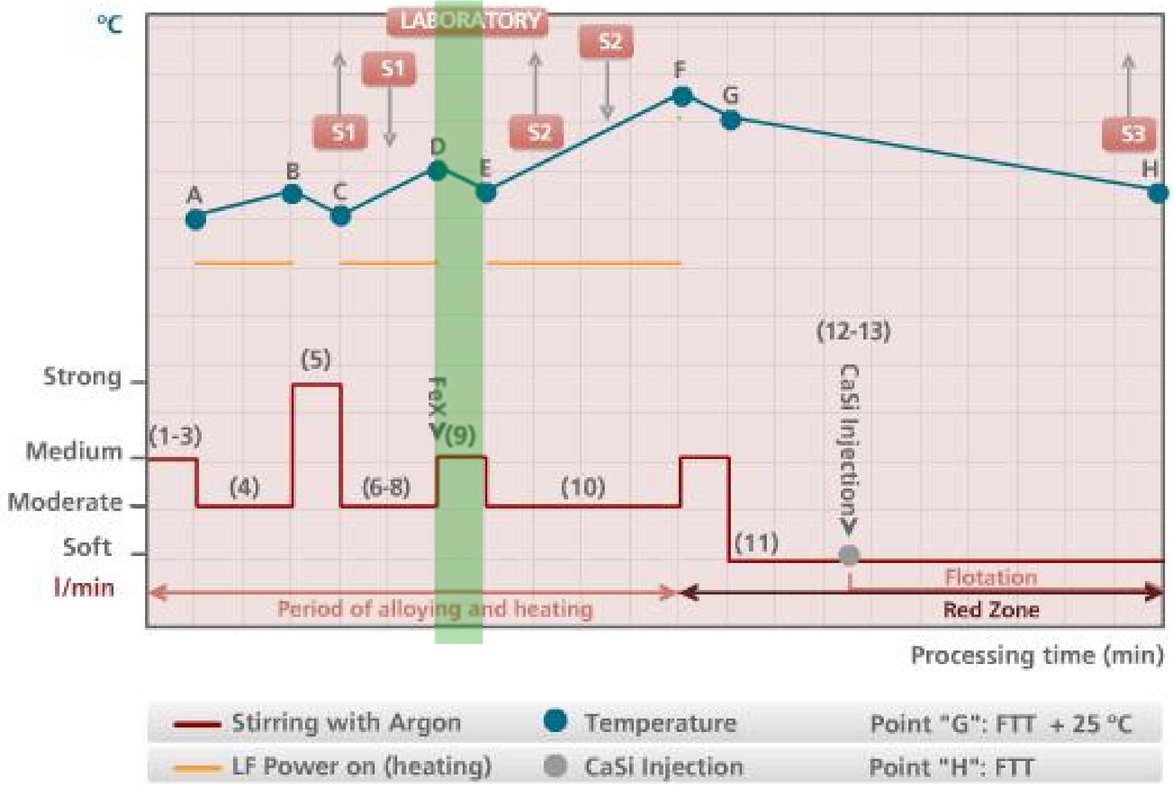
8. Adjustment of chemical analysis according to the first sample



Sequence of Operation

LF treatment

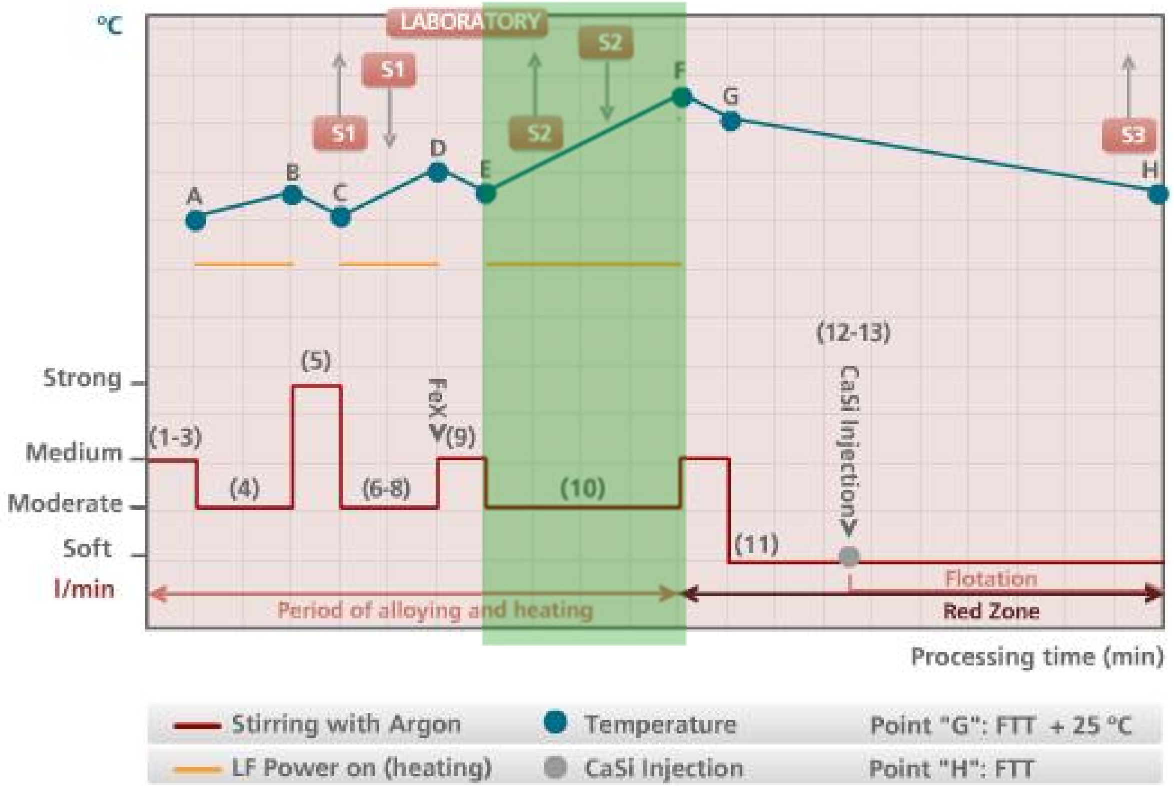
9. Stirring for steel homogenization



Sequence of Operation

LF treatment

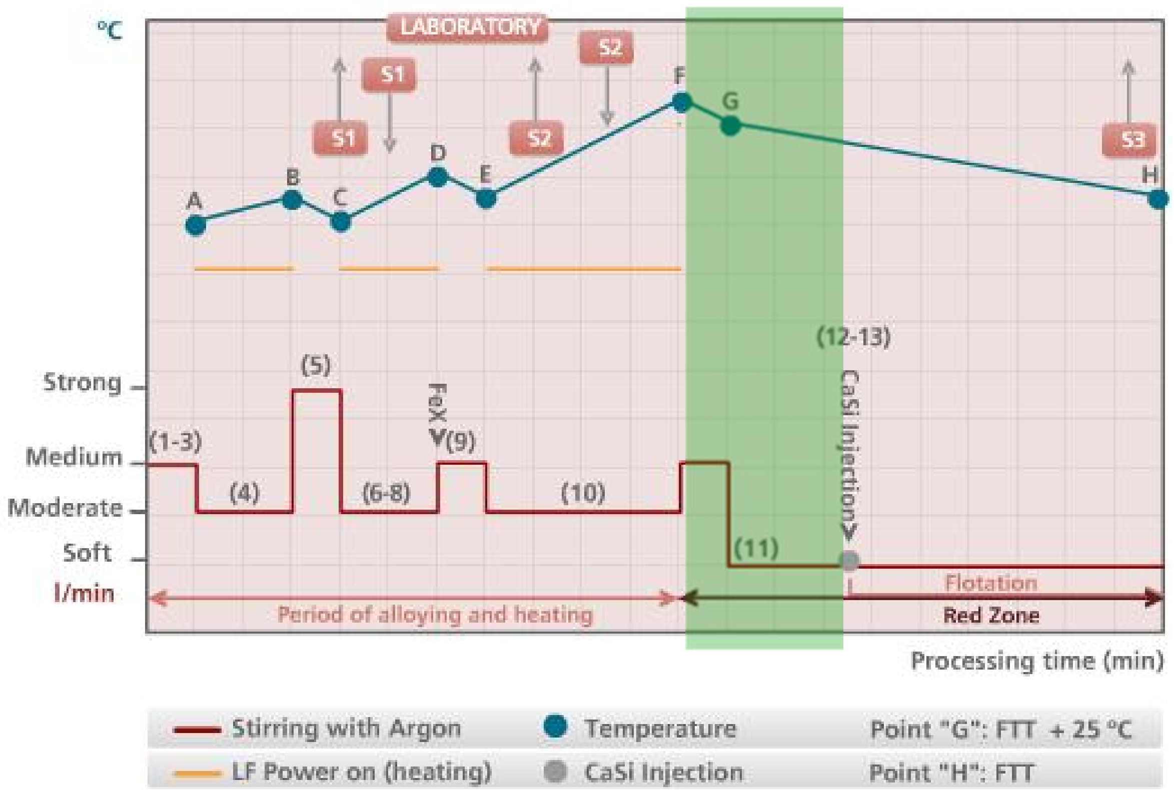
10. Second sampling and temperature measurement.



Sequence of Operation

LF treatment

11. Start of Red Zone



Sequence of Operation

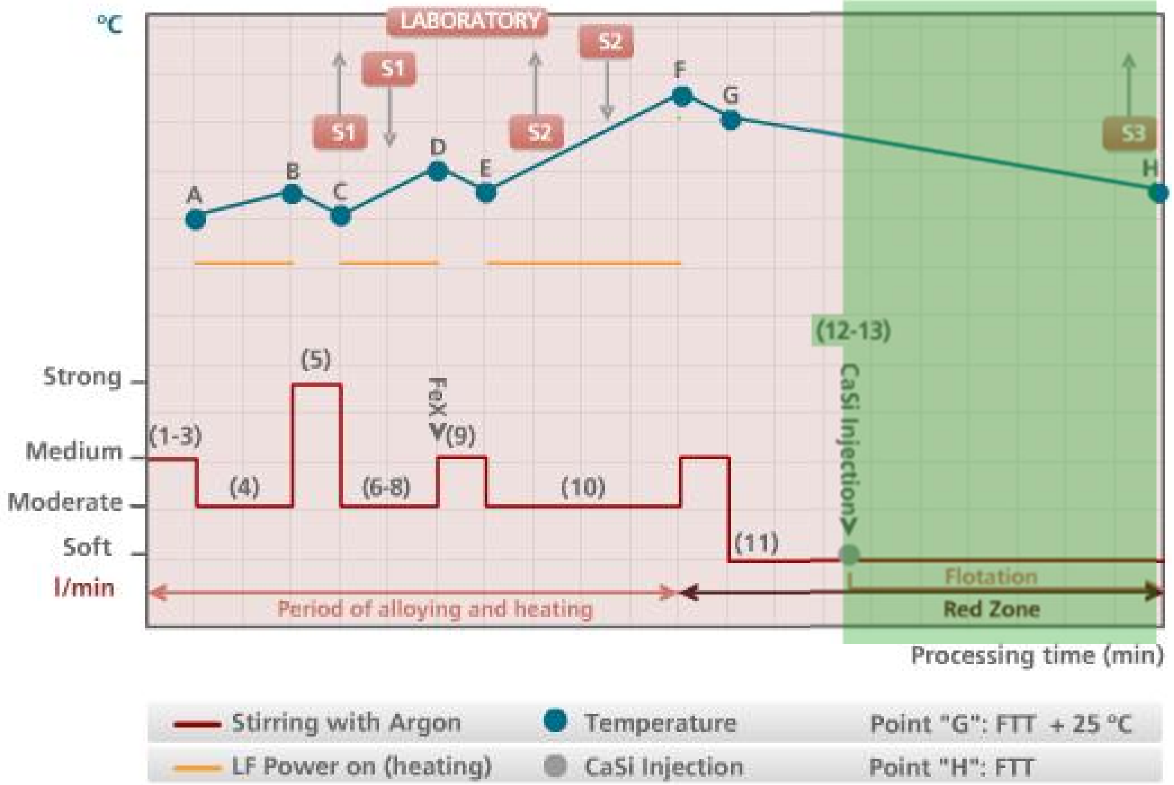
LF treatment

12. Injection of CaSi

13. Final flotation

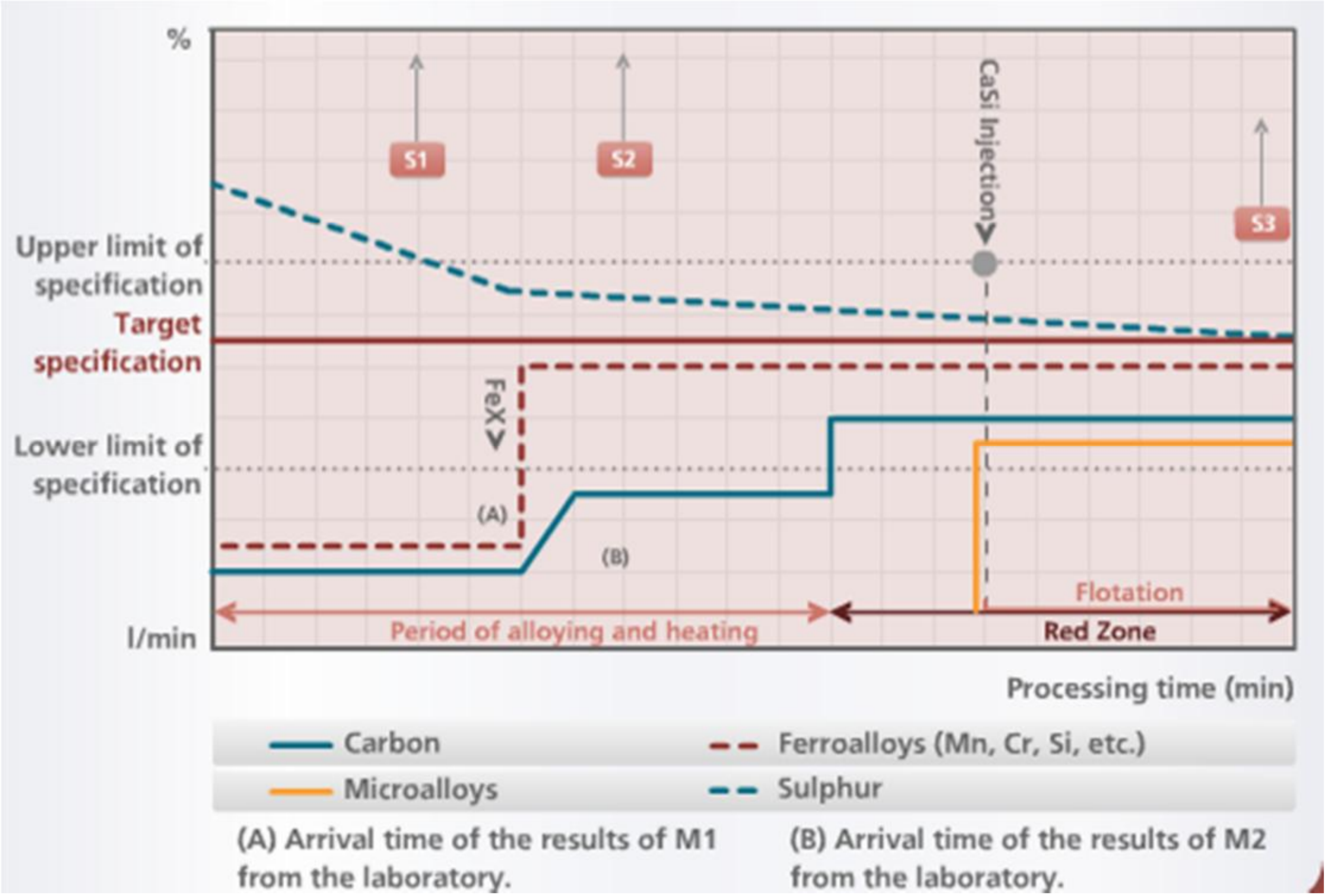
14. Final sampling of steel and slag

15. Final temperature measurement



Sequence of Operation

Chemistry evolution



Secondary Steelmaking

Metallurgical operations

Plant Lay Out

Equipment Description

Sequence of Operation

Ferroalloy Additions

Ferroalloy Additions

When are ferroalloy added?

At tapping

Big quantities or bulk addition

- **High temperature**
- **Strong stirring**
- **Fast**

LF – TS - VD

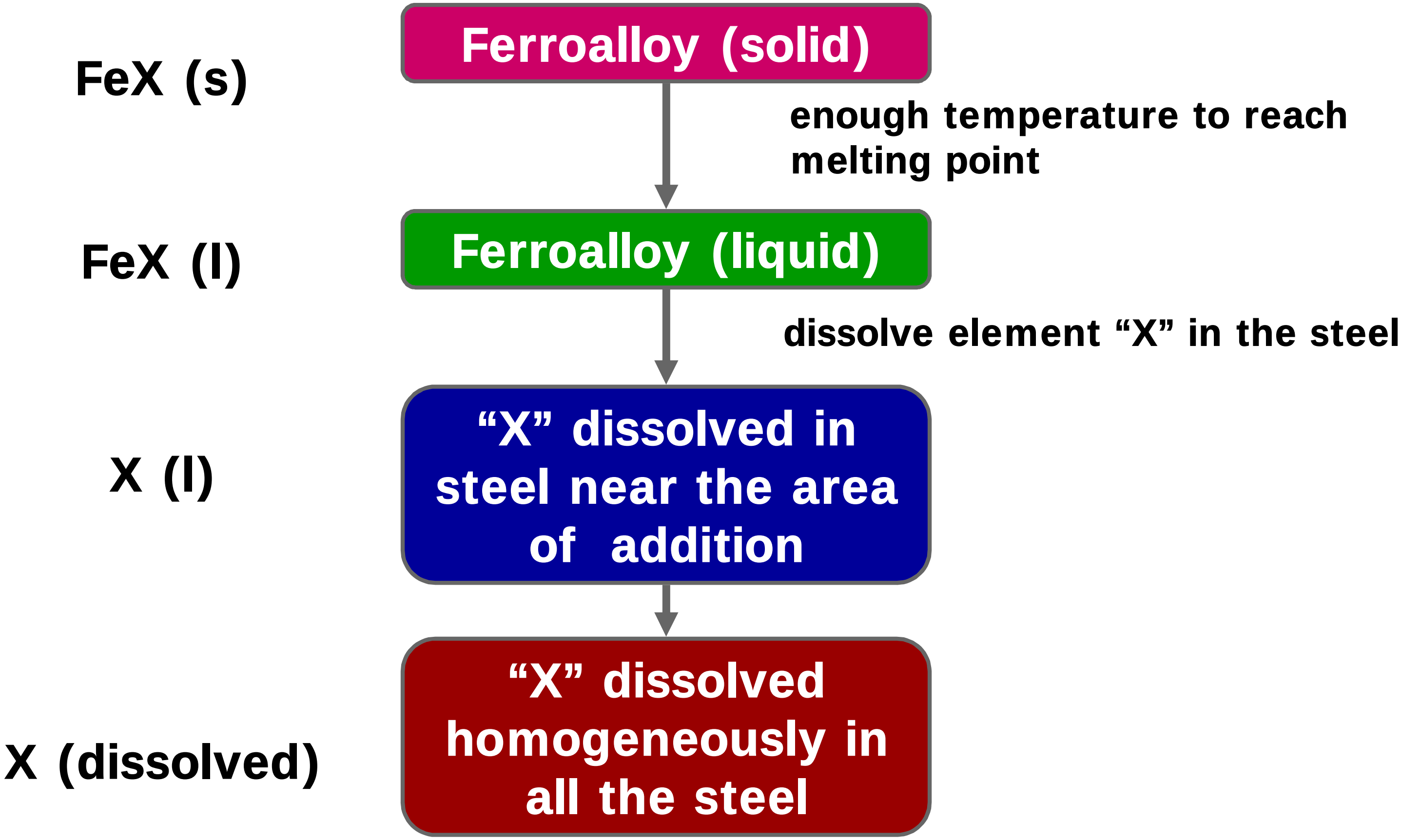
Small quantities or trimming additions

- **Controlled operation**
- **Stirring (double Argon plug)**
- **Temperature (Heating)**
- **More time required**

- **Steel temperature: consider the melting point of FeX**
- **Cooling Effect: different for each FeX (std=0.03 °C/kgFeX)**
- **Stirring**
- **Time to complete the process**

Ferroalloy Additions

Alloying process



Ferroalloy Additions

Additions calculation

$$\%\Delta X_{steel} = \frac{kgFeX \cdot \%FeX \cdot \%FeX_{yield} \cdot 100}{tn_{liq\ steel}}$$

where,

ΔX %: increment in % of element “X”

FeX: Ferroalloy containing element “X”

% FeX: % content of element “X” in the FeX

Ferroalloy Additions

Additions calculation

	%Al	kg/m	Yield at tapping %	Yield LF addition %
Aluminum wire	**99.5**	**0,307**	**74**	**100**

$$mAl_{wire} = \frac{\%Al \cdot tn_{liq\ steel} \cdot 10}{\left.\%Al_{content}/100 \cdot \%Al_{yield}/100 \cdot kg/m\right|_{Alwire}}$$

Agenda

Steelmaking Overview

Raw Materials

Electric Arc Furnace Steelmaking

Secondary Steelmaking

Continuous Casting of Round Bars

Continuous Casting of Round Bars

Overview

Process Characteristics

Equipment description

Sequence of Operation

Defectology

Charge-to-thousand

Productivity

Continuous Casting of Round Bars

Overview

Process Characteristics

Equipment description

Sequence of Operation

Defectology

Charge-to-thousand

Productivity

Overview

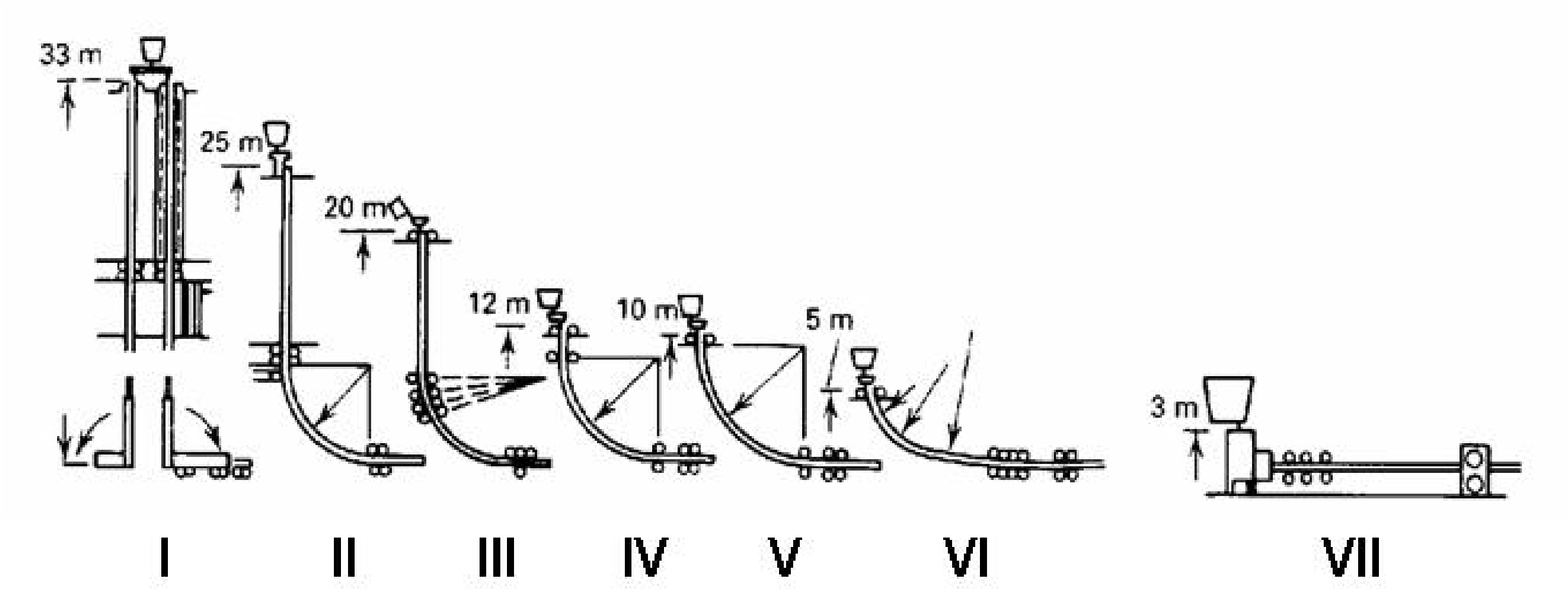
Continuous Casting Machines

The purpose of continuous casting machine is to transform the liquid steel into solid bars with the geometry, dimensions and quality requested by the rolling mill.

Overview

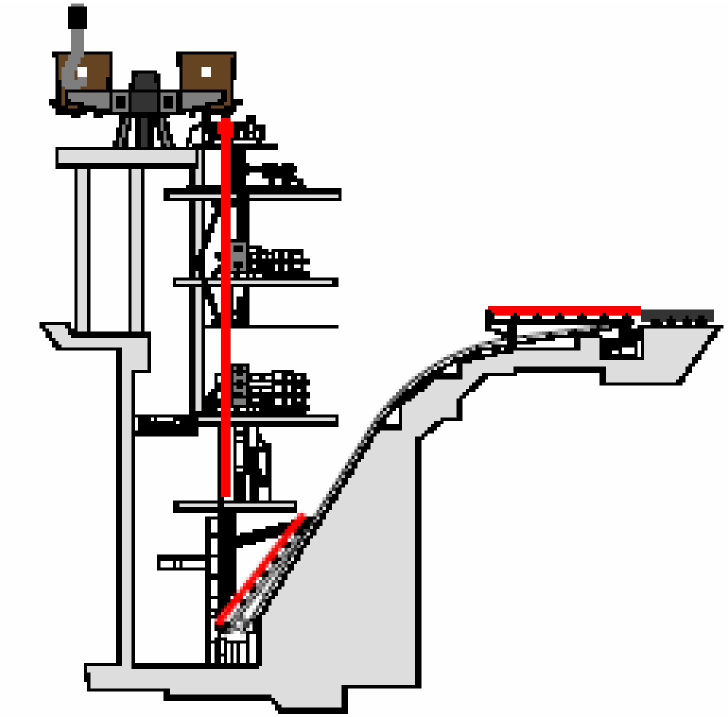
Continuous Casting Machines

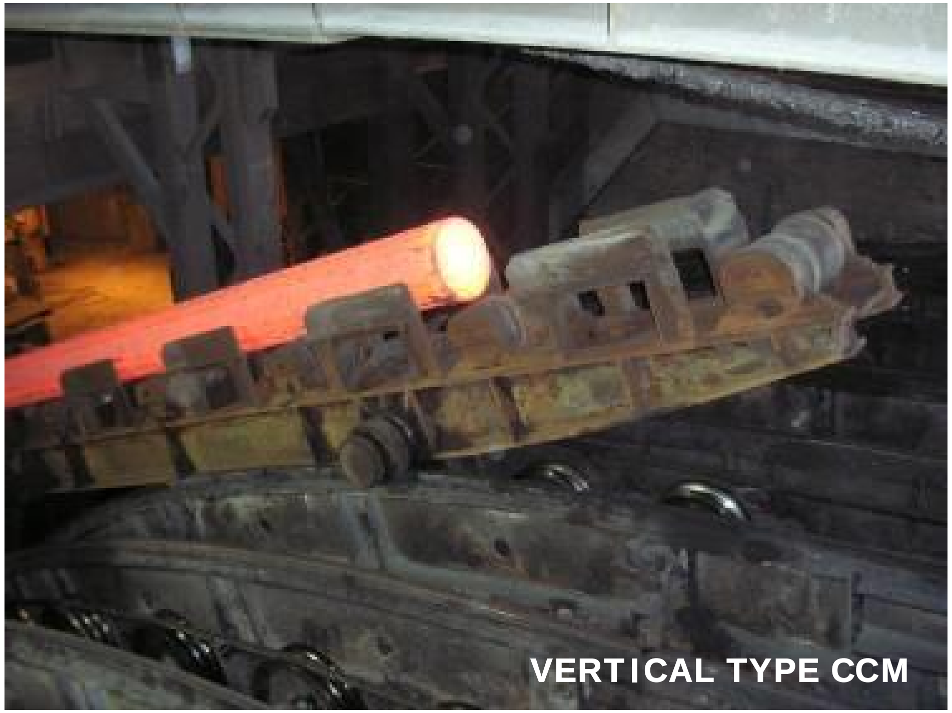
There is a wide variety of CC machines according to the shape of the product, the production capacity and the mechanical, metallurgical and operational designs.



Overview

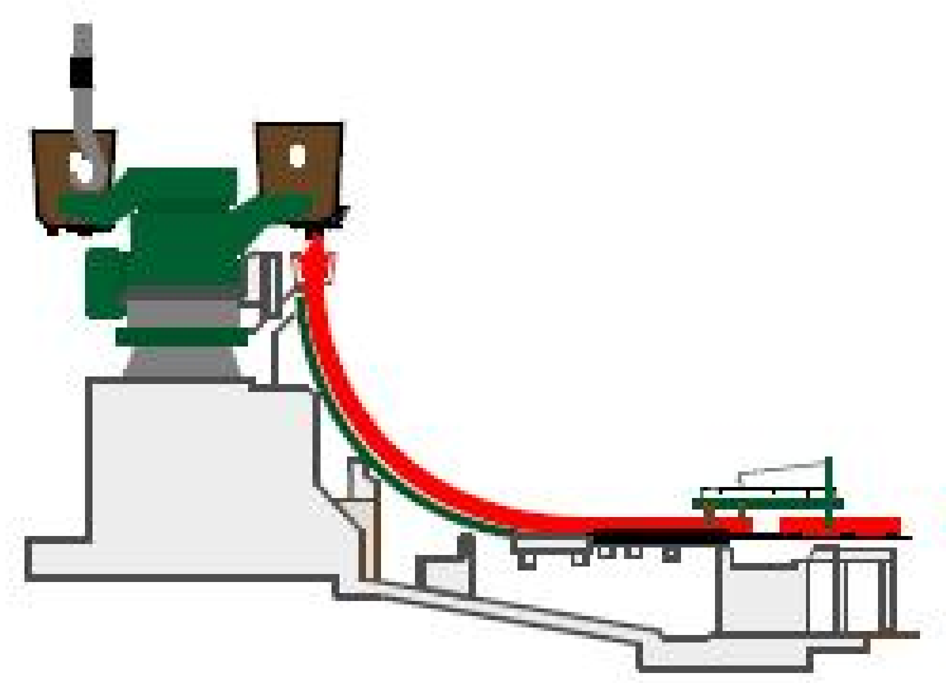
Continuous Casting Machines in Tenaris





Overview

Continuous Casting Machines in Tenaris



Continuous Casting of Round Bars

Overview

Process Characteristics

Equipment description

Sequence of Operation

Defectology

Charge-to-thousand

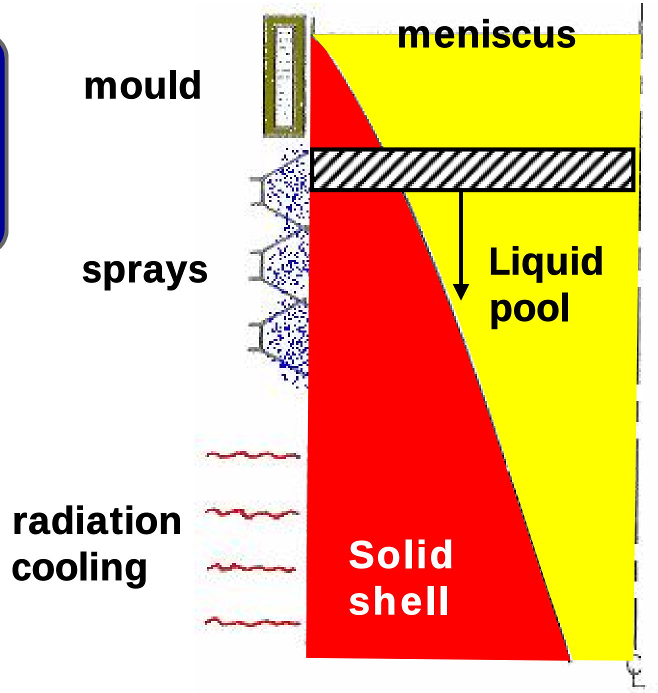
Productivity

Process Characteristics

Steel solidification

Bar cooling in the casting machine takes place along three areas:

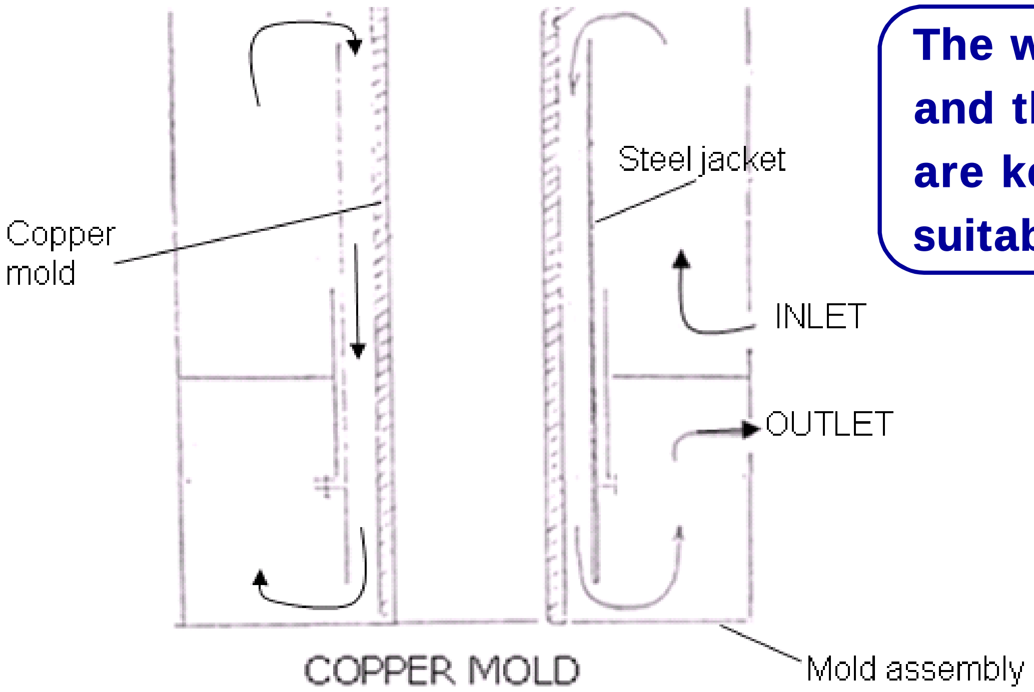
- **Primary (mould)**
- **Secondary (spray and roll cooling)**
- **Final (cooling bed).**



Process Characteristics

Steel solidification: Primary Cooling

This heat transfer is performed through strong water cooling of the outer wall of the copper mould. The water flow rate depends on the operating conditions



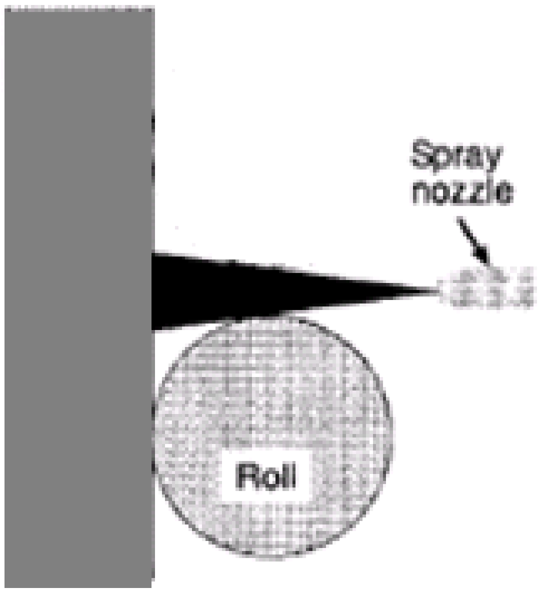
The water flow rate, temperature, and the inlet and outlet pressures are key parameters to achieve a suitable heat transfer

Process Characteristics

Steel solidification: Secondary Cooling

The direct contact of the guide rolls with the hot strand generates heat extraction by conduction.

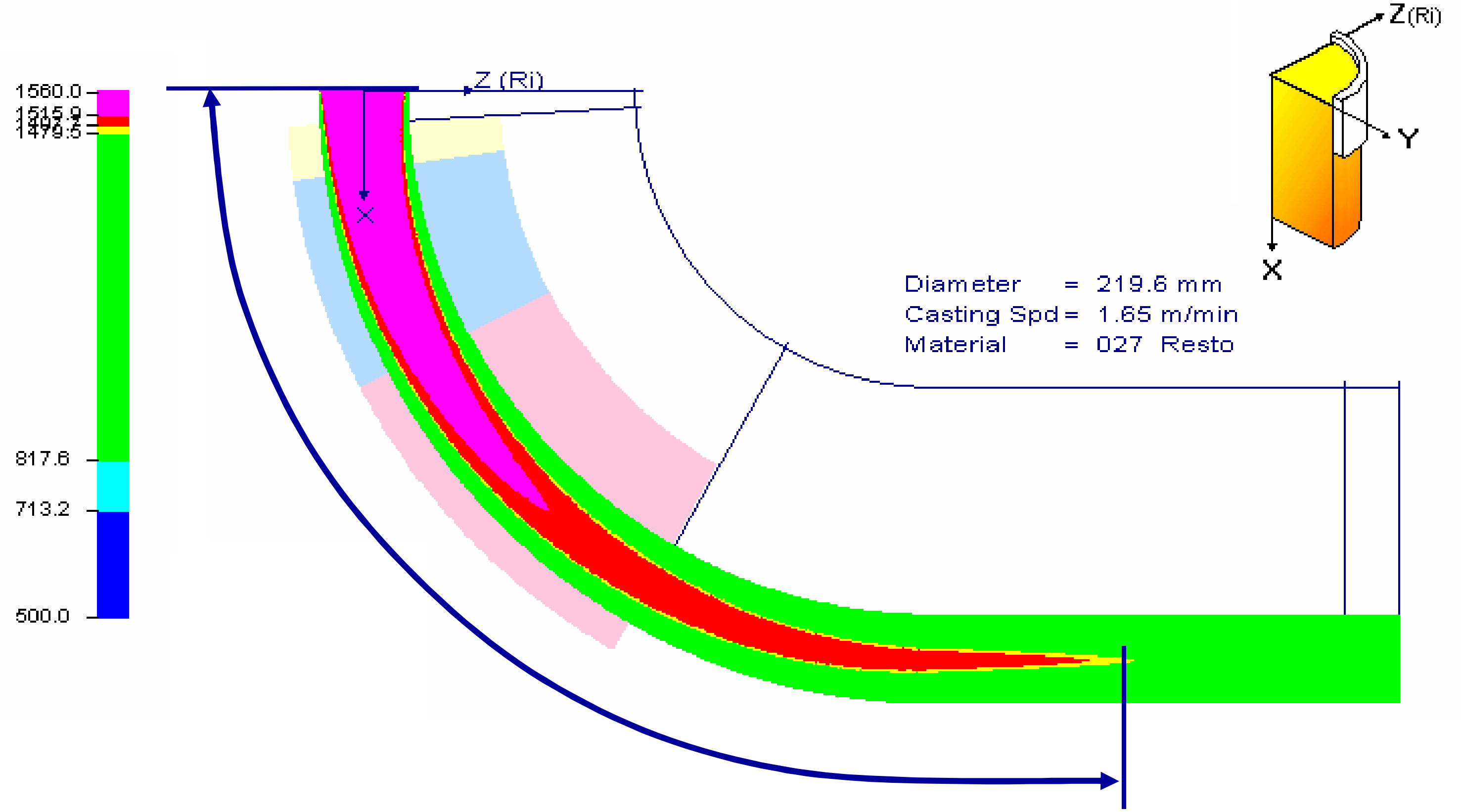
It is proportional to the surface and time of contact. It represents a small fraction of the heat extraction by spray cooling.



Process Characteristics

Steel solidification: Metallurgical Length

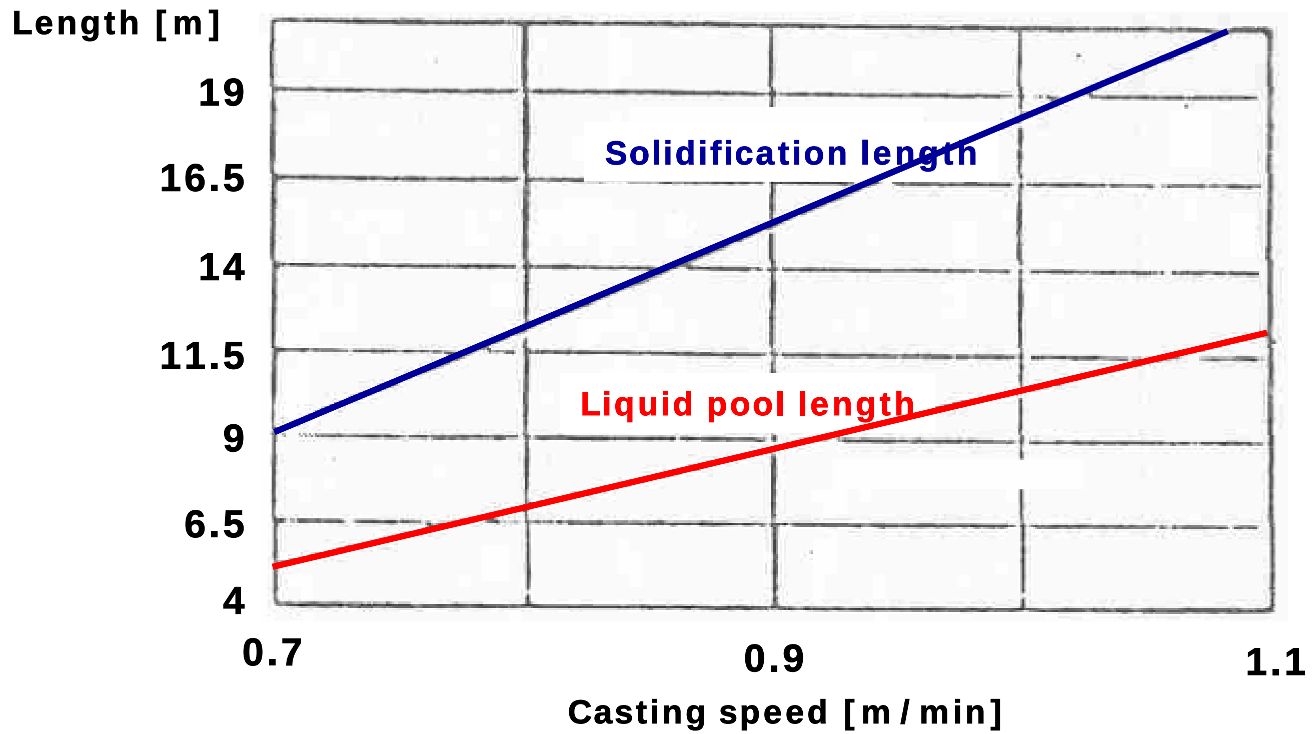
It is defined as the length of the liquid core inside the bar from the meniscus to the first section completely solidified.



Process Characteristics

Steel solidification: Metallurgical Length

It depends on the casting speed, the casting temperature and the steel grade. On the other hand, secondary cooling has little influence on the metallurgical length.



Process Characteristics

Steel solidification: Metallurgical Length

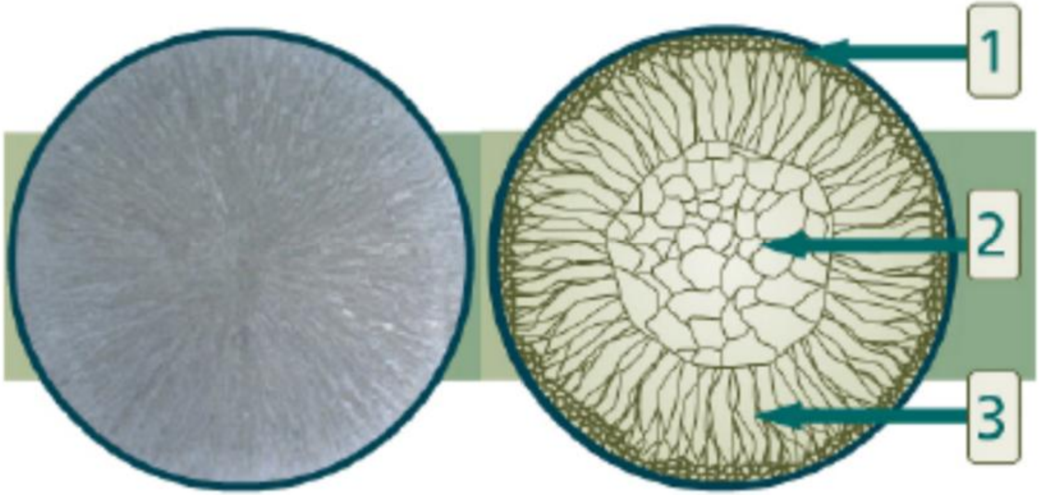
The existence of a liquid core mainly depends on the thickness of the solid shell, which grows following the relationship:

$$E = K \cdot t^{1/2}$$

where,
E = thickness of the solidified shell
K = a constant that depends on the shape factor of the bar, the thermal conductivity of steel and on the difference between the casting temperature and the surface temperature of the bar.
t = time elapsed

Process Characteristics

Solidification structure



Continuous Casting of Round Bars

Overview

Process Characteristics

Equipment description

Sequence of Operation

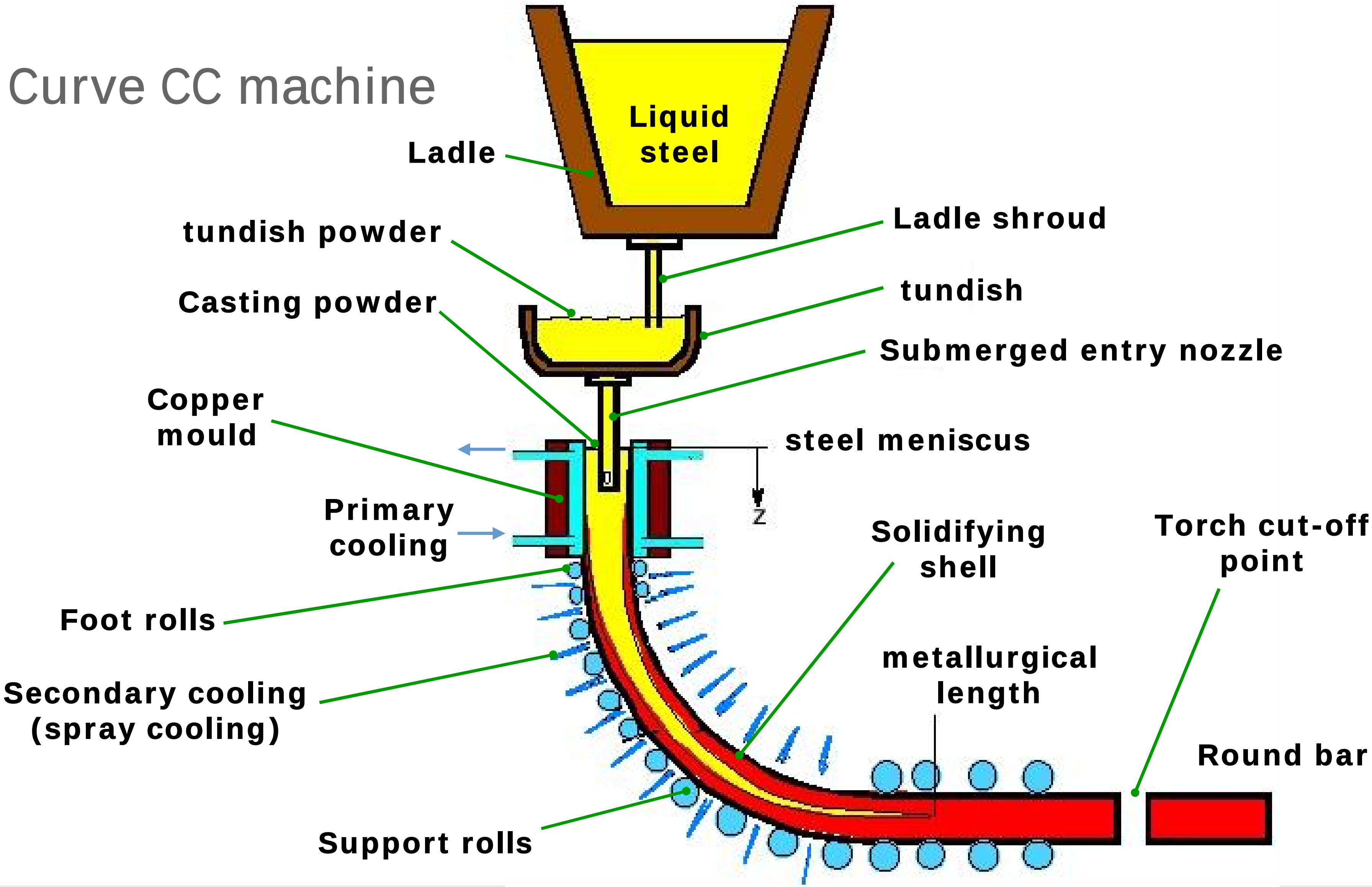
Defectology

Charge-to-thousand

Productivity

Equipment Description

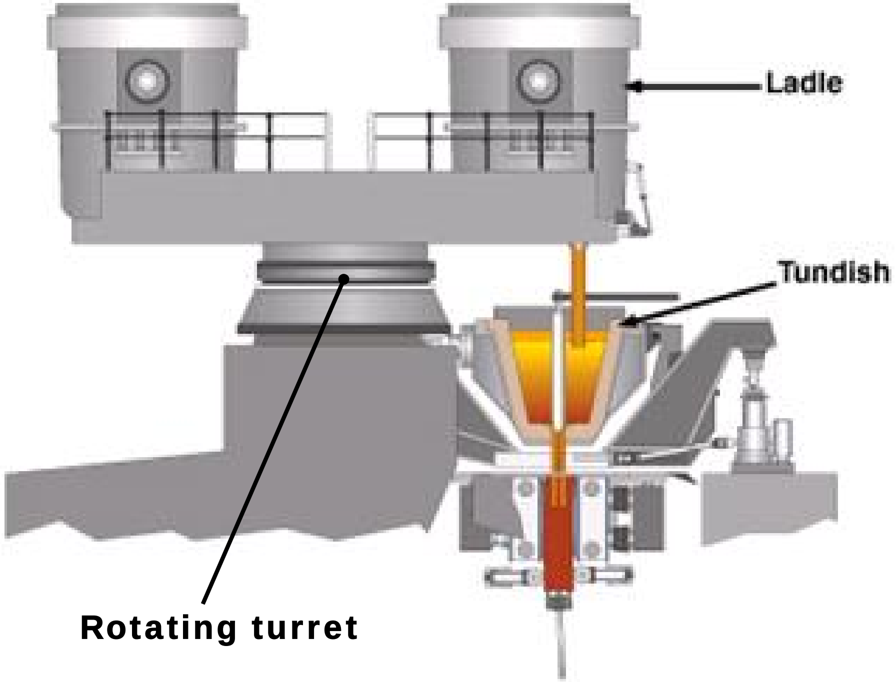
Curve CC machine



Equipment Description

Ladle turret

Its purpose is to move the ladle from the <u>waiting position</u> to the <u>pouring position</u> in a short period of time to allow a continuous casting sequence.



Equipment Description

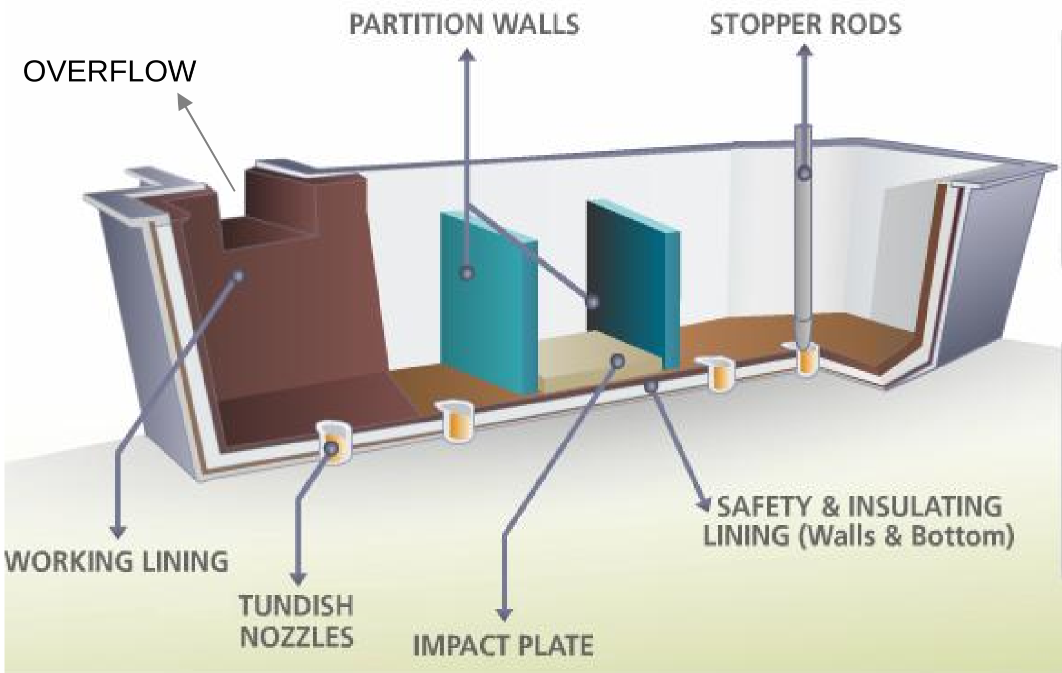
Ladle shroud

To avoid air-steel contact, a ceramic tube connected to the collector nozzle of the ladle is used. During casting it remains submerged in the liquid steel of the tundish, in such a way that the liquid steel jet never gets in contact with the air (except at the beginning of the first heat of the sequence or during the ladle change).

Equipment Description

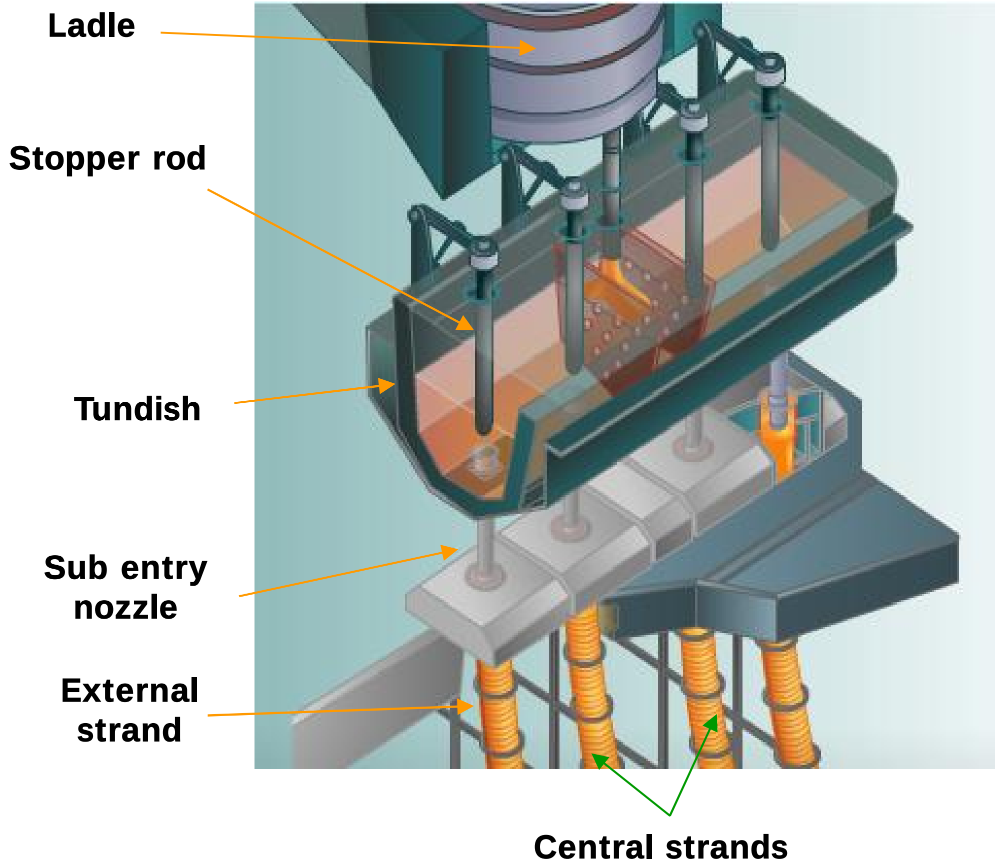
Tundish

Its design and dimensions (e.g. its depth, distance between strands, and distance between the ladle discharge and the submerged entry nozzles of the central strands), have a relevant influence in the steel cleanness.



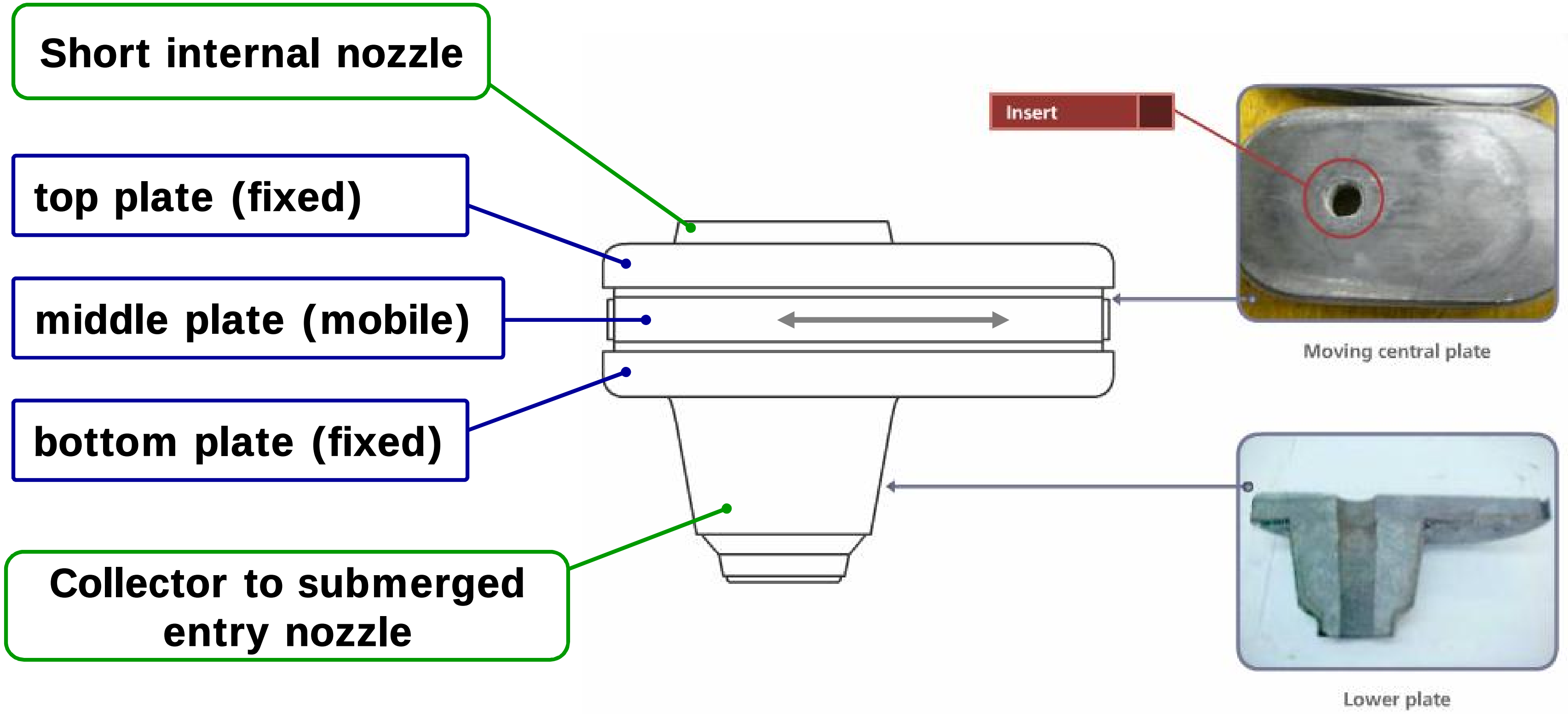
Equipment Description

Tundish flow control devices: stopper rod



Equipment Description

Tundish flow control devices: slide gate

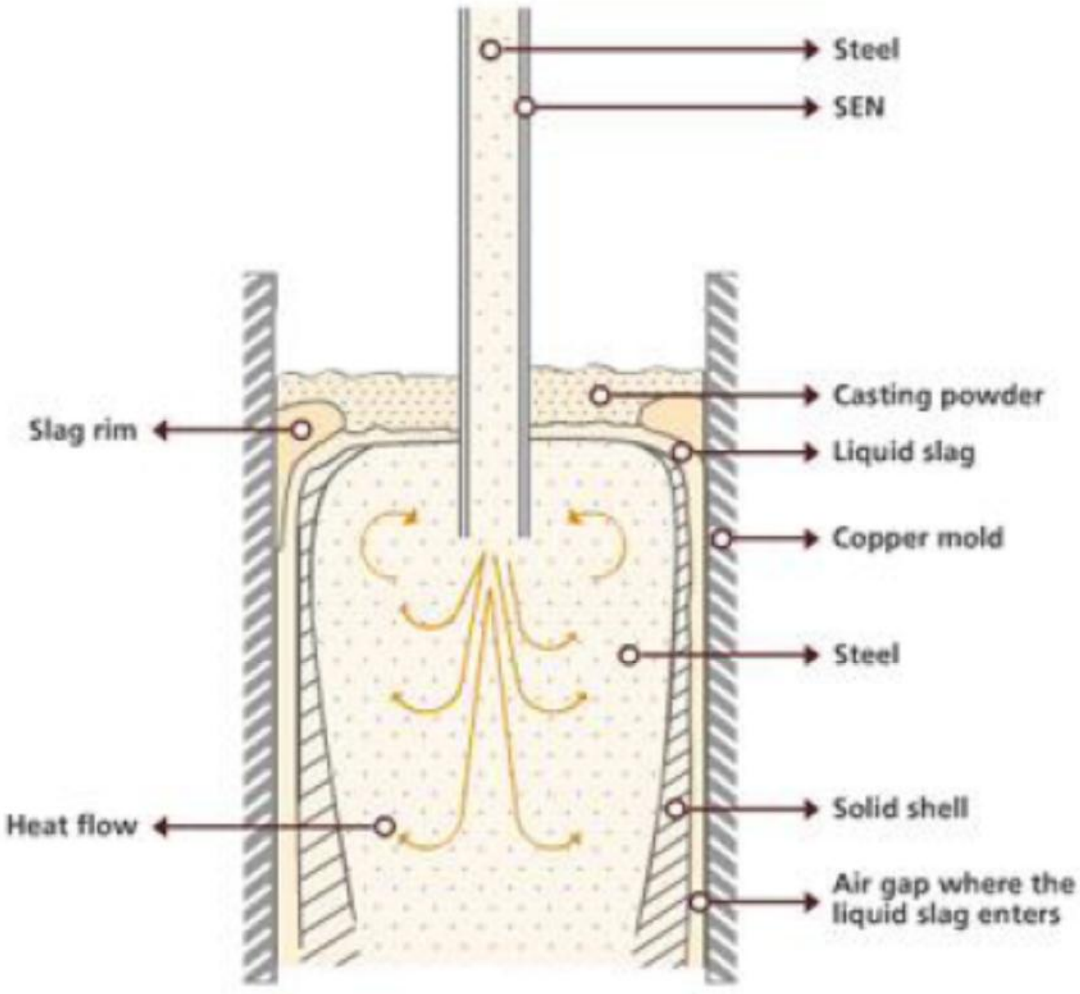


Equipment Description

Automatic Powder feeder to mould

The target is to achieve the automatic continuous addition of mold powder into the copper mould.

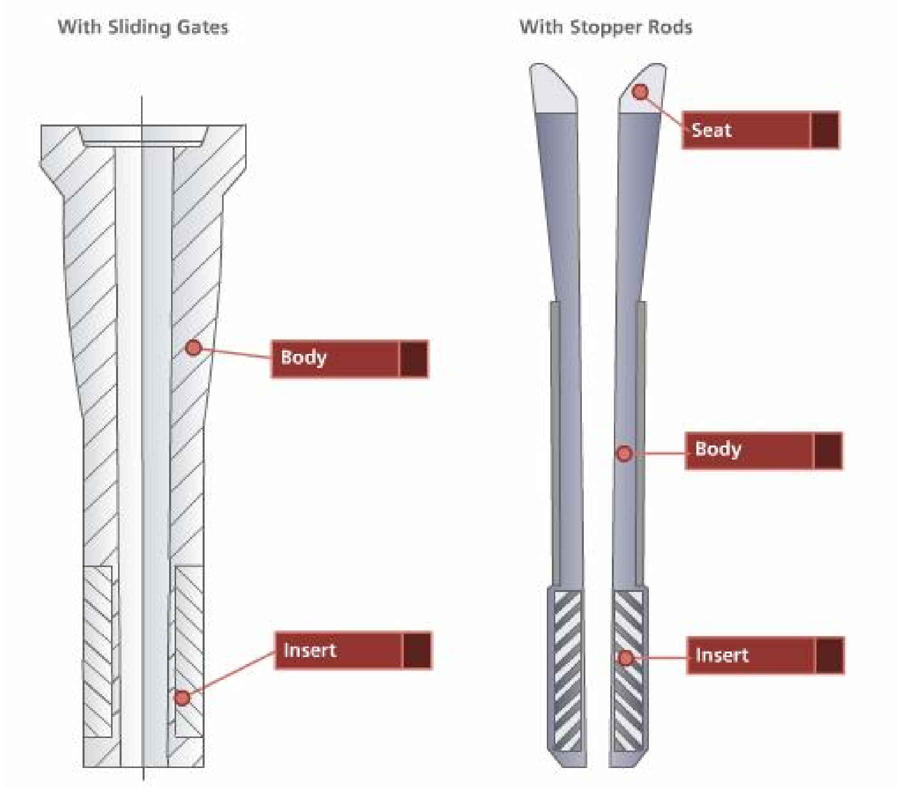
Equipment Description



Equipment Description

Submerged entry nozzle

To prevent the air and steel contact a ceramic tube known as submerged entry nozzle (SEN) is used.

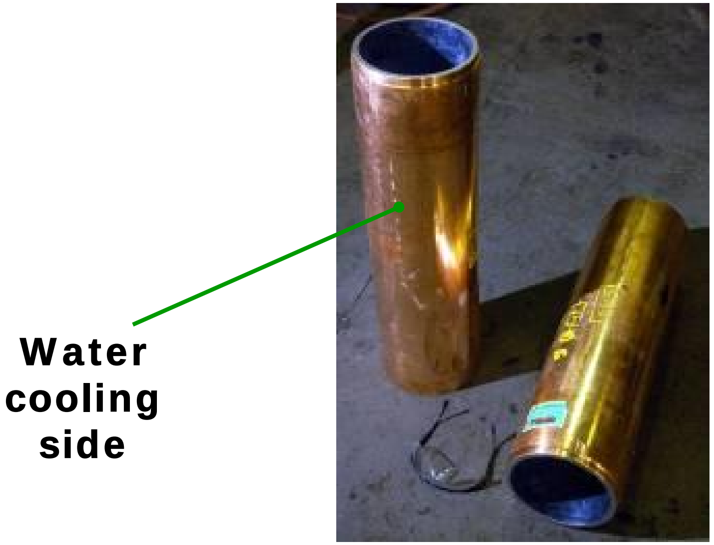


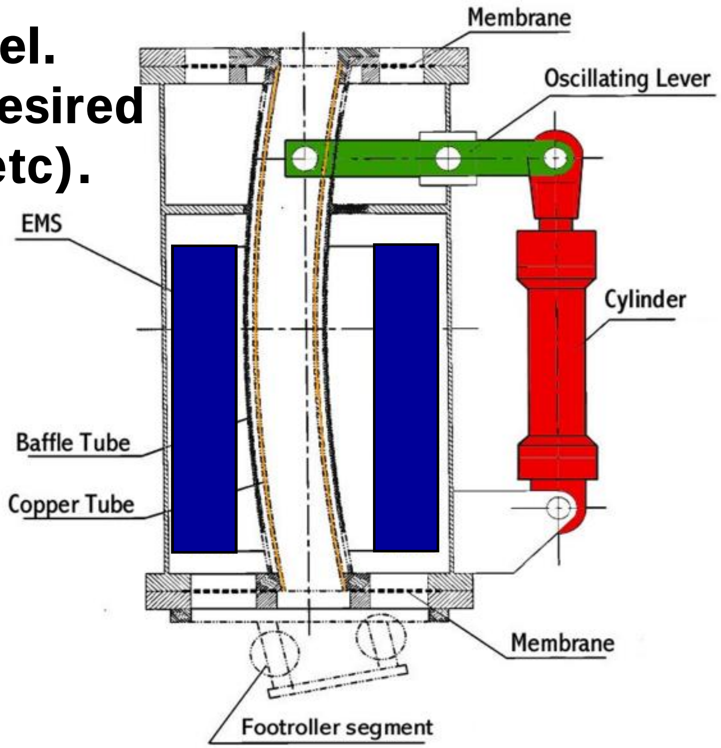
Equipment Description

Copper mould

This is the most important component of the CC. It has a double function:

- **Start the solidification of liquid steel.**
- **Supply to the solidified steel the desired shape (round, square, rectangular, etc).**

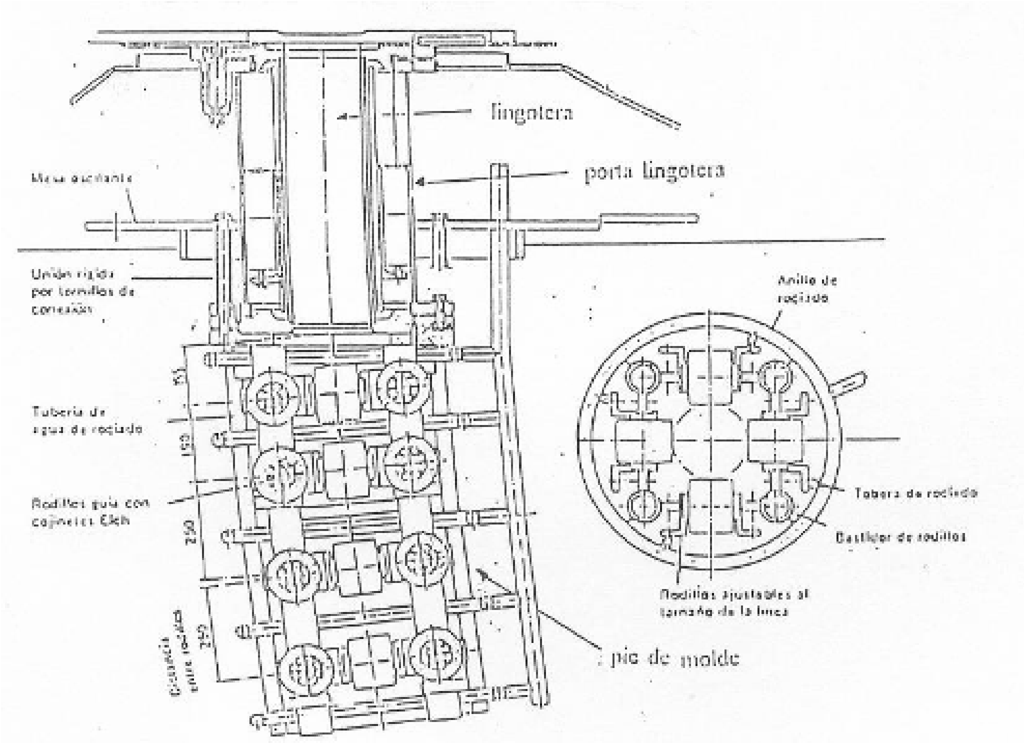




Equipment Description

1st zone of secondary cooling: Foot rolls

It is a high intensity cooling zone and water flow rate varies according to the diameter of the bar and casting speed



Equipment Description

2nd zone of secondary cooling

It is formed by a set of rolls for support and guidance, on the major radius. The cooling intensity is lower than in the first zone.

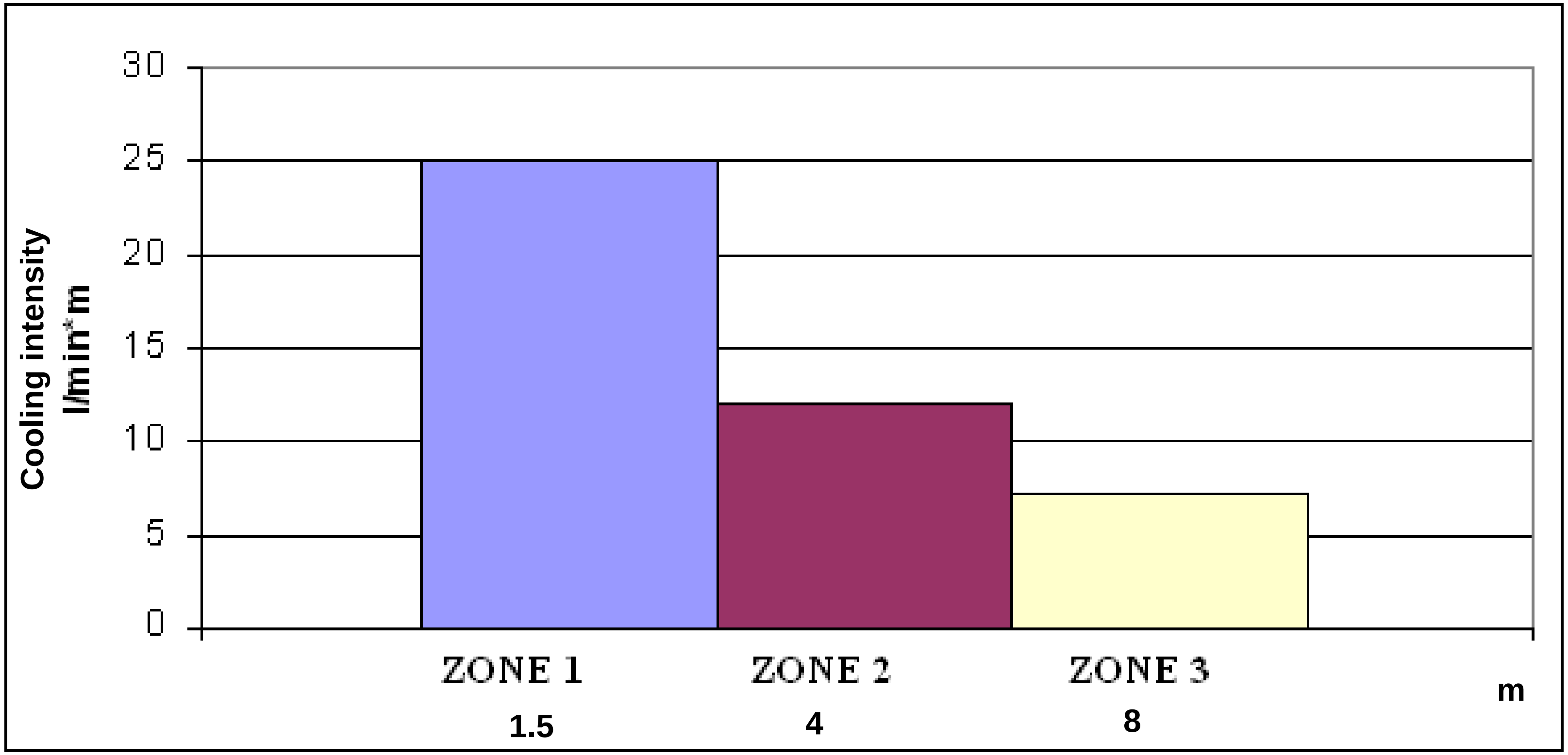
Equipment Description

3rd zone of secondary cooling

The length of this zone practically doubles the previous one. In some CCM the 3rd zone has no water cooling and the bars cool down by radiation and/or direct contact with rolls.

Equipment Description

Cooling Intensity per zone

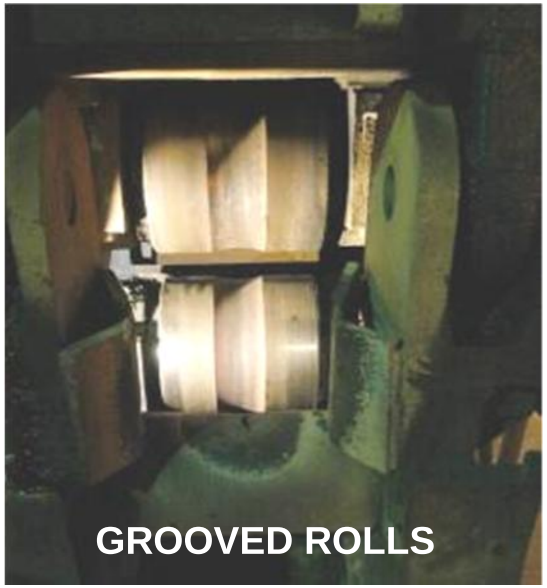


Equipment Description

Withdrawal – straightening units

They have the following functions:

- **Lift the dummy bar to the "start cast" position.**
- **Control the speed of the dummy bar during the CC start up.**
- **Control the speed of the hot continuous bar during casting.**
- **Straighten the bar from curved to straight shape (only in the case of one point of unbending).**



Equipment Description

Run out table

It transports the bars from the cutting zone to the marking (bar identification) position, and then to the cooling bed.

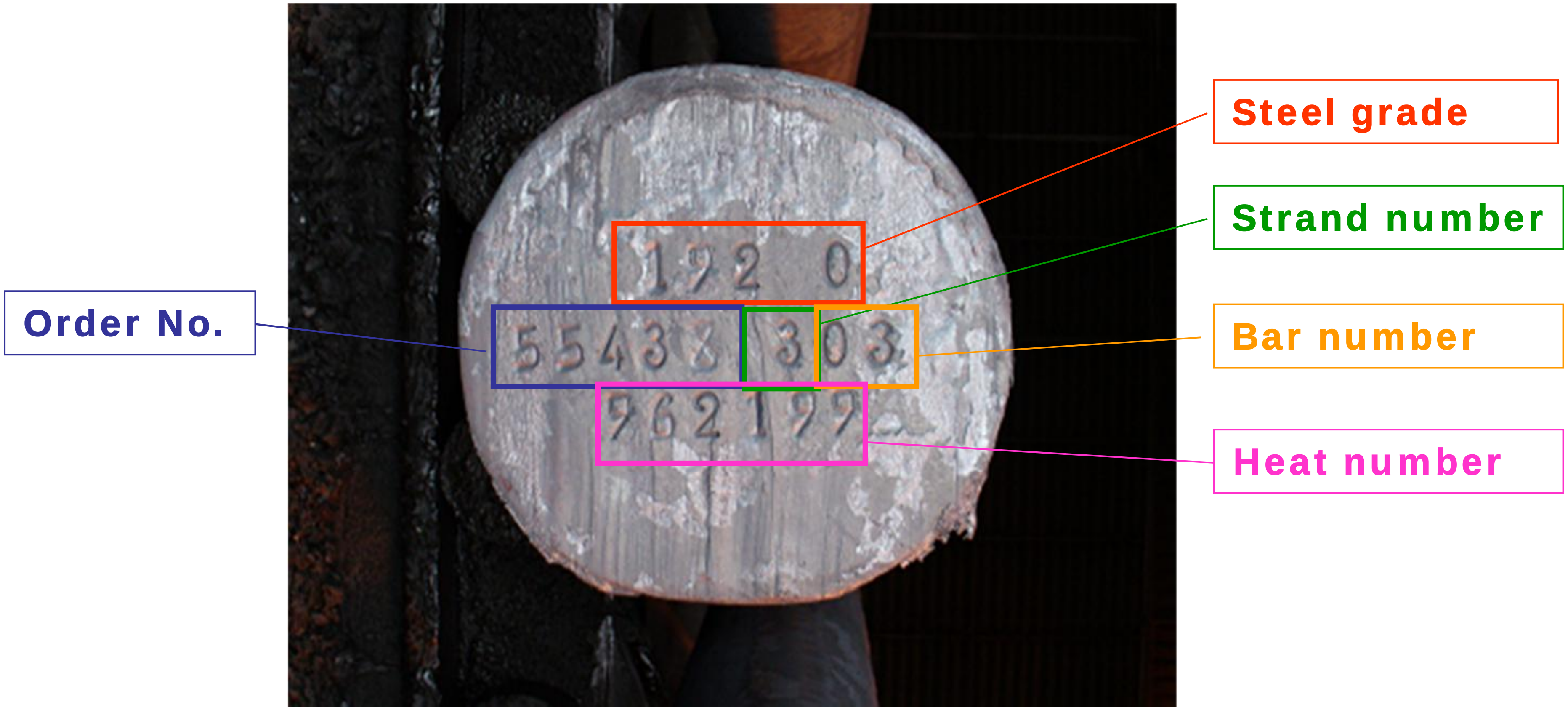
Equipment Description

Bar cutting unit

The bar cutting unit cuts the bar to specified length according to the Rolling Mill requirements.

Equipment Description

Bar Marking Machine



Equipment Description

Cooling bed

It is the last zone of the CC. along this area a gradual cooling of the bars - between 800 and 400 ºC - is obtained

Continuous Casting of Round Bars

Overview

Process Characteristics

Equipment description

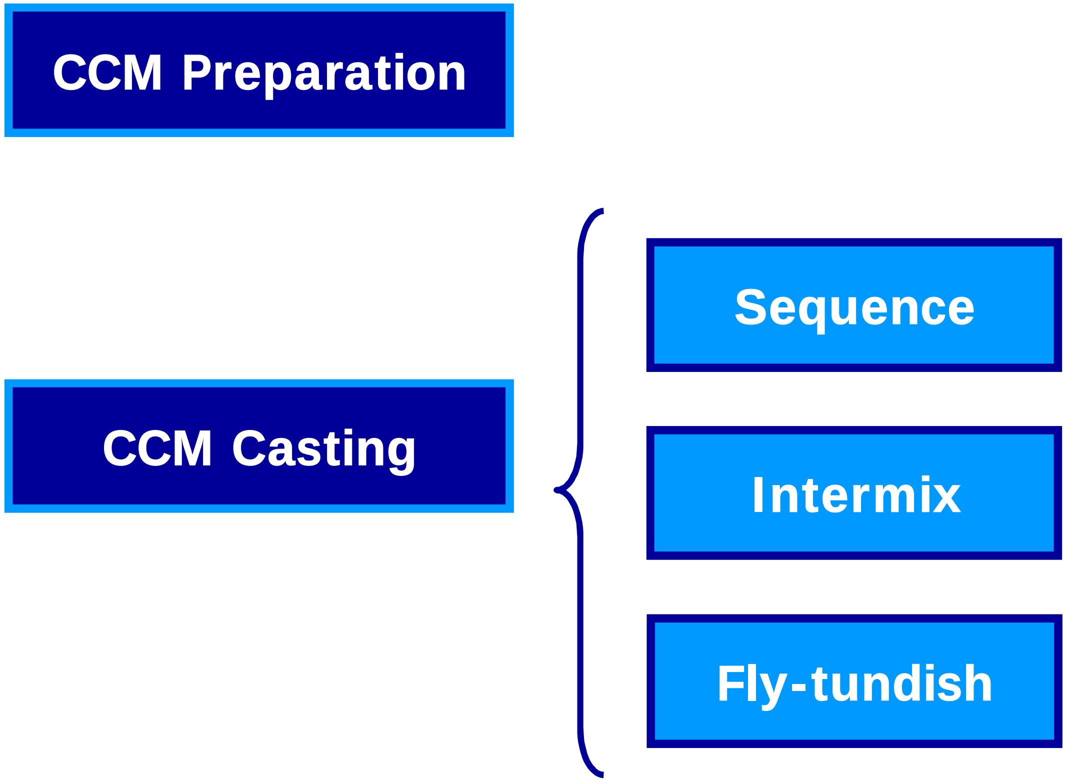
Sequence of Operation

Defectology

Charge-to-thousand

Productivity

Sequence of Operation



Sequence of Operation

CC machine preparation

They are all the operations performed from the closure of the strands of the last heat of a sequence until the start of casting the next sequence.

1. **Machine test**
2. **Tundish operations**
3. **Heating of submerged nozzles**
4. **Sealing of the dummy bar inside the copper mould**
5. **Tundish centering**
6. **Ladle operation**

Sequence of Operation

Start-up operation: dummy bar

The dummy bar is a chain like articulated steel bar which length depends directly on the CC radius. It must be long enough to cover the distance from the copper mould to the withdrawal units.

Sequence of Operation

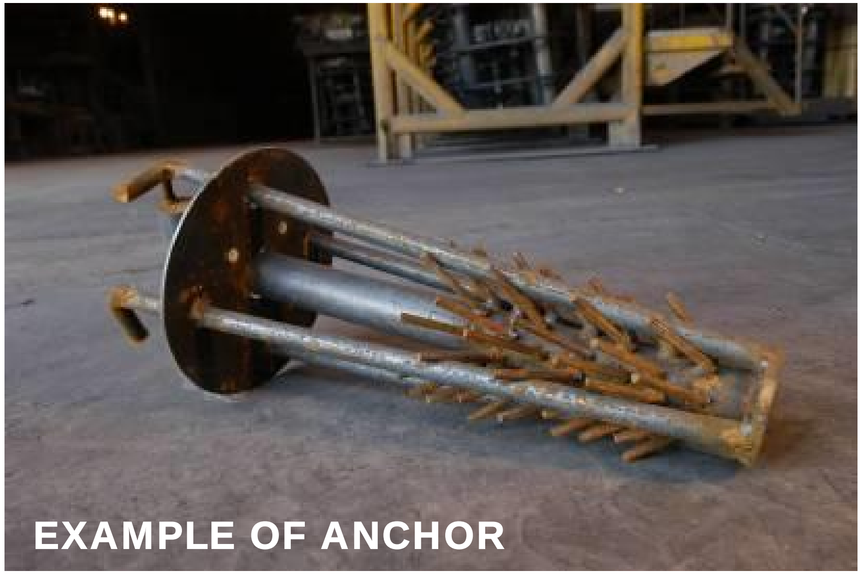
Start-up operation

1. **The dummy bar is lifted using the withdrawal units until its head enters approximately 20 cm into the mould bottom.**
2. **The space between the dummy head and the mould wall is sealed using a “sealing cord”.**

Sequence of Operation

Start-up operation

3. An anchor is linked to the dummy bar head to join it with the hot bar. Some steel pieces are placed around the link to accelerate the cooling of the first liquid steel that gets into the mould



Sequence of Operation

Start-up operation

4. The liquid steel solidifies around the anchor to form a permanent joint between the dummy bar and hot bar.

5. When the steel in the mould exceeds a certain level (submerged nozzles height) the dummy bar starts dragging the hot bar driven by the withdrawal units.

6. When the joint goes beyond the withdrawal rolls, the separation of both bars takes place (first cut) and only the hot bar remains on the strand line.

Sequence of Operation

Continuous casting

The Continuous Casting is flexible and adapts to the scheduled production of the steel mill.

- **Heats of the same steel grade in a sequence (using the same tundish)**
- **Heats of different steel grades (intermix) in a sequence (using the same tundish)**
- **Heats of different steel grades in Fly-tundish (change of tundish without restarting the machine with the dummy bar). Do not generate intermix**

Continuous Casting of Round Bars

Overview

Process Characteristics

Equipment description

Sequence of Operation

Defectology

Charge-to-thousand

Productivity

Defectology

Surface / Sub-surface Defects

Internal Defects

Dimensional Defects

Defectology

Surface / Sub-surface Defects

Internal Defects

Dimensional Defects

Defectology

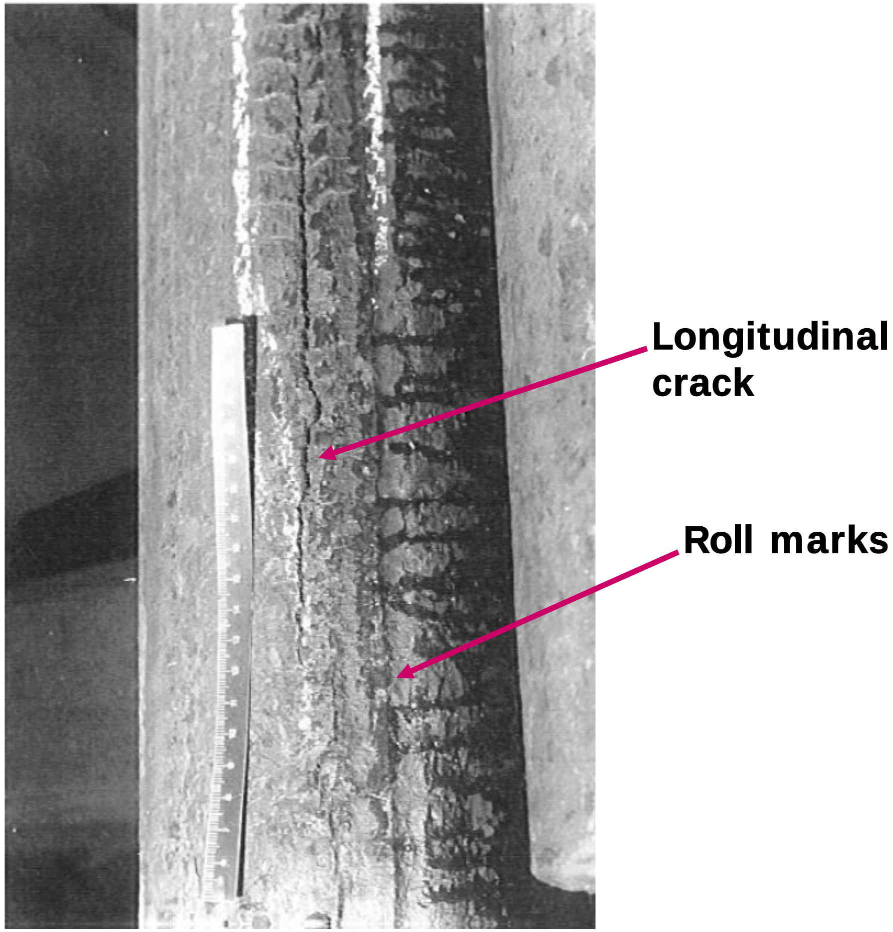
Surface and subsurface defects are those that appear in the surface of the bar and continue some millimetres under the skin. The length and depth qualifies the severity of the defect.

The main Surface or sub-surface defects are:

- **–Longitudinal cracks and depressions (BLC)**
- **–Transversal cracks (BTC)**
- **–Deep oscillation marks (BDO)**
- **–Slag entrapments in the bar (BEN)**
- **–Continuous casting interruption marks (BCI)**
- **–Cutting torch marks (BCT)**
- **–Surface pores (BPO)**

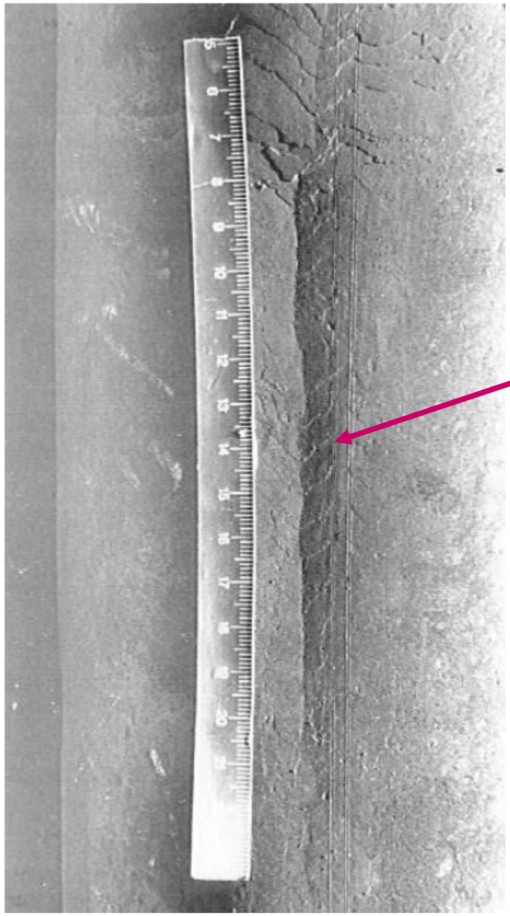
Defectology

Longitudinal crack



Defectology

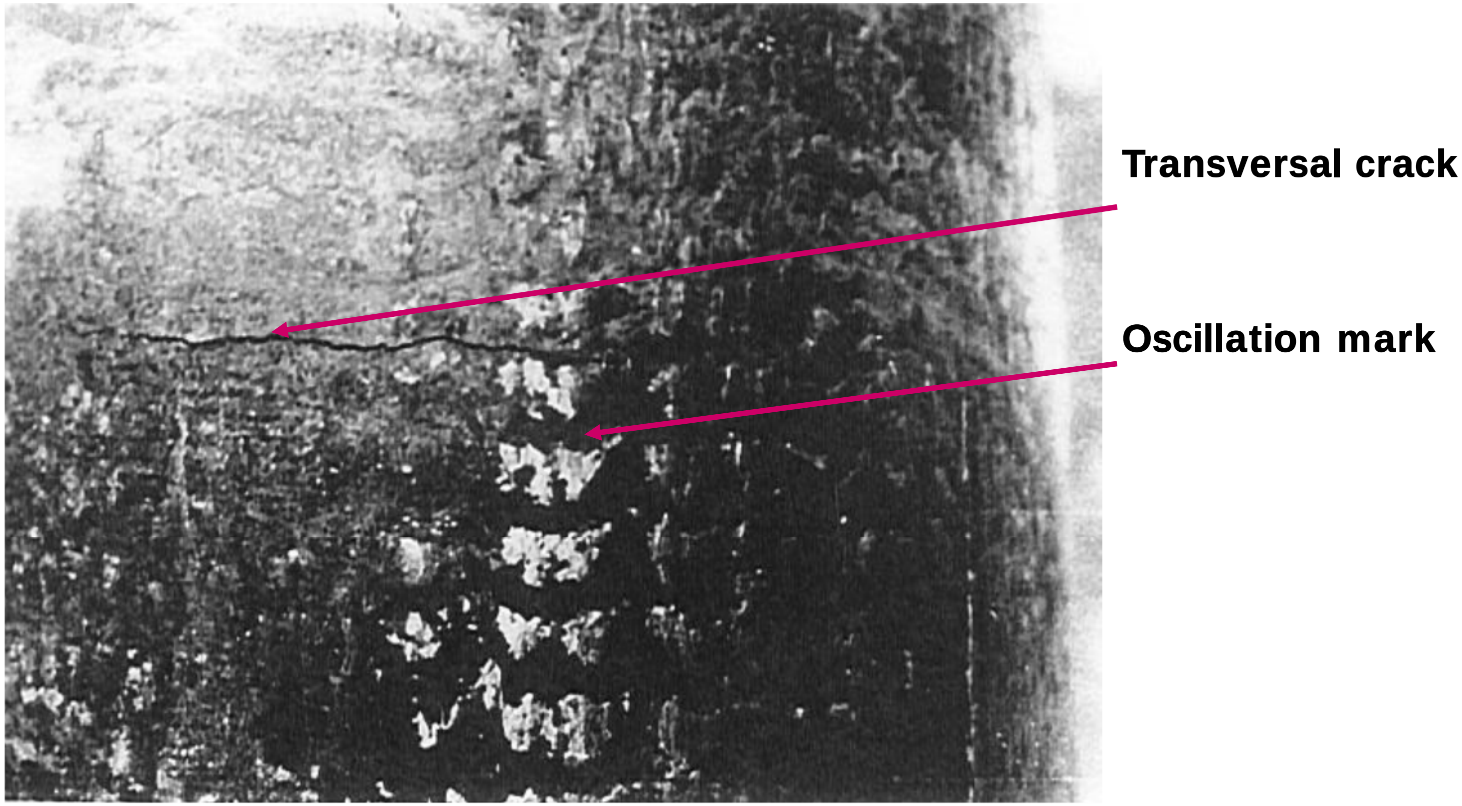
Longitudinal depression



Longitudinal depression

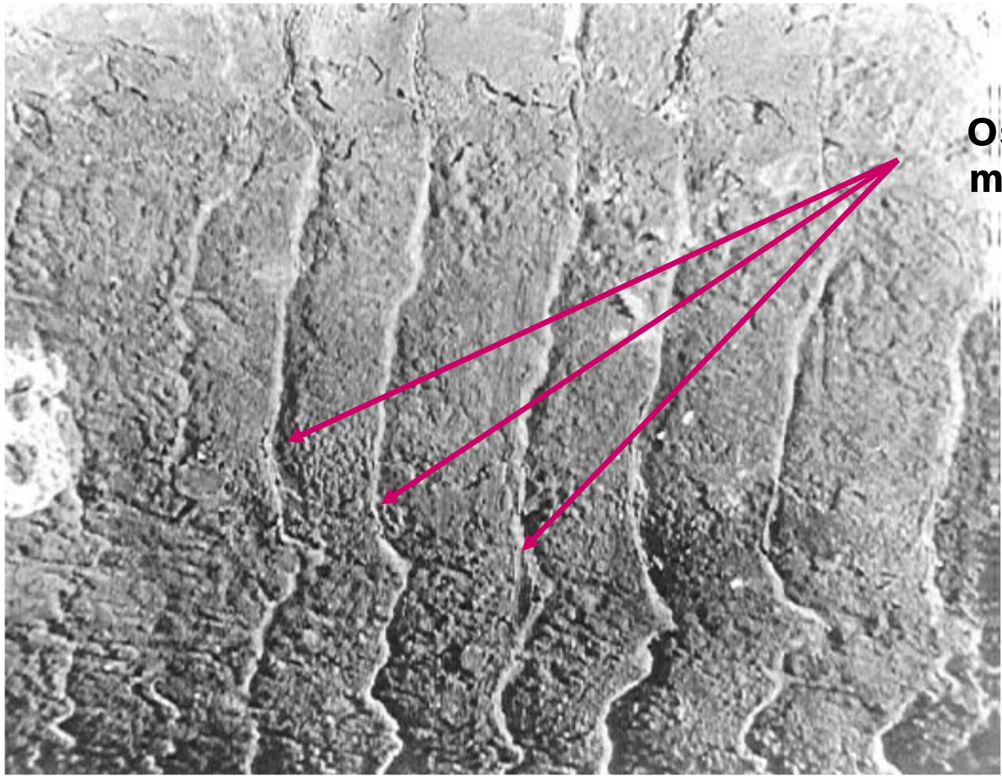
Defectology

Transveral crack



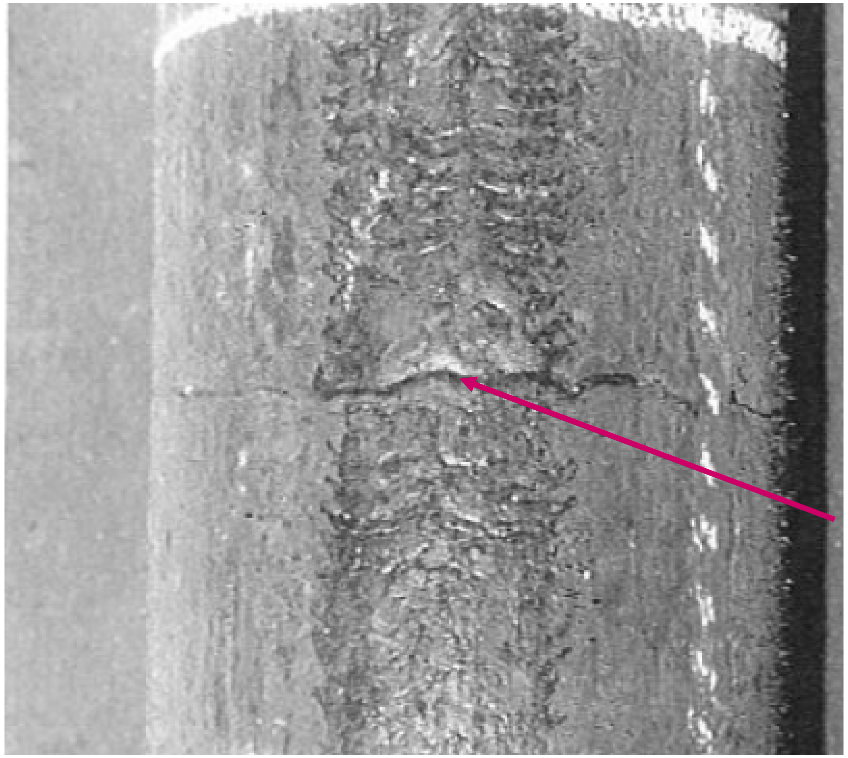
Defectology

Deep oscillation mark



Defectology

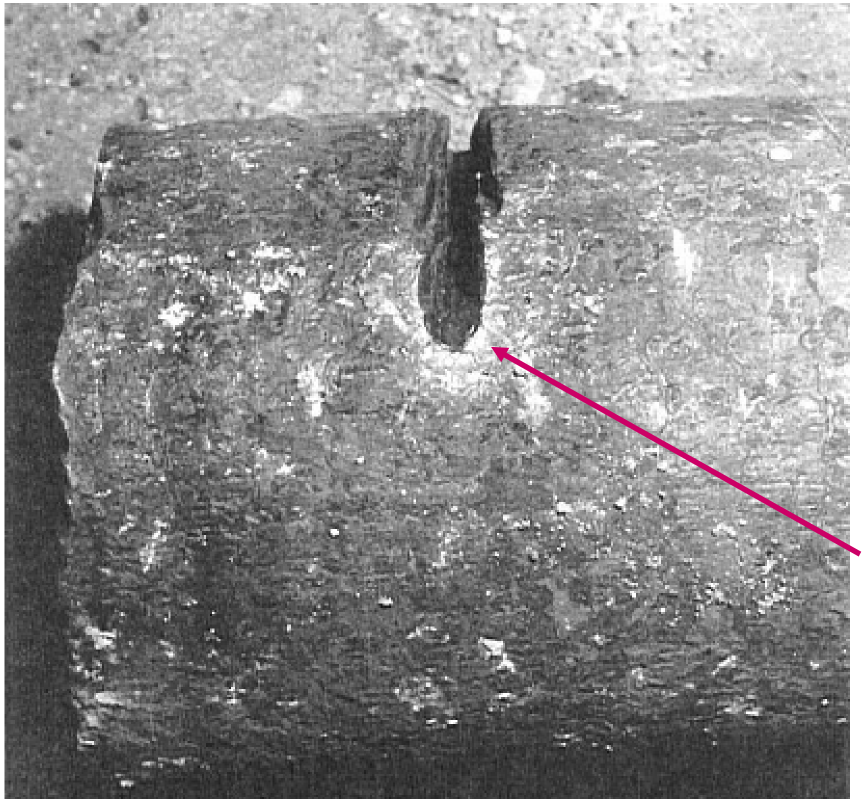
Continuous casting interruption mark



Interruption of casting

Defectology

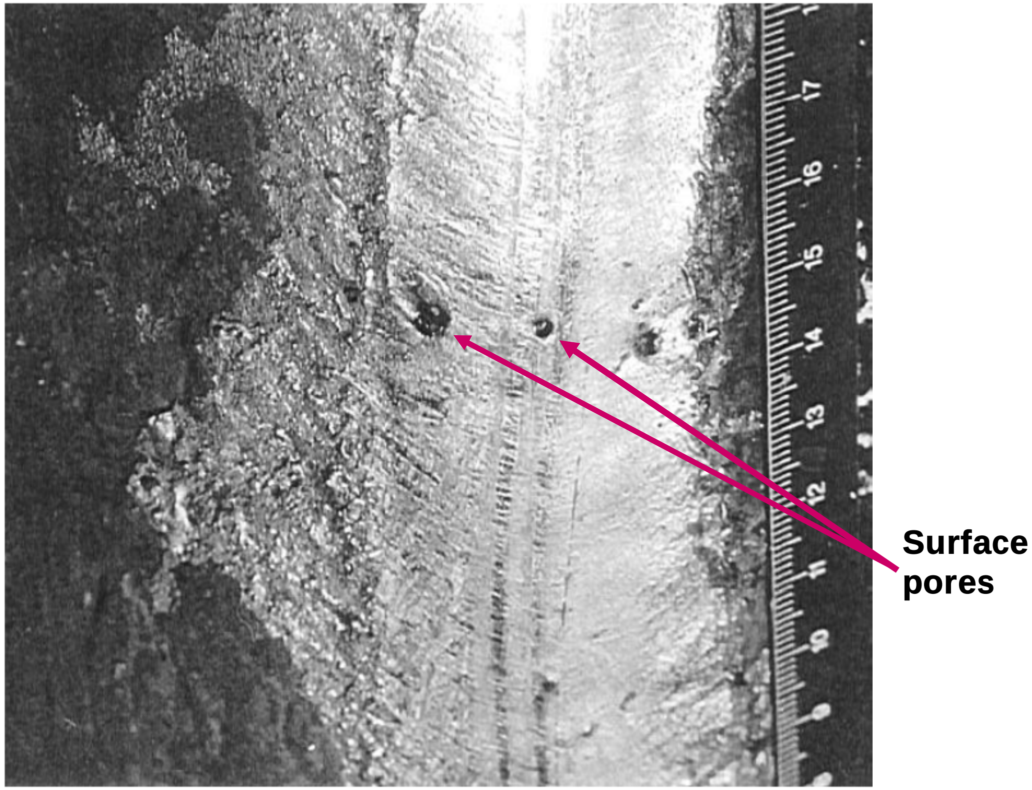
Cutting torch mark



Cutting torch mark

Defectology

Surface pores



Defectology

Surface / Sub-surface Defects

Internal Defects

Dimensional Defects

Defectology

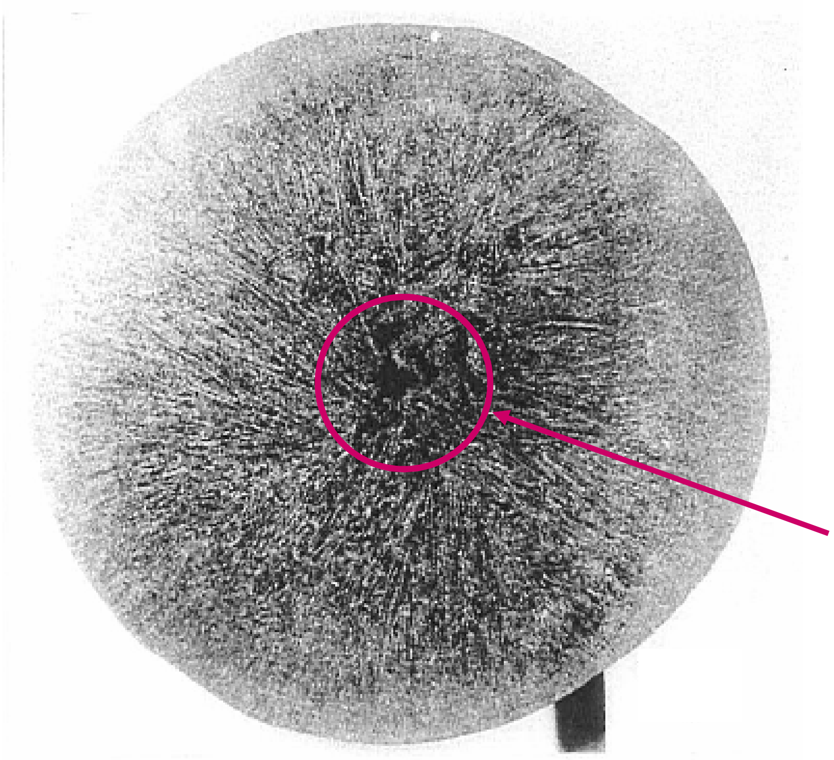
Internal defects are those found inside the bar. They are very difficult to detect unless a destructive test is performed on the bar (macroetch , Bauman test, etc).

The main Internal defects are:

- **–Bar with central porosity (BCE)**
- **–Chill Zone cracks (BCH)**
- **–Halfway cracks (BHW)**
- **–Centerline cracks (BCC)**
- **–Bars with macroinclusions (BIN)**

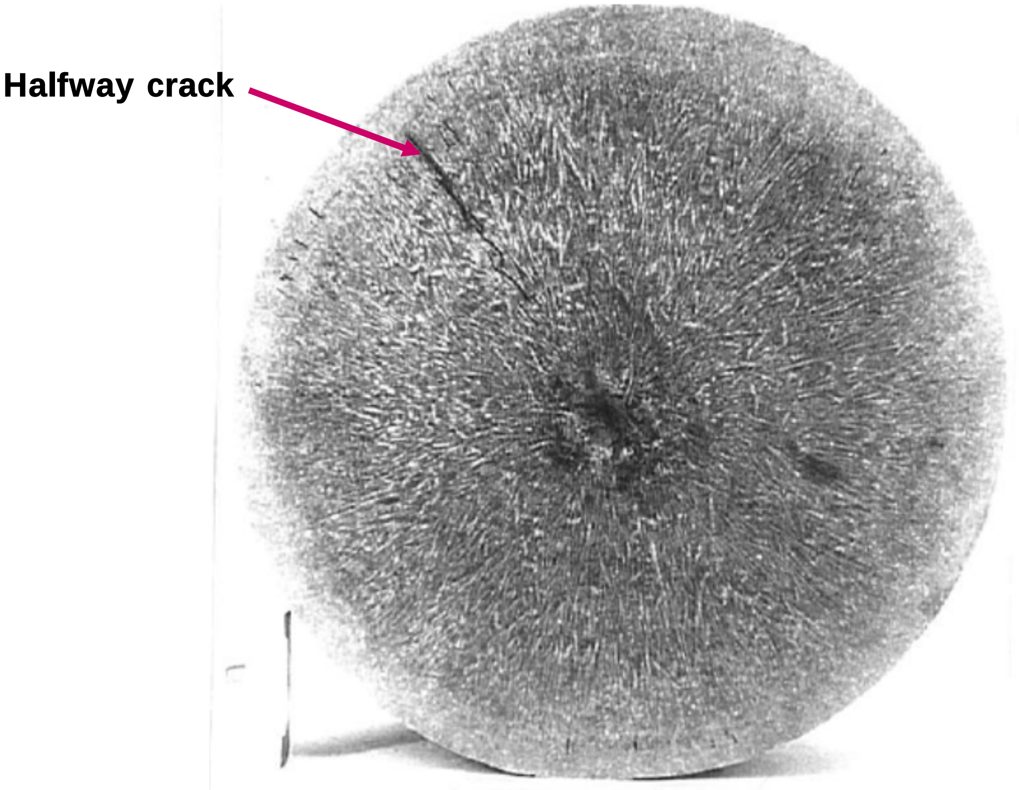
Defectology

Central porosity



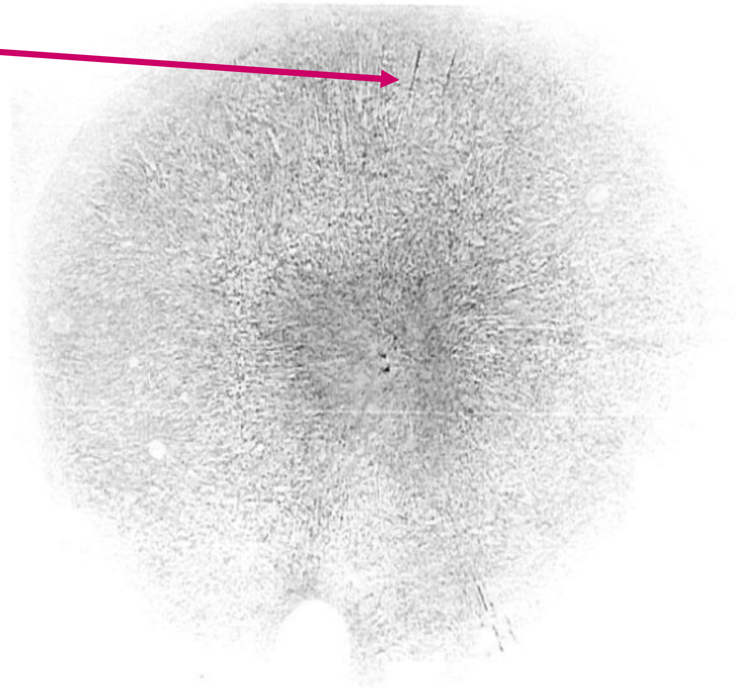
Defectology

Halfway crack



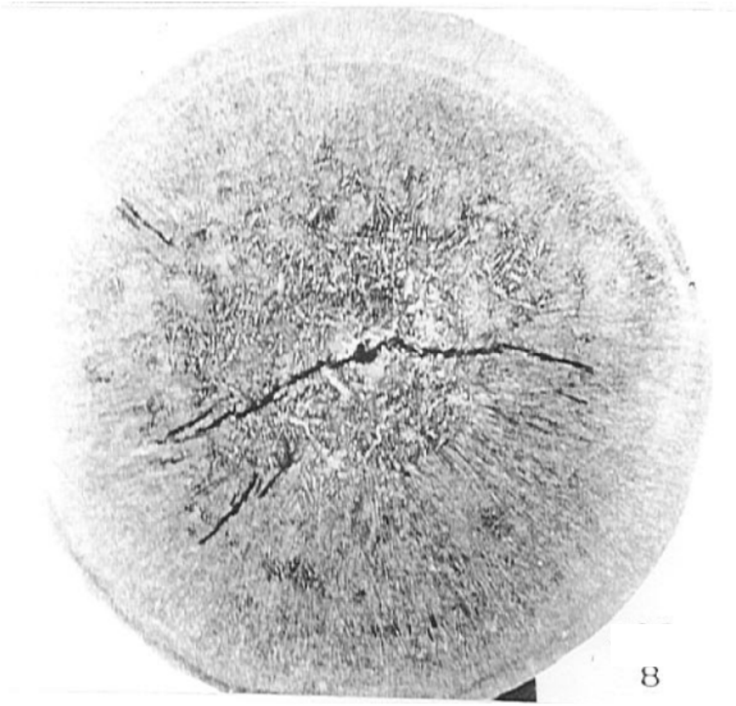
Defectology

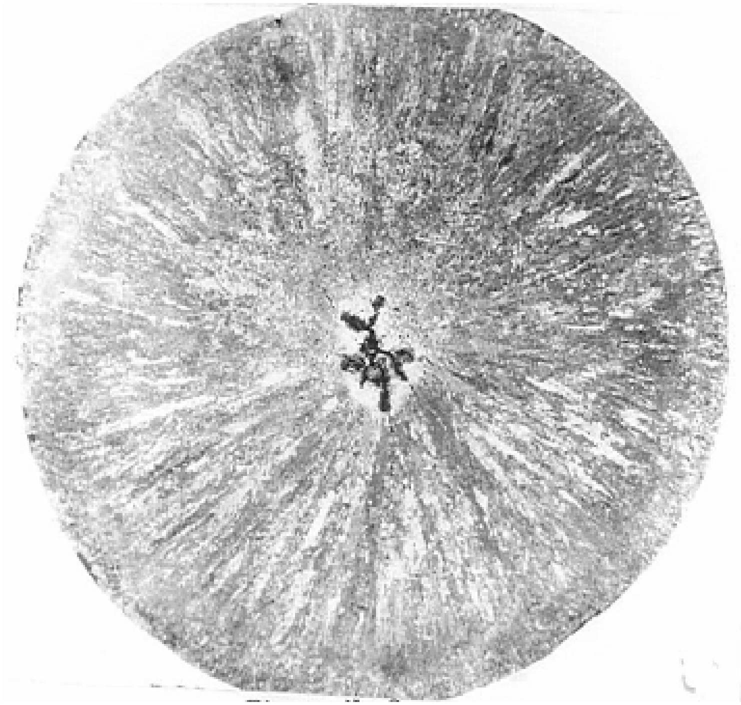
Chill zone crack



Defectology

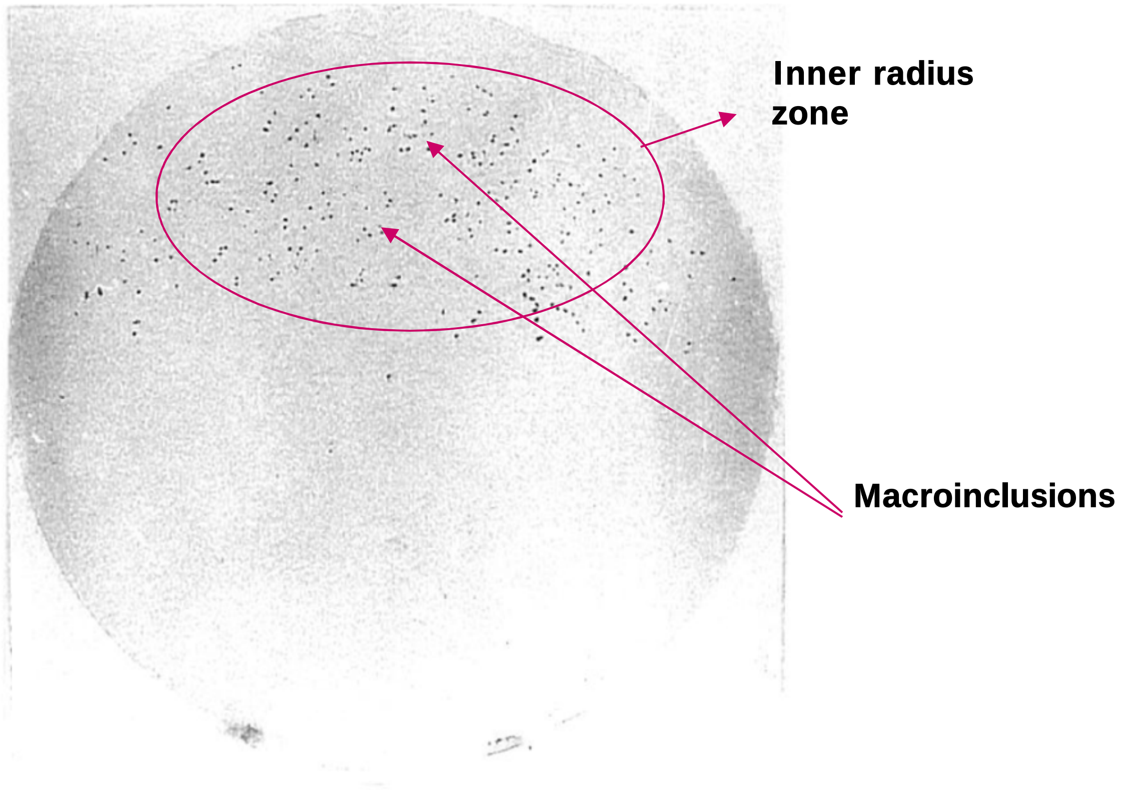
Centerline crack





Defectology

Macroinclusions



Defectology

Surface / Sub-surface Defects

Internal Defects

Dimensional Defects

Defectology

Dimensional defects are those that change the standard dimensions and shapes of an specific bar size.

Most of these defects are detected by simple visual inspection.

The main Dimensional defects are:

- **–Ovalization**
- **–Withdrawing roll marks**
- **–Bar length out of specification**
- **–Twisted or bent bars**
- **–Bars with diameters larger than scheduled**

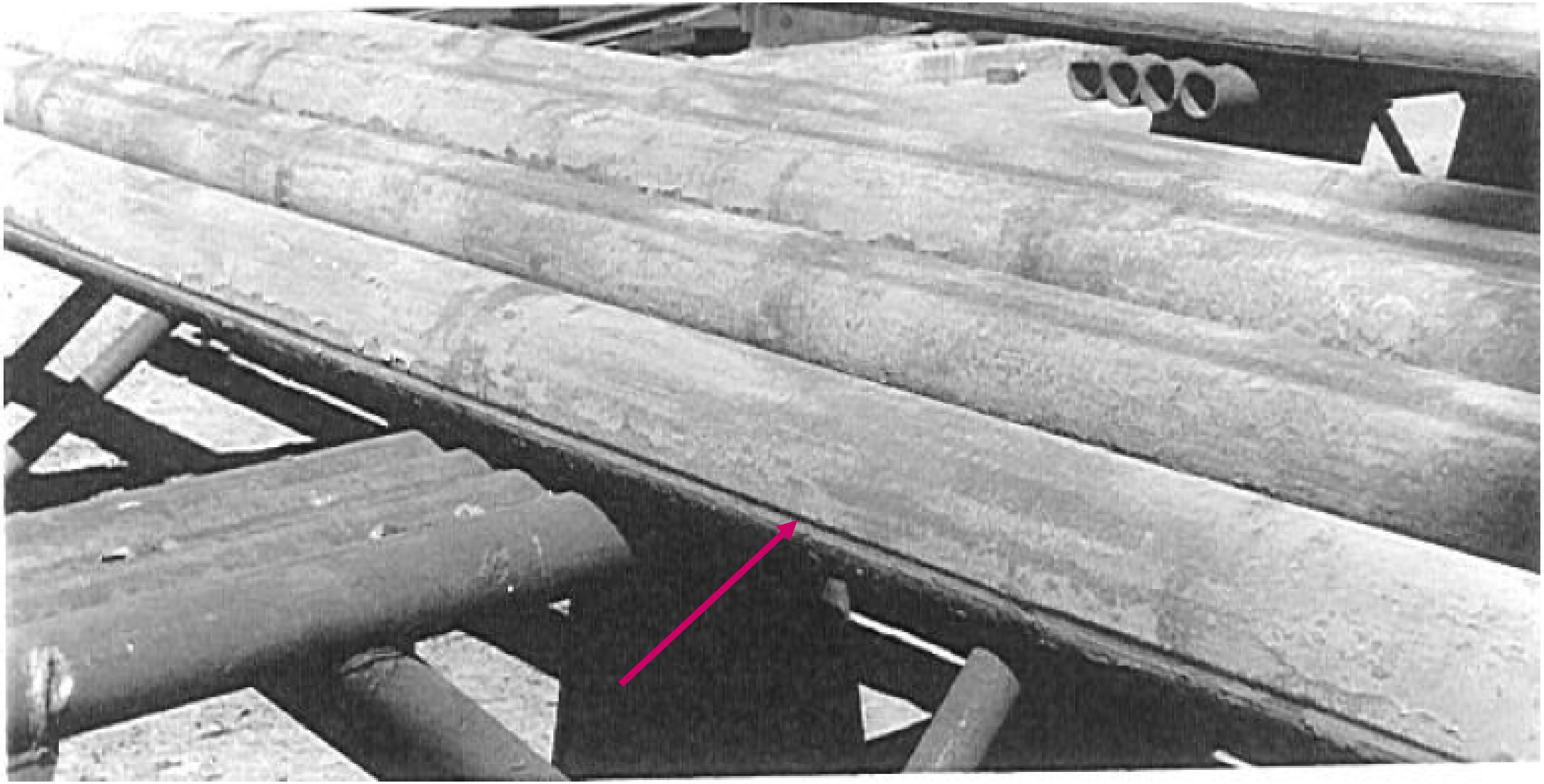
Defectology

Oval bar

Ovalization 11.6%

Defectology

Mechanical mark



Continuous Casting of Round Bars

Overview

Process Characteristics

Equipment description

Sequence of Operation

Defectology

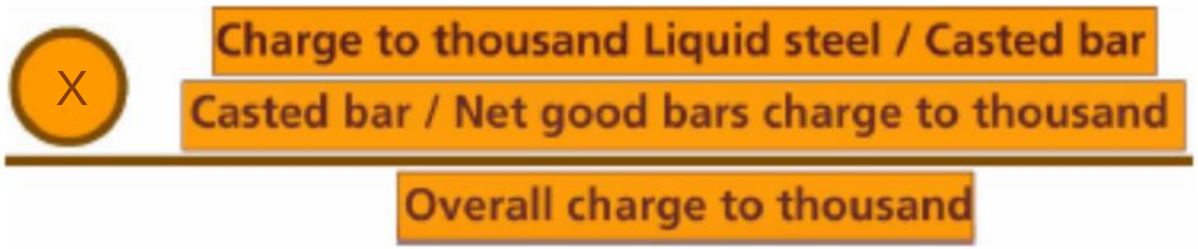
Charge-to-thousand

Productivity

Charge-to-thousand

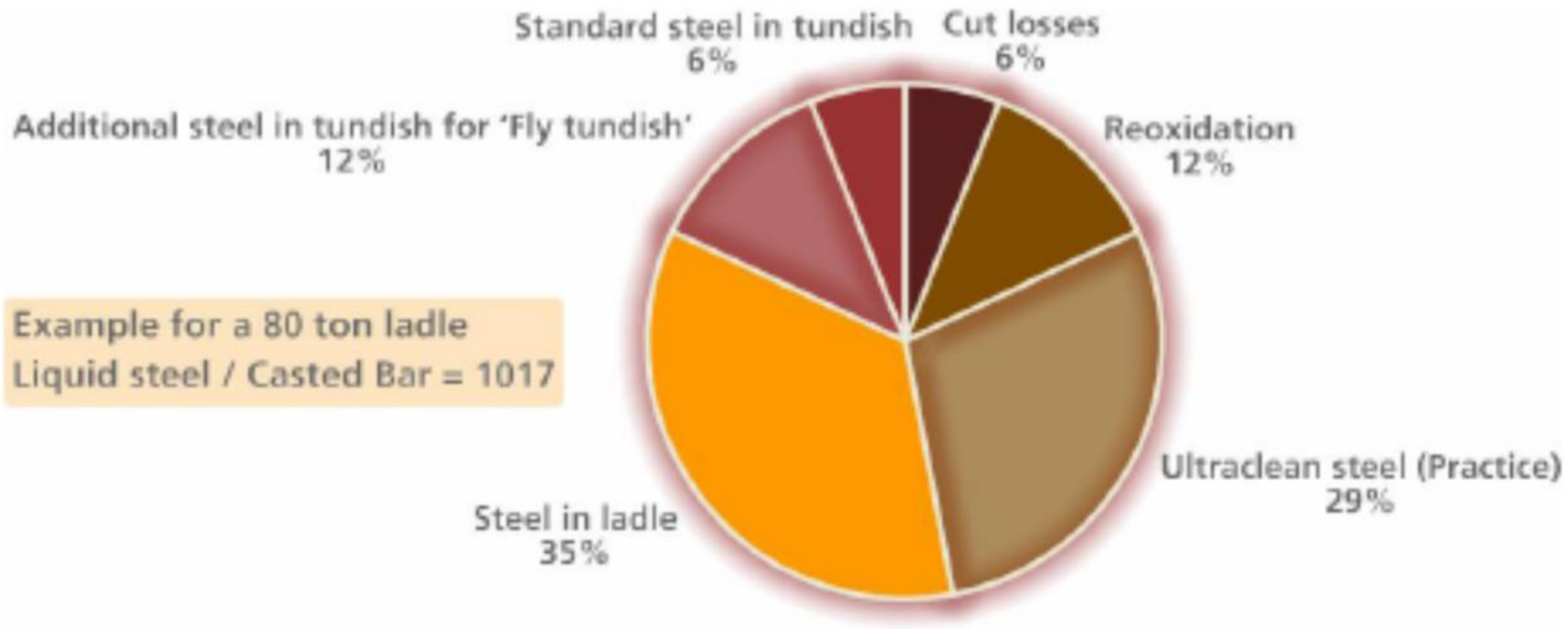
The concepts 'metallic yield' and/or 'charge-to-thousand' are related to the capacity of the CC to transform the liquid steel into bars, that meet rolling specification.

Part of the total liquid steel in the ladle is lost during casting operation. These losses are divided into two groups:



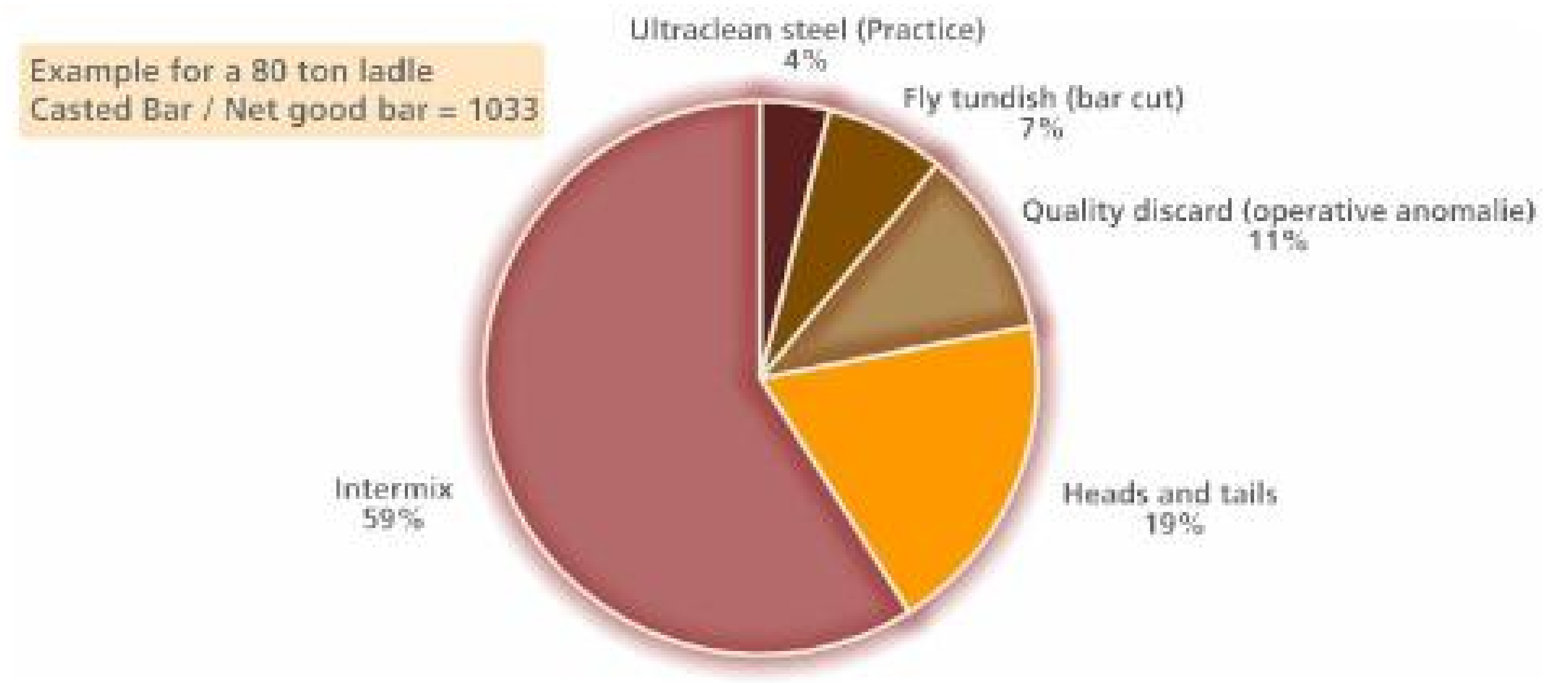
Charge-to-thousand

Liquid steel / Casted bar



Charge-to-thousand

Casted bar / Net Good bar



Continuous Casting of Round Bars

Overview

Process Characteristics

Equipment description

Sequence of Operation

Defectology

Charge-to-thousand

Productivity

Productivity

This parameter quantifies the tons of bars cast per hr. of operation (ton/hs). It is affected by several factors:

- **Internal factors, originated in the caster**
  - **Size of the bar in operation (caliber)**
  - **Losses of the sequence**
- **External factors, originated in other stage of the production line**
  - **Steel Temperature / Casting speed**
  - **Castability**

Productivity

1. Variation of productivity due to the effect of the bar size

	Bar diameter	Steel grade	Max. Casting speed	Metric weight of the bar
a	148 mm	600	3.0 m / min	132 kg / m
b	170 mm	600	2.6 m / min	175 kg / m

Productivity (tn / h) = casting speed ▪ metric weight ▪ number of strands ▪ 60 min

a) **Productivity = 3 m/min ▪ 132 kg/m ▪ 4 strands ▪ 60 min = 95 tn / h**

b) **Productivity = 2.6 m/min ▪ 175 kg/m ▪ 4 strands ▪ 60 min = 109 tn / h**

Productivity

2. Variation of productivity due to the number of strands in operation (strand losses)

Productivity (tn/h) = casting speed · metric weight · number of strands · 60 min

Bar diameter 170 mm

b.1) Productivity = 2.6 m/min · 175 kg/m · 4 strands · 60 min = **109 tn/h**

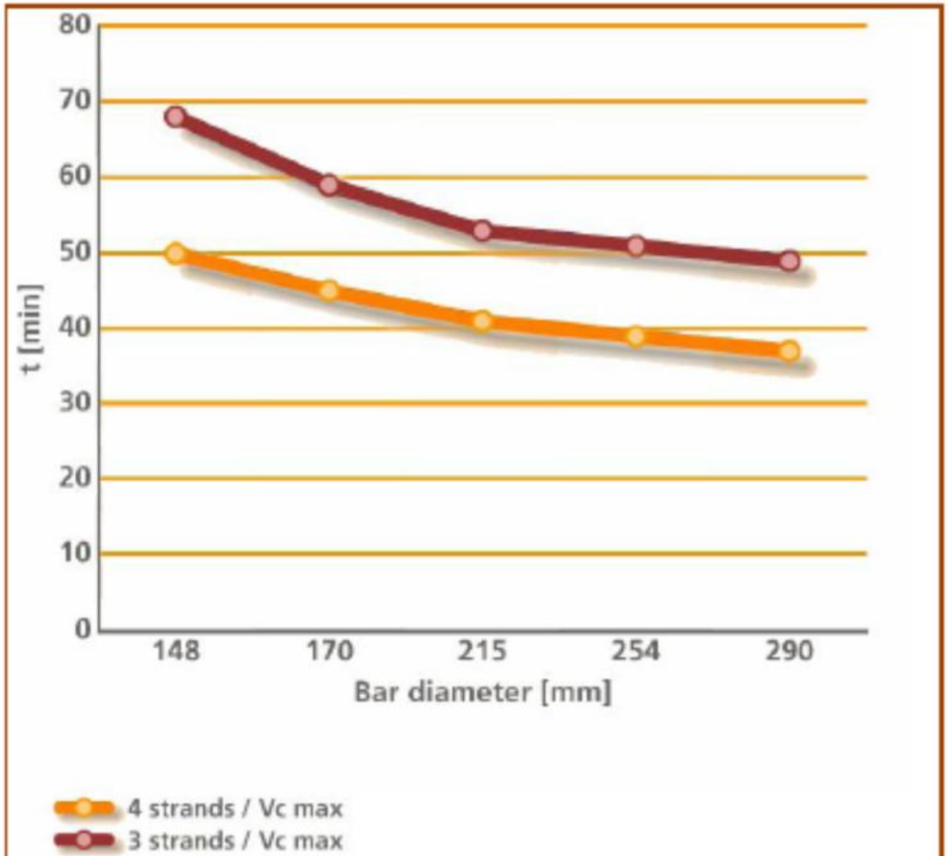
b.2) Productivity = 2.6 m/min · 175 kg/m · 3 strands · 60 min = **82 tn/h**

3. Variation of productivity due to casting speed

b.1) Productivity = 2.6 m/min · 175 kg/m · 4 strands · 60 min = **109 tn/h**

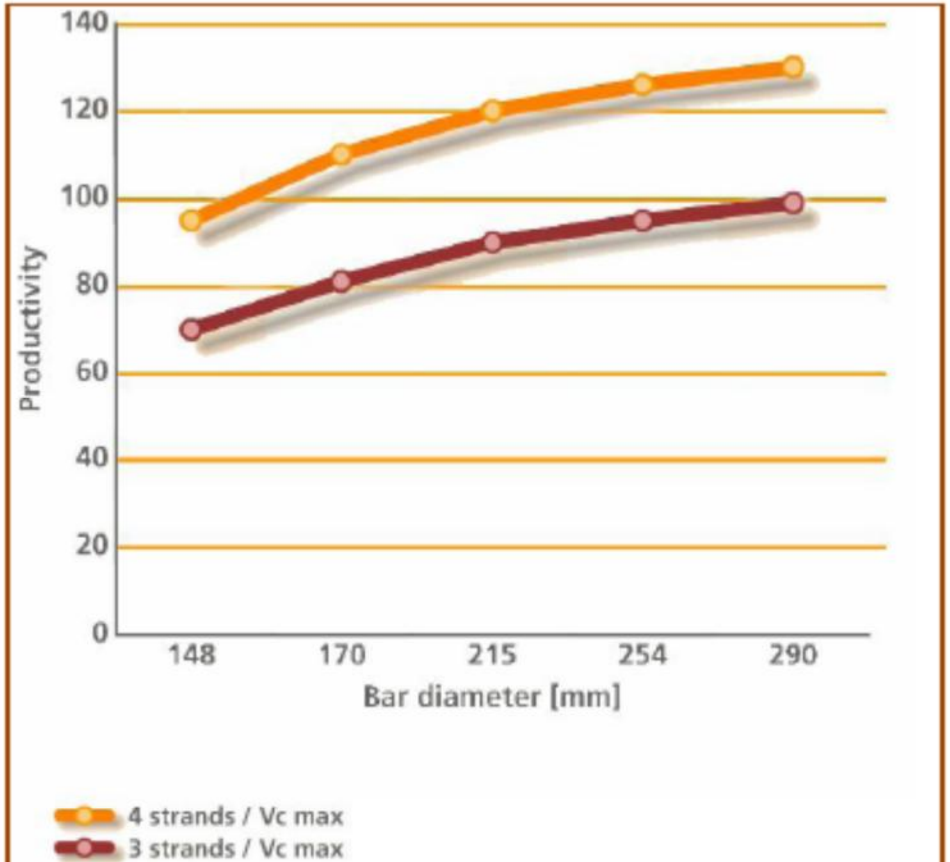
b.2) Productivity = 1.6 m/min · 175 kg/m · 4 strands · 60 min = **67 tn/h**

Productivity



Bar diameter	Vc MAX [m/min]
148	3
170	2,6
215	1,75
254	1,3
290	1,05

Casting time



Bar diameter	Vc MAX [m/min]
148	3
170	2,6
215	1,75
254	1,3
290	1,05

Productivity

Tenaris Casters

	Dalmine		Siderca		Tamsa	Donasid
Ladle capacity tn	100		84		160	100
Steel in Ladle, tn	std 95 VD 89		81		std 160 VD 146	90
Number of Strands	4		4		5	3
Bar diameter, mm	320 - 370 – 395	148-180-225 - 330	148-170-215	215 – 254 – 290 - 310	215 – 270 – 310 – 330 - 370	148 – 180 – 225 - 270
Design	Vertical CC1	Curved CC2	Curved CC2	Curved CC3	Curved	Curved

Tenaris Casters

		Dalmine CC1	Dalmine CC2	Siderca CC2	Siderca CC3	Tamsa	Donasid
Tundish	Capacity, tn	18	18	12	14	38	14
	Shape	T	T	rectang	rectang	T	T
	Dams - baffles	Anti-turbulence pad	Anti-turbulence pad	baffles with oriented holes	baffles with oriented holes	Anti-turbulence pad	Anti-turbulence pad
	Flow control	Stopper rod	Stopper rod	Stopper rod	Stopper rod	Stopper rod	Stopper rod
Mold	Oscillator	mechanic	Hydraulic	mechanic	Hydraulic	Hydraulic	Mechanic
	Level control	radioactive					
Secondary cooling		water spray cooling					

Many Thanks.

Nr.	ISTE-C139
Revision	01
Effective Date	12/20/2018

TenarisUniversity

Instructor Presentation – Steelmaking for Non-Specialist

Created by: Debora Taullard Revised by: Carlos Cicutti Approved by: Marcelo Romani

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