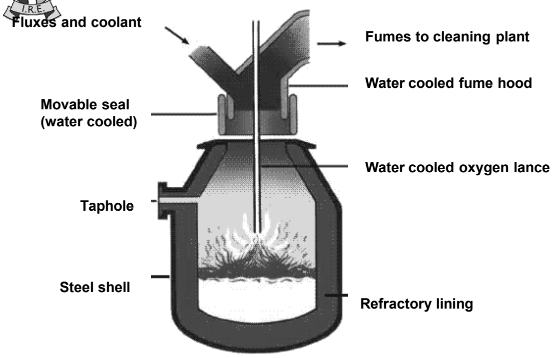
Institute of Refractories Engineers

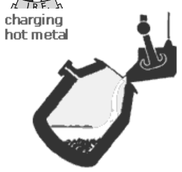
PRIMARY STEELMAKING REFRACTORIES

Training Day 2010
Rotherham

Primary Steelmaking: BOS Vessel



BOS Vessel sequence of operation: Charging



After the steel scrap has been charged, three or four times as much hot metal is poured into the vessel from a ladle.

The hot metal Si content has an major influence on the addition of lime and therefore on the amount of slag in the converter.

Hot metal analysis: typical

C [%]	Si [%]	Mn [%]	P [%]	S [%]	O_2 [%]
4.2 – 4.5	0.2 – 1.2	0.2 – 0.5	0.05 – 0.13	0.01 – 0.07	----
Temperature [°C]:	1340 - 1380				

BOS Vessel sequence of operation: Blowing

After charging, the vessel is blown by blasting oxygen through a water cooled lance that is lowered into the converter.

Basic Oxygen Furnace
Sequence of operation : Tapping

After the blow has continued for about 20 minutes, the metal is sampled by means of a sub-lance system that allows analysis with a minimum of operational interuption

A typical composition at this stage can be seen below.

The BOS process is now complete and the converter can be tapped. Steel run out via the taphole into a ladle, separating it from the lighter slag.

Crude steel analysis: typical

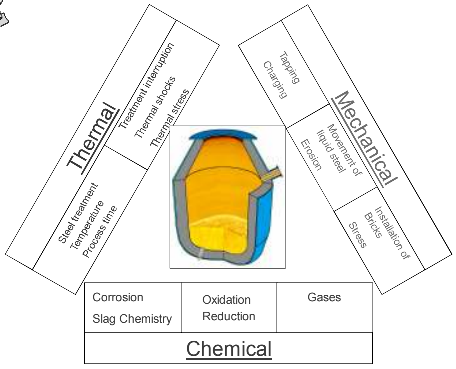
C [%]	Si [%]	Mn [%]	P [%]	S [%]	O_2 [ppm]
< 0.02	0	0.1 – 0.4	0.01 – 0.02	0.01 – 0.05	400 - 1000
Temperature [°C]:	1600 - 1760				

Recap: Wear processes

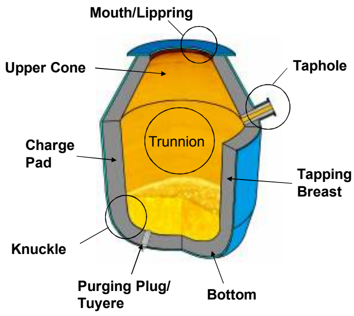
In the Steelplant:

- Erosion:
  - From molten metal (Iron/Steel); e.g. during tapping, stirring
  - From gases/dust; e.g. fume off-take systems
- Corrosion:
  - From process slags; e.g. working lining brick 'dissolving' in the process slags
  - From corrosive gases
- Thermal Shock:
  - Caused by very rapid changes in temperature
  - e.g. Tuyere elements in a BOS converter cooling the local brickwork

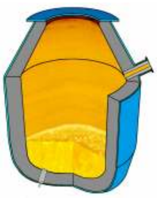
BOS vessel refractories: Main wear mechanisms



BOS Vessel Refractories: Lining Primary Zones



BOS Vessel Refractories: Lining Operational Stresses

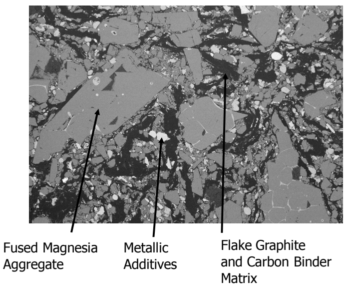


- Mouth/Lipring: May require frequent deskulling which can lead to mechanical damage and destabilisation of the brickwork
- Taphole: Erosion from liquid steel flow during the tapping operation
- Tapping Breast: Slag corrosion and vortex erosion
- Knuckle: If a ramming joint is applied this can be weaker than the surrounding brickworks and suffer preferential erosion
- Tuyere: Thermal shock and gas erosion effects due to introduction of inert gas under pressure
- Charge Pad: Mechanical damage due to charging of hot metal and scrap
- Trunnions: Deformation stresses due to rotation of the vessel during operation and oxidation due to lack of slag cover

Refractory Application in BOS Vessel

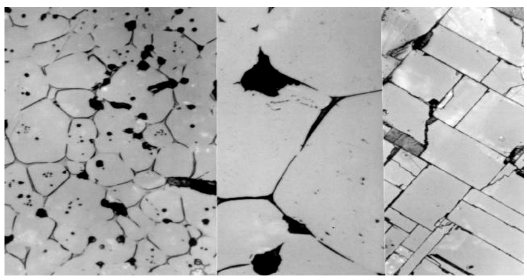
- **Basic Chemical Environment – therefore Basic product application**
- **Primary product type applied**
  – MAGNESIA CARBON BRICK
- Advantages:
  - High corrosion resistance to basis slag chemistries
  - Good high temperature strength therefore high resistance to high temperature erosive processes
  - Carbon matrix gives resistance to slag infiltration and high thermal shock resistance (due to high thermal conductivity
- Disadvatages:
  - Carbon matrix can be oxidised by gaseous O2 in the BOS process and due to reaction with easily reducible oxides in the primary steelmaking slag (e.g. FeO)
  - Corrosion resistance lowers rapidly if the lime:silica ratio of the slag becomes less than 1.5

Magnesia Carbon Bricks



- Magnesia carbon bricks are manufactured from high purity sintered or fused magnesia aggregates in combination with up to 15% (by weight) carbon, normally in the form of natural flake graphite.
- A carbonaceous system such as pitch or phenolic resin is used as a binder; the binder forms a solid carbon relic on pyrolysis.
- Antioxidant metals such as Al, Mg or Si may be added to protect the carbon from burning out during use. Reaction products from these metals have the added benefit of improving the high temperature strength of the material.

Magnesia Aggregate- Qualities



Sintered Magnesia 50-70 Microns | **Polycrystalline fused 400-600 Microns** | **Monocrystalline Fused >600 Microns**

BOS Vessel Refractories
Quality Zoning – Performance Optimisation

Wear Process	Bottom	Tuyere Surround	Knuckle	Charge Pad	Trunnions & Slagline	Tapping breast & Vortex	Cone
Corrosion	+	+	++	+	+++	+++++	+
Oxidation	+	+	+	++	+++	++++	+++
Thermal	+	++++	+++*	+	++	++++*	+
Erosion	+	+++++	+++	++++	++	+++	++

* Depends on construction type

BOS Vessel Refractories
Quality Zoning – Performance Optimisation

Wear Process	Carbon Level Increase	Magnesia Purity Increase	Fused Magnesia Increase	Metallic Additives	Bond Type (Pitch or Resin)	Pitch Impregnation
Corrosion	+++++	+++	+++++	+++	Either	+++
Oxidation	---	-/+	-/+	++	Pitch	++
Thermal	++	-/+	-/+	++	Either*	+
Erosion	--	-/+	-/+	+++	Either*	+++

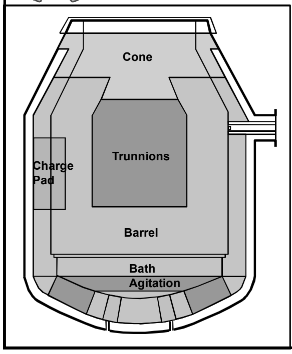
* Depends on other factors (e.g. metallic additives)

BOS Vessel Refractory Performance:
Effect of Operational Parameters

Parameter	Change	Effect on Life
Steel Temperature	+10°C	-280
Slag Fe	+1%	-151
Dolomite Consumption	+1kg/t	+72
Heats / Day	+1	+30
Lime Consumption	+1kg/t	+12
Steel C Content	+1 Point	+27
Reblows	+1%	-15

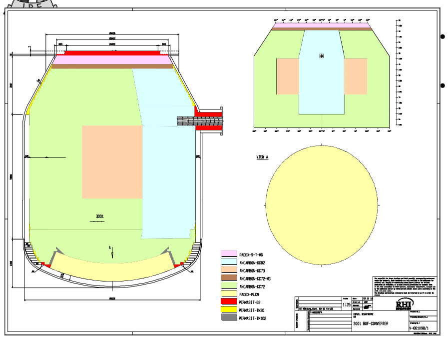
Figures apply to Sollac, France.
Relationships at Corus Plants may not be exactly the same.

BOS Vessel Design Methodology



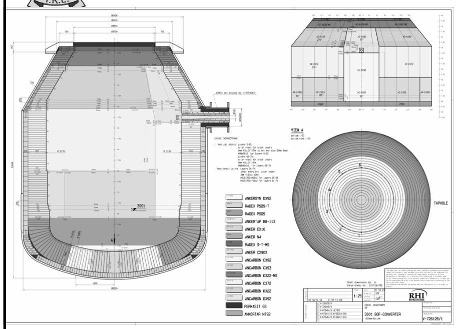
- Zoned linings, containing different qualities of magnesia-carbon are employed.
- The most durable materials are used in high wear areas and cheaper materials used where appropriate.
- The converter has a relatively simple design and a low refractory consumption of 1.5-2.0 kg/t.
- The life of the lining and the refractory consumption are affected by:
  - **Lining material quality.**
  - **Installation quality.**
  - **Process control.**
  - **Product range.**
  - **Operational consistency**

BOS Vessel Design
Stadium Bricking Pattern



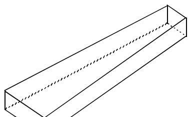
- Note ramming gap brickwork in 'knuckle'
- Bottom is bricked in a 'herringbone' pattern from 2 brick 'tapers'

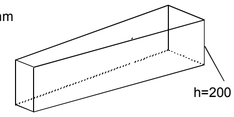
BOS Vessel Design
Radial Bricking Pattern



- Note continuous brickwork in 'knuckle'
- Bottom is bricked in rings from a central 'kingbrick'
- Enhanced quality is used in the bottom to surround the tuyere elements

Bricks for BOS vessel installation





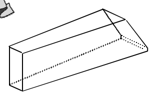
ISO – Key or Crown

Standard brick for
BOS vessel Installation.
100mm brick height is
critical and requires control
To +/- 0.5mm

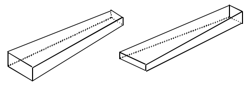
End arch

Standard brickshape for
BOS vessel mouth

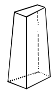
Shape - Special BOS Bricks



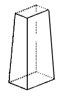
Special adapted 'chamfer'
for cone



Inclined keys
for inclined cone lining

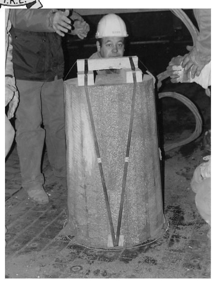


Key arch
for radial bottom



Key wedge
especially for safety
linings

Installation – Radial Design (1)

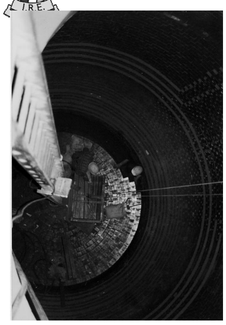


- Installation of the kingbrick is critical
- The block must be levelled and centralised to ensure that the bottom 'arrives' at the correct point in the knuckle
- The kingbrick is constructed from special high quality magnesia carbon brick shapes that have been machined and glued to produce the shape seen on the left

Installation – Radial Design (2)

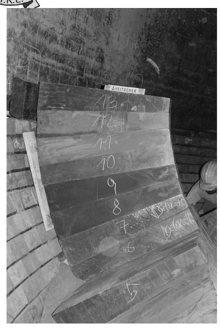
- The bottom is then bricked from the central kingbrick, firstly with side-arch type bricks and later with the special keys seen previously.
- Note the design shown this case has stirring elements pre-installed which is not the case at SCP
- A special basic mortar is used to ensure bricks fall at the correct angle to avoid open joints where necessary

Installation – Radial Design (3)



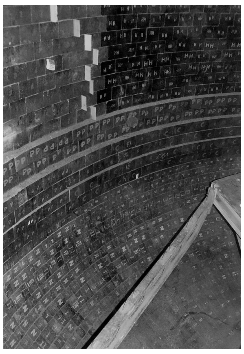
- View from the top of the vessel showing the radial bottom almost completed.
- Note the concentric ring construction

Installation – Radial Design (4)



- Double tapered key design employed to 'turn' the knuckle of the vessel and develop the 'gap-less' construction
- Note that some ramming is employed in the lower area of the knuckle
- The thickness of the working lining in this area is 1000mm

Installation – Radial Design (5)

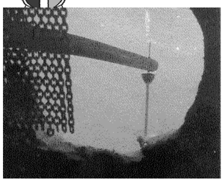


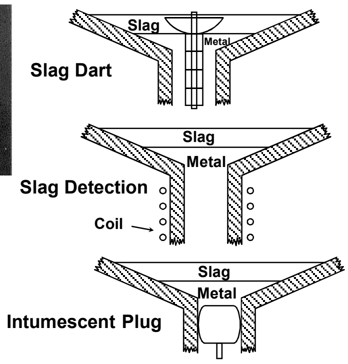
- Radial knuckle nearing completion (above)
- Continuous radial knuckle and lower barrel complete (right)

BOS Vessel: Slag control (1)

- The quantity of slag carried over from the vessel to the ladle effects the refractory performance of the ladle and the steel quality.
- A large volume of converter slag in the ladle can result in poor control of steel phosphorous levels and excessive wear of the ladle slag line.
- Slag control can be achieved by,
  - Slag darts which float and then plug the taphole.
  - Electromagnetic coils that detect slag in the taphole.
  - Intumescent plugs which expand to fill the taphole.
- Correct use of these procedures helps to improve quality and minimise refractory costs.

BOS Vessel: Slag control (2)

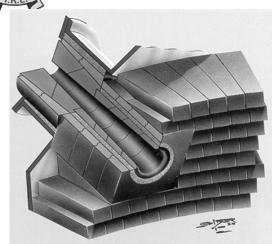




BOS Vessel: Maintenance

- **Gunning: - used to repair/protect the vessel refractories.**
  - Within Corus UK, wet spraying is used.
  - This technique involves the application of a mixture of water and magneisa or magnesia/doloma grains with a gunning lance.
- **Slag Modification:**
  - Lining protection can be carried out by the use of soft burned doloma to increase the MgO content of the steelmaking slag.
- **Slag splashing: - now the most favoured way of protecting the vessel.**
  - This is a cheap and effective method using a high-pressure nitrogen blast through the top lance to splash doloma/dolomite doped finishing slag on to the vessel refractories.

BOS Vessel Taphole - Function



- Long life
- Quick change – better vessel availability
- Controlled steel stream (minimising re-oxidation)
- Controlled tapping time with non-turbulent flow

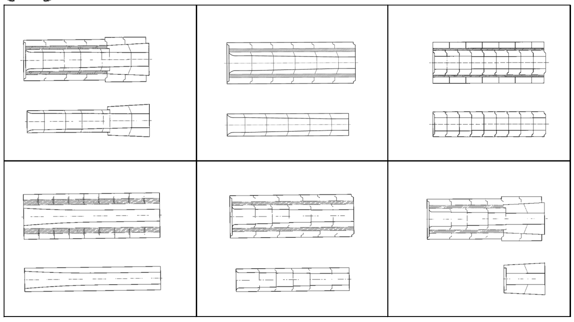
BOS Vessel Taphole Magnesia Carbon – Required product characteristics

Required product characteristics	Actions
High hot erosion resistance	• Highly pure raw materials • Strong C-matrix • Dense, low porosity structure
High capacity to absorb tensions	• Tough brick matrix/bond • Optimised Carbon contents
High oxidation resistance	• Potential for sintering of decarburized hot face, e.g. by dense MgO packing in brick matrix • Antioxidants
High redox resistance	• Limited C-content • Limited addition of antioxidants

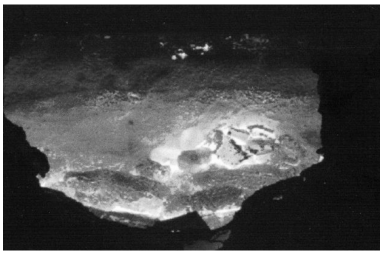
BOS Vessel Tapholes
Effect of steelmaking process on taphole life

PARAMETER	RANGE	AVERAGE CAMPAIGN INCREASE/DECREASE	AVERAGE NO. OF HEATS INCREASE/DECREASE
TAP TEMPERATURE	1660 – 1690°C	INCREASE OF 1°C	⇒ DECREASE OF 1,2 HEATS
TAP OXYGEN	550 – 950 ppm	INCREASE OF 100ppm	⇒ DECREASE OF 3,4 HEATS
TAP CARBON	0,040 – 0,070 %	DECREASE OF 0,010%	⇒ DECREASE OF 5,3 HEATS
PERCENTAGE OF REBLOWS	20 – 50%	INCREASE OF 5%	⇒ DECREASE OF 3,8 HEATS
REBLOWS TIME	12 – 50 SECONDS	INCREASE OF 5 SECONDS	⇒ DECREASE OF 2,8 HEATS

BOS Vessel Taphole Designs



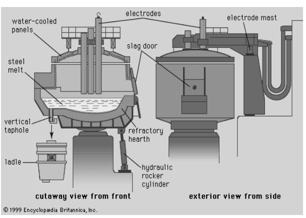
Primary Steelmaking - EAF



Primary Steelmaking: EAF

- The modern EAF used for steelmaking is a water cooled refractory lined vessel covered with a retractable roof
- There are 3 main sections:
  - Shell: consisting of the sidewalls and the lower steel 'bowl'
  - Hearth: consisting of refractory that lines the lower bowl
  - Roof: generally water cooled in UHP furnaces. The roof supports the refractory delta through which 1 or more graphite electrodes enter
- Separate from the furnace structure is an electrode support and electrical system (transformer) and tilting platform on which the furnace rests
- There are two main types of EAF; AC which utilises 3 electrodes and DC which employs a single electrode with current return through the conductive bottom.
- Modern EAF systems employ both electrical and chemical (O2 and oxy-fuel burners) heating to minimise costs and melting time

EAF: Basic Format (AC Furnace)



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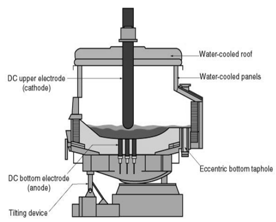
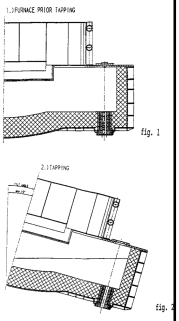
EAF:DC Furnace Design



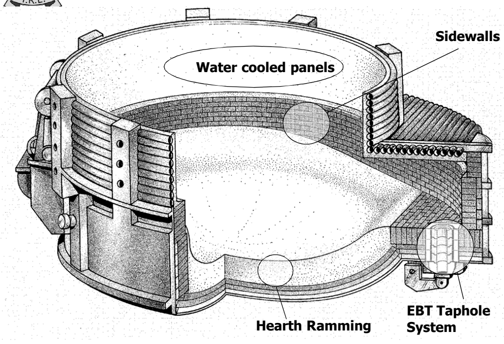
- DC EAFs offer a number of potential advantages over the more standard AC type designs:
  - Lower electrode consumption (as only one electrode is used
  - Less electrical 'noise'
  - Lower sidewalls refractory wear.
- The limit on available electrode size limits DC furnace size
- Maintenance of the conductive bottom can become a bottleneck for the process

EBT EAF Steelmaking: Basic operations

- Charging:
  - Roof swung off, scrap charged via baskets
- Melting:
  - Arc struck, melting commences
- Tapping:
  - Furnace tipped forwards
  - Via EBT or submerged taphole
- Slagging off:
  - Furnace tipped backwards
  - Molten slag discharged through slag-door
- Typical tap-tap times ~ 45-60 minutes (160T)



AC EAF: Main Refractory Zones



EAF Refractories: General

- Simple design:
  - Sidewalls in magnesia graphite qualities, zoned as appropriate
  - Hearth in basic dry ramming materials
  - Precast designs for 'delta section (roof section where 3 electrodes pass through)
  - Tapholes in magnesia graphite
- Consumption: Typical AC UHP
  - Hearth ramming ~1.45Kg/T
  - Sidewall brick ~0.75Kg/T

Part of sidewall bricking area

EAF Refractories: Major wear processes

- Mechanical:
  - Scrap impact
  - Erosion from movement of metal, slag and gases
  - Thermo-mechanical stresses caused by thermal loading
- Chemical:
  - Corrosion by oxidative basic slags (c.f. BOS Vessel)
  - Oxidation from O2/Oxy-fuel burners
  - Hydration from leakage of water cooled panels
- Thermal:
  - From electrode hot spots – localised arc-flare
  - Thermal shock

EAF Sidewalls: Stresses by Area

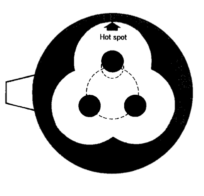
	Cold Spots		Hot Spots		Slagline	
	A	B	A	B	A	B
Mechanical						
Scrap Charging	+++	+++	+++	+++	++	++
Steel/Slag Erosion	++	+	++++	+++	++	+
Chemical						
Slag Corrosion	++	+	+++	++	++++	+++
Oxidation	++++	+++	++++	+++	++	++

- A = non foaming slag practice
- B = foaming slag practice

Foaming slag practice:

- Foaming slag is created via controlled C content/basicity and O2 injection
- Slag height is increased by 3-4 times covering the arc and electrodes
- 'Foam' shields the sidewalls from arc flare and helps mitigate some of the corrosive slag wear effects

Refractory Solutions: Bricked Side Walls and Slagline



- As with BOS vessel lining a range of MgO-C qualities are used to suit the various wear conditions pertaining in the individual lining areas
- Aim: Balanced wear
- Typical Configuration:
  - Hearth: Burned/Fired magnesia based bricks. Durable over time and not susceptible to oxidation
  - Sidewalls: 10-15% carbon containing MgO-C. May contain fused magnesia for improved slag resistance if required
  - Slagline: 15% carbon containing MgO-C. Higher carbon level helps protect the magnesia from slag corrosion
  - Hot Spots: 15% or more carbon to resist thermal shock damage. Fused magnesia employed to reduce corrosion. May contain metallic additives to resist oxidation of the carbon within the brick
- Typical lining thickness (150 – 180T EAF) 400 – 450mm (greater in EBT 'bullnose')

Control of the slag attack

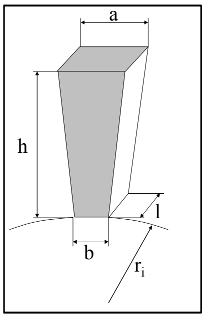
Chemical:

- pre-saturate slag with refractory oxides to reach equilibrium (buffer slag with MgO)
- lower temperature to reduce reaction rate
- shorter contact time

Physical:

- Thickening of the slag (more CaO, less FeO)
- Foaming slag practice
- Lower temperature to thicken the slag
- reduced turbulence (appropriate application of the oxygen lance)
- Shorter contact time

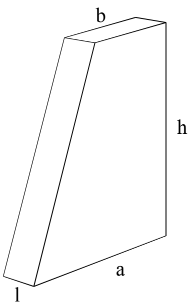
Construction - Key for the side wall



Key 35/40
a = 170 mm
b = 130 mm
h = 350 mm
l = 100 mm

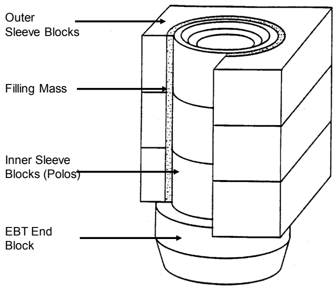
$r_i = b.h / (a-b)$

Jamb bricks for the door area



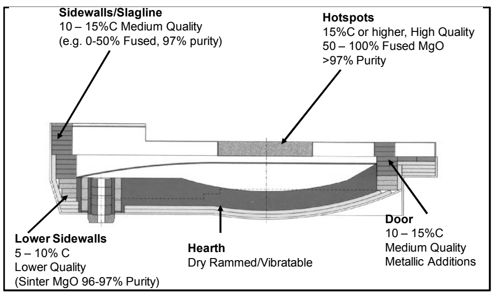
Jamb brick V2L-100
a = 250 mm
b = 150 mm
h = 375 mm
l = 100 mm

Taphole – EBT Type

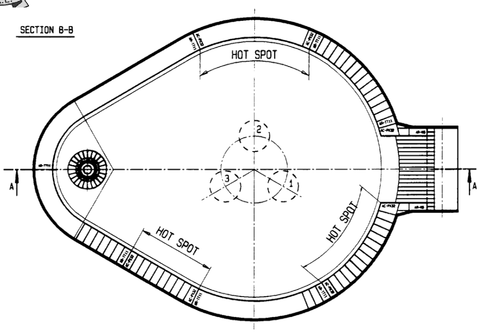


- The outer and inner sleeve blocks are magnesia carbon based. The inner blocks are higher quality reflecting the slag/metal contact requirement.
- Inner sleeve changes are made routinely to fit in with fettling and general furnace maintenance. Lives of around 100 heats are typical.
- The outer blocks are replaced at longer intervals generally due to oxidation/mechanical damage.
- The inner-outer sleeve gap is filled with DV or a basic slurry mix.
- The EBT end block is subjected to extreme thermal shock and oxidative processes and is normally a special oxidation resistant magnesia carbon product or a Alumina-SiC-C product

EBT EAF – Product Application



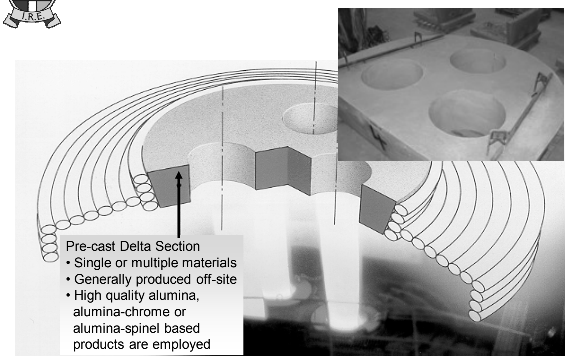
EAF - HOT SPOTS



Side wall lining in Belval, Luxembourg

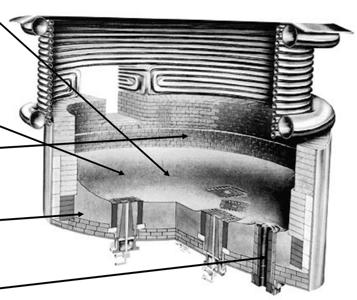
Door area in Belval, Luxembourg

EAF – Roof Design

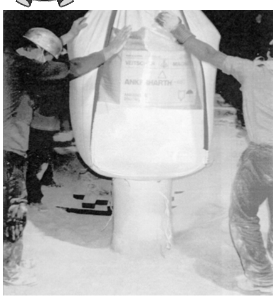


EAF Refractories: Basic monolithics

- Hearth Ramming Mixes
- Fettling Mix
- Gunning Mixes
- Ramming Mix
- Taphole Filler



EAF Refractories: Installation of heath ramming



- Hearth ramming is a magnesia or magnesia-lime based material designed to 'frit' during use
- High quality materials designed to withstand erosive and corrosive wear processes are used for the main body/large installation
- Rapidly sintering 'fettling' mixes are used to repair the hearth during furnace operation

Many thanks to R.H.I Refractories for kind permission to use their drawings.

Thank you for your attention.