Special Metallurgical Production Processes of Ingots

Alexander Scheriau
Managing Director, CSO
Typical process route for tool/special steels

Melting

Secondary Metallurgy

Casting

Special Meltshop (Re)Melting VIM-ESR-VAR

Metal Powder Production

Hot Deformation

Heat Treatment Machining Testing
Outline

- Introduction
- Why alternative routes to conventional ingot production?
- Operational results and attainable ingot quality
  - Vacuum Induction Melting (VIM)
  - Electro Slag Remelting (ESR)
  - Vacuum Arc Remelting (VAR)
  - Metal Powder Production (PM)
- Summary, Conclusion & Outlook
The INTECO Group

Hard Facts

HEADQUARTER
Bruck an der Mur, Austria

EMPLOYEES
Approx. 400 worldwide

TURN OVER
Approx. 100 Mio €

EXPERIENCE
Over 45 years

LOCATIONS
14 Offices on 4 Continents
Leadership in metallurgical process technology and equipment for melting, refining, casting, atomization and solidification of

- High Performance Steels
- Super-Alloys
- Titanium
INTECO´s Product Portfolio

- MELTING & REFINING
- VACUUM TECHNOLOGY
- CASTING TECHNOLOGY
- HEAT TREATMENT
- ROLLING MILLS
- SPECIAL MELTING
- REMELTING
- TITANIUM TECHNOLOGY
- POWDER TECHNOLOGY

INTECO Metals Application Suite (IMAS)
INTECO´s Product Portfolio

- MELTING & REFINING
- VACUUM TECHNOLOGY
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- HEAT TREATMENT
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- POWDER TECHNOLOGY

INTECO Metals Application Suite (IMAS)
Development of Product Portfolio
Special Metallurgy

1973
- Electro Slag Remelting (ESR)

Since 1995
- Vacuum Induction Melting (VIM)
- Vacuum Arc Remelting (VAR)

Since 2010
- Special Melting and Remelting Shops
  - VIM – ESR – VAR

Now & Future
- Powder Metallurgy
  and Titanium Technologies

www.inteco.at
Macroseggregations in large Conventional Ingots

Typical solidification structure and macrosegregation appearance in conventional ingots
Benefits of the ESR process for the production of forging ingots

**WHY REMELTING? – Influence of Remelting**

**Cleanliness Level**
- Reduced content of non-metallic inclusions
- Lower size of remaining inclusions
- Close control of chemical analysis from bottom to top

**Ingot Structure**
- Slow directional solidification
- Minimization of segregations
- Minimization of pores
- Dense and sound top part of the ingot

**Forging Operation**
- Higher Yield
- Lower forging ratio
- Cylindrical Ingot with uniform diameter
- Less Forging Steps

Higher ductility, less anisotropy

Improved mechanical properties
Ingot structure of ESR material

Comparison:
left: conventional cast ingot
right: remelted condition

Microstructure evolution in the annealed condition:
Above: conventionally cast ingot
Below: ESR remelted ingot
Superalloys - Why VIM-ESR-VAR?

Demand for material with:
- High temperature stability
- Excellent creep behaviour
- High corrosion resistance, etc.

Nickel-base alloys:
These alloys have a complex structure and usually contain a high amount of reactive elements such as Al, Ti, Zr, Nb, etc.

In order to end up with the correct chemical composition matching the high requirements on the final product performance a special production process is needed.
Primary melting and subsequent remelting of high demanding steels and alloys containing high reactive elements with a high oxygen affinity such as Al, Nb, Ti, etc.
VIM
Vacuum Induction Melting
Benefits and Design aspects - VIM

Benefits of VIM:
• Melting, refining, alloying and casting under vacuum
• Controlled addition of high reactive elements
• Close tolerance achievable for various alloying elements such as Al, Ti, Nb, Zr, etc.
• Reduction of gas content (H, N, O) and removal of undesirable trace elements

Design aspects for state of the art VIM plants:
• Modular **multi-chamber design** with small chamber volumes (diagonal split design) for highest operational flexibility
• Movable melt chamber bottom for **best accessibility** for crucible cleaning, cold charging, relining and maintenance
• **Highly efficient vacuum system** adjustable to process needs
• All process related **vacuum valves** are of **vertical design**
• **Shortest tundish** design for reduced heat losses and risk of nozzle freezing as well as low operational costs for tundish relining
Shortest possible tundish design

Short Tundish Design:

- Pouring in tundish axis direction
- Reduced heat losses and risk of nozzle freezing
- Low metal superheat for casting
- Quick and effective preheating
- Low operational costs for tundish relining
- Clean casting procedure and low amount of skull
Chemical composition of VIM electrodes

Achievable quality:

• Smooth surface formation without any cracks due to correct casting parameters
• Lowest gas contents achievable due to reliable vacuum system
• Lowest sulfur content due to correct raw material selection
• Practically no deviation in chemical composition from bottom to top
• Soft annealing if required to adjust the correct hardness value

Analysis done in a certified laboratory at Böhler

<table>
<thead>
<tr>
<th>Name of Sample</th>
<th>Name of Sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>In600 VIM-BOTTOM</td>
<td>In600 VIM-TOP</td>
</tr>
</tbody>
</table>

| parameter value | | parameter value |
|-----------------|-----------------|
| Carbon 0.070 | Carbon 0.075 |
| Silicon 0.10 | Silicon 0.10 |
| Manganese 0.29 | Manganese 0.31 |
| Phosphorus < 0.005 | Phosphorus < 0.005 |
| Sulphur 0.0006 | Sulphur 0.0007 |
| Chromium 15.43 | Chromium 15.7 |
| Molybdenum < 0.02 | Molybdenum < 0.02 |
| Nickel 76.47 | Nickel 76.42 |
| Vanadium < 0.02 | Vanadium < 0.02 |
| Tungsten < 0.05 | Tungsten < 0.05 |
| Copper < 0.02 | Copper < 0.02 |
| Cobalt 0.09 | Cobalt 0.09 |
| Titanium < 0.02 | Titanium < 0.02 |
| Aluminium < 0.23 | Aluminium < 0.24 |
| Niobium < 0.02 | Niobium < 0.02 |
| Hydrogen 1.2 | Hydrogen 1.2 |
| Boron 0.0039 | Boron 0.0052 |
| Iron 7.19 | Iron 7.14 |
| Nitrogen < 0.0004 | Nitrogen < 0.0004 |
| Tantalum < 0.02 | Tantalum < 0.02 |
| Oxygen 0.0008 | Oxygen 0.0009 |
| Arsenic < 0.005 | Arsenic < 0.005 |
| Tin < 0.005 | Tin < 0.005 |
| Zirconium < 0.005 | Zirconium < 0.005 |
| Antimony < 0.005 | Antimony < 0.005 |

Preconditions for the subsequent remelting operation

440mm dia. VIM ingot IN718

250mm dia. VIM ingot 80A
Further processes in production route...

**Improvements** of material quality by means of Remelting via **ESR and VAR**:

- Improved **solidification structure** and consequently better **forgeability**
- **Prevention of Macro- and Microsegregation** in the remelted ingot
- Homogeneous Distribution of remaining **non-metallic inclusions** within the ingot
- Further **reduction of gas content and undesired trace elements** during VAR process
- Improvements in regard to **shrinkage cavities**
ESR
Electro Slag Remelting
Benefits and Design aspects - ESR

Benefits of ESR:
- Improved cleanliness level due to refining with slag
- Minimization of segregations
- Slow directional solidification
- Complete dense ingot with no porosities

Design aspects for state of the art ESR furnaces:
- Coaxial high current line to minimize electromagnetic stirring within the slag and metal bath
- Weighing system and XY-adjustment for precise control of the remelting parameters
- Sophisticated control system (close control of melt rate and electrode immersion depth)
- Vacuum tight furnace design and protective gas operation for lowest hydrogen pick up and highest cleanliness requirements
High cleanliness level of ESR ingot
- Minimized hydrogen pick up
- Close control of analysis from bottom to top of ingot
- Remelting of steel with low Si and / or Al contents
- Remelting of Ti – stabilized steels

Due to maintaining a **predefined overpressure** by a **controlled gas regulation** a reliable protective atmosphere by using **lowest consumption of gas** can be ensured.

Additionally a **pre-evacuation of the furnace** before melt start ensures perfect preconditions.
8t ESR results

320Ø (Alloy718)

**Surface quality:**
- Smooth surface formation due to stable remelting operation
- Shallow immersed electrode leading to thin slag skin thickness (0.5-1.5mm)
- Well adjusted starting curve and slag filling sequenz resulting in no unremelted slag at the bottom part of the ingot
- Controlled hot topping procedure (power as well as melt rate controlled possible) resulting in a complete dense top part of the ingot
Non metallic inclusion examination (IN718 dia. 160mm forged)

<table>
<thead>
<tr>
<th>Contents</th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
<th>Ni</th>
<th>Cr</th>
<th>Mo</th>
<th>Cu</th>
<th>Al</th>
<th>W</th>
<th>Ti</th>
<th>B</th>
<th>Co</th>
<th>Nb</th>
<th>Fe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrode</td>
<td>0.045</td>
<td>0.12</td>
<td>0.20</td>
<td>0.010</td>
<td>0.0010</td>
<td>50.14</td>
<td>17.99</td>
<td>2.99</td>
<td>0.14</td>
<td>0.51</td>
<td>0.20</td>
<td>0.91</td>
<td>0.67</td>
<td>5.46</td>
<td>20.62</td>
<td></td>
</tr>
<tr>
<td>ESR Top</td>
<td>0.045</td>
<td>0.13</td>
<td>0.20</td>
<td>0.009</td>
<td>0.0005</td>
<td>50.15</td>
<td>17.98</td>
<td>3.01</td>
<td>0.14</td>
<td>0.49</td>
<td>0.20</td>
<td>0.94</td>
<td>0.0000</td>
<td>0.65</td>
<td>5.68</td>
<td>20.37</td>
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<tr>
<td>ESR Bottom</td>
<td>0.047</td>
<td>0.14</td>
<td>0.20</td>
<td>0.009</td>
<td>0.0007</td>
<td>49.99</td>
<td>17.95</td>
<td>3.00</td>
<td>0.14</td>
<td>0.49</td>
<td>0.20</td>
<td>0.91</td>
<td>0.0000</td>
<td>0.65</td>
<td>5.70</td>
<td>20.57</td>
</tr>
</tbody>
</table>

Internal quality:
- No chance in chemical composition from electrode to ingot
- Close control of chemical deviation from bottom to top
- Highest cleanliness level achieved due to complete protective gas atmosphere and proper slag selection

Contents

<table>
<thead>
<tr>
<th>Contents</th>
<th>Thin</th>
<th>Heavy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>B</td>
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<tr>
<td>Standard</td>
<td>≤ 0.5</td>
<td>≤ 0.5</td>
</tr>
<tr>
<td>Value</td>
<td>0</td>
<td>0.5</td>
</tr>
</tbody>
</table>

✓ Pass standard

* Standard : ASTM E-45
VAR
Vacuum Arc Remelting
## Process Comparison ESR - VAR

### ESR - Elektro Slag Remelting
- Refining due to metallurgical reactive slag
- Process and Production flexibility (slag types, dimensions)
- controlled solidification
- no evaporation losses
- superior macro cleanliness
- good micro cleanliness
- less segregation
- good surface quality (direct hot working)
- square dimensions possible
- excellent desulphurization (open ESR)
- yield > 93%

### VAR - Vacuum Arc Remelting
- no slag
- inert heat source (electric arc)
- inert atmosphere and mould
- controlled solidification
- low gas content (H, N, O)
- good macro cleanliness
- superior micro cleanliness
- less segregation
- lowest melt rates possible

### Advantages

<table>
<thead>
<tr>
<th>ESR- Elektro Slag Remelting</th>
<th>VAR- Vacuum Arc Remelting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Advantages</td>
<td></td>
</tr>
<tr>
<td>– Refining due to metallurgical reactive slag</td>
<td>– no slag</td>
</tr>
<tr>
<td>– Process and Production flexibility (slag types, dimensions)</td>
<td>– inert heat source (electric arc)</td>
</tr>
<tr>
<td>– controlled solidification</td>
<td>– inert atmosphere and mould</td>
</tr>
<tr>
<td>– no evaporation losses</td>
<td>– controlled solidification</td>
</tr>
<tr>
<td>– superior macro cleanliness</td>
<td>– low gas content (H, N, O)</td>
</tr>
<tr>
<td>– good micro cleanliness</td>
<td>– good macro cleanliness</td>
</tr>
<tr>
<td>– less segregation</td>
<td>– superior micro cleanliness</td>
</tr>
<tr>
<td>– good surface quality (direct hot working)</td>
<td>– less segregation</td>
</tr>
<tr>
<td>– square dimensions possible</td>
<td>– lowest melt rates possible</td>
</tr>
<tr>
<td>– excellent desulphurization (open ESR)</td>
<td></td>
</tr>
<tr>
<td>– yield &gt; 93%</td>
<td></td>
</tr>
</tbody>
</table>

### Disadvantages

<table>
<thead>
<tr>
<th>ESR- Elektro Slag Remelting</th>
<th>VAR- Vacuum Arc Remelting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Disadvantages</td>
<td></td>
</tr>
<tr>
<td>– no degassing</td>
<td>– high effort for electrode preparation</td>
</tr>
<tr>
<td>– possible hydrogen pick up</td>
<td>– undesirable evaporation losses (Mn)</td>
</tr>
<tr>
<td>– control of reactive elements</td>
<td>– no desulphurization</td>
</tr>
<tr>
<td>– complex process control</td>
<td>– relative low productivity</td>
</tr>
<tr>
<td>– high remelting costs (Slag)</td>
<td>– poor surface quality</td>
</tr>
<tr>
<td>– limitation of melt rate (freezing of slag)</td>
<td>– low yield; surface dressing of electrode and ingots</td>
</tr>
<tr>
<td></td>
<td>– only round ingots possible</td>
</tr>
</tbody>
</table>
Benefits and Design aspects - VAR

Benefits of VAR:
• Improved cleanliness level
• Minimization of segregations
• Slow directional solidification
• Reduction of gas content (Hydrogen, Oxygen and Nitrogen)

Design aspects for state of the art VAR furnaces:
• Coaxial furnace design with defined current path
• horizontal XY-adjustment of the electrode within the crucible to maintain a constant gap with the possibility of automatic adjustment during remelting
• Partial pressure remelting and helium cooling possible for precise control of chemical composition and better heat transfer conditions
• Precise weighing system for accurate control of remelting parameters
• Sophisticated control system (close control of melt rate and arc gap)
Control of the VAR process - IREC + IDRIP

INTECO Remelting Controller (IREC®) and INTECO Drip short controller (IDRIP):

- Precise melt rate and gap (VAR) calculation algorithm
- Maintaining a constant gap between electrode tip and liquid metal bath by means of Drip short or voltage control
- The dripshort frequency is measured with an oscilloscope and compared with the setpoint → IDRIP

VAR melt trend with constant electrode movement and stable melt rate
8t VAR results

Surface formation of IN718 in dependency of the ingot size

**Surface quality:**
- Bigger dimensions than in ESR feasible
- Due to low melt rates the surface needs to be conditioned after remelting in certain cases
- Constant gap between electrode and liquid metal bath ensures perfect remelting conditions
- Well adjusted starting curve resulting in highest yield of the bottom part of the ingot
- Controlled hot topping procedure (power as well as melt rate controlled possible) resulting in a complete dense top part of the ingot

Shown results courtesy of sēAHcss
## Inner quality examination
(IN718 dia. 180mm forged)

Shown results courtesy of SēAH CSS

### Chemical component (wt%)

<table>
<thead>
<tr>
<th>VA0005 (ALLOY718)</th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
<th>Ni</th>
<th>Cr</th>
<th>Mo</th>
<th>Cu</th>
<th>Al</th>
<th>W</th>
<th>Ti</th>
<th>B</th>
<th>Co</th>
<th>Nb</th>
<th>Fe</th>
<th>N</th>
<th>O</th>
<th>H</th>
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<tbody>
<tr>
<td>Max.</td>
<td>0.050</td>
<td>0.20</td>
<td>0.35</td>
<td>0.015</td>
<td>0.0020</td>
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<td>3.30</td>
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<td>0.70</td>
<td>-</td>
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<td>0.0060</td>
<td>1.00</td>
<td>5.50</td>
<td>21.00</td>
<td>35</td>
<td>5</td>
<td>1</td>
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<tr>
<td>Min.</td>
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<tr>
<td>Electrode</td>
<td>0.034</td>
<td>0.08</td>
<td>0.18</td>
<td>0.012</td>
<td>0.0013</td>
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</tr>
</tbody>
</table>

### Gas content (ppm)

<table>
<thead>
<tr>
<th>Electrode</th>
<th>N</th>
<th>O</th>
<th>H</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max.</td>
<td>35</td>
<td>5</td>
<td>1</td>
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</tbody>
</table>

### Non-metallic inclusion

<table>
<thead>
<tr>
<th>Cont.</th>
<th>Thin</th>
<th>Heavy</th>
<th>Class1</th>
<th>Class2</th>
<th>Class3</th>
<th>Class4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>B</td>
<td>C</td>
<td>D</td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>Std.</td>
<td>≤ 0.5</td>
<td>≤ 0.5</td>
<td>≤ 0.5</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
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<td>0</td>
<td>0</td>
<td>0.5</td>
<td>0</td>
<td>0</td>
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</table>

### Macro Structure

<table>
<thead>
<tr>
<th>Cont.</th>
<th>Class1</th>
<th>Class2</th>
<th>Class3</th>
<th>Class4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Freckles</td>
<td>White spots</td>
<td>Radial segregation</td>
<td>Ring pattern</td>
</tr>
<tr>
<td>Std.</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>Value</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>Result</td>
<td>Pass</td>
<td>Pass</td>
<td>Pass</td>
<td>Pass</td>
</tr>
</tbody>
</table>

### Result

- **Pass**
- **Non-metallic inclusion**
  - Thin: Pass
  - Heavy: Pass
- **Macro Structure**
  - Freckles: Pass
  - White spots: Pass
  - Radial segregation: Pass
  - Ring pattern: Pass

### Internal quality:

- **No change in chemical composition from electrode to ingot**
- **Lowest residual gas content** possible under vacuum
- **Highest cleanliness level** achievable
- **Complete dense ingot with best macro structure rating**

* Standard : ASTM E-45
Supersized ESR (>100t)
The Starting Process

- Type and condition (dry) of the used slags especially to ensure no or limited hydrogen pick up
- Special additions in the start slag such as deoxidizing elements (FeSi, etc.)
- Right quantity of starting slag for a good usable ingot bottom
- Slag addition sequence for a close control of the chemical analysis
- Control of furnace atmosphere
- Starting parameters such as voltage, current and time to ensure the complete melting of the entire slag quantity
1900mm dia., 112t ESR ingot
Al-pick up and Si loss

Main reactions in starting phase of the ESR process:

$$3 \text{[Si]} + 2 \text{(Al}_2\text{O}_3) \leftrightarrow 4 \text{[Al]} + 3 \text{(SiO}_2)$$

2 main Parameters:

- Right choice of starting slag composition
- Addition sequence is important

<table>
<thead>
<tr>
<th>Steel grade</th>
<th>Analysis position</th>
<th>Si loss [%]</th>
<th>Al pick up [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low alloyed steel</td>
<td>Top</td>
<td>Max. 0,02</td>
<td>0</td>
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<tr>
<td></td>
<td>Middle</td>
<td>Max. 0,03</td>
<td>Max. 0,001</td>
</tr>
<tr>
<td></td>
<td>bottom</td>
<td>Max. 0,02</td>
<td>Max. 0,002</td>
</tr>
<tr>
<td>10% Cr steel-A</td>
<td>Top</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Middle</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>bottom</td>
<td>Max. 0,01</td>
<td>0</td>
</tr>
<tr>
<td>10% Cr steel-B</td>
<td>Top</td>
<td>Max. 0,01</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Middle</td>
<td>Max. 0,01</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>bottom</td>
<td>Max. 0,02</td>
<td>0</td>
</tr>
</tbody>
</table>
The special focus lies on the following parameters:

- Control of a predefined melt rate
- Control of the electrode immersion depth
- Control of a predefined slag bath level
- Well controlled furnace atmosphere
- Well controlled electrode change procedure
## Chemical Analysis of a 10% Cr Steel

<table>
<thead>
<tr>
<th>position</th>
<th>Si</th>
<th>Al</th>
<th>Cr</th>
<th>Nb</th>
<th>N [ppm]</th>
<th>O [ppm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>electrode</td>
<td>0.09</td>
<td>0.006</td>
<td>10.24</td>
<td>0.050</td>
<td>235</td>
<td>27</td>
</tr>
<tr>
<td>Top (90-94%)</td>
<td>0.08-0.09</td>
<td>0.005</td>
<td>10.23-10.26</td>
<td>0.051-0.052</td>
<td>233</td>
<td>23</td>
</tr>
<tr>
<td>Mid (49-53%)</td>
<td>0.08</td>
<td>0.005</td>
<td>10.21-10.27</td>
<td>0.050-0.051</td>
<td>241</td>
<td>22</td>
</tr>
<tr>
<td>Bottom (9-13%)</td>
<td>0.07</td>
<td>0.005</td>
<td>10.15-10.22</td>
<td>0.043-0.046</td>
<td>210</td>
<td>23</td>
</tr>
</tbody>
</table>
Ø2600mm, 250t ESR ingot
C-segregation of different electrode sizes

It can be concluded that the bigger the electrode diameter, the more pronounced is the segregation level in the electrode.
It can be derived that in the ESR ingot which has a bigger diameter than the electrode, the elements are more evenly distributed.

It can be stated that for these big ingots a certain center segregation is obvious and can be expected.
Hot Topping

- Adequate decreasing of the power input level respectively right settings of the electrical parameters
- Sufficient time for the hot topping process
- Enough hot topping weight
Shrinkage cavity and slag inclusions in the top part of the ingot

Procedures for optimized Hot Topping have been developed

Smaller electrode diameter is helpful to maintain the remelting (feeding) process during Hottopping
Optimized Hot topping process
2.600mm dia. ESR ingot

Well controlled reduction in power respectively melt rate
Top parts of big ESR ingots after optimization
INTECO BIG ESR plants—already in operation
in China

- 2 furnace heads,
- 2 static mold melt stations
- max. ingot weight 150t
- max. ingot diameter 2.200mm
ESR/VAR Process Simulations Research & Development

Proposal for the Foundation and Support of a Christian Doppler Laboratory on

Metallurgical Applications of Magnetohydrodynamics

Project with focus on VAR already started and continued until 2025

Dr. A. Kharicha
University of Leoben
POWDER METALLURGY
# Powder Metallurgy

## Why do we need it?

<table>
<thead>
<tr>
<th><strong>Necessity</strong></th>
<th><strong>Economy</strong></th>
<th><strong>Uniqueness</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Refratory</td>
<td>Productivity</td>
<td>Microstructure</td>
</tr>
<tr>
<td>Reactive</td>
<td>Precision</td>
<td>Composite</td>
</tr>
</tbody>
</table>

1. It is impossible to form the metal or material by any other technique

2. When the PM route is more economical

3. When PM gives unique properties
The PM-Process has the:

- Highest Raw Material Utilization (95 %)
- Lowest Energy Requirement per kg of Finished Part
- Highest Production Flexibility
- Highest Homogeneity
- Lowest Amount of Segregations

Comparison of Solidification Conditions:

- IC: Solidification Time several Hours
- ESR: High Temperature Gradient, Low Velocity
- CC: Lower Temperature Gradient, Higher Velocity
- SF: Very High Temperature Gradient
- PM: Highest Cooling Rate, Low Solidification Time
# Powder Metallurgy

## Selected Key Technologies

### Additive Manufacturing (AM)

<table>
<thead>
<tr>
<th>Strength of AM</th>
<th>Weakness of AM</th>
</tr>
</thead>
<tbody>
<tr>
<td>+ Freedom to design and innovate</td>
<td>- Size limitations</td>
</tr>
<tr>
<td>+ Complex shapes, structures</td>
<td>- Mechanical / material properties</td>
</tr>
<tr>
<td>+ One part versus multiple pieces</td>
<td>- Slow build rates, cycle times</td>
</tr>
<tr>
<td>+ Short manufacturing time</td>
<td>- High costs (machines, materials)</td>
</tr>
<tr>
<td>+ Support of green manufacturing</td>
<td>- Quality Control / reliability</td>
</tr>
<tr>
<td></td>
<td>- Standards missing</td>
</tr>
</tbody>
</table>

### Hot Isostatic Pressing (HIP)

<table>
<thead>
<tr>
<th>Strength of HIP</th>
<th>Weakness of HIP</th>
</tr>
</thead>
<tbody>
<tr>
<td>+ Large sized Parts</td>
<td>- Not suitable for complex parts</td>
</tr>
<tr>
<td>+ Small part runs cost effective</td>
<td>- Container shrinkage</td>
</tr>
<tr>
<td>+ Mechanical properties</td>
<td>- Design consideration</td>
</tr>
<tr>
<td>+ Less welding needed</td>
<td>- Production Volumes (&lt;10,000 runs)</td>
</tr>
<tr>
<td>+ Economical (less material loss)</td>
<td></td>
</tr>
<tr>
<td>+ HIP-ing of other parts (densification)</td>
<td></td>
</tr>
</tbody>
</table>

### Metal Injection Molding (MIM)

<table>
<thead>
<tr>
<th>Strength of MIM</th>
<th>Weakness of MIM</th>
</tr>
</thead>
<tbody>
<tr>
<td>+ Small size</td>
<td>- Binder removal step</td>
</tr>
<tr>
<td>+ Mechanical properties</td>
<td>- Part shrinkage</td>
</tr>
<tr>
<td>+ Accuracy, surface finish</td>
<td>- Design consideration</td>
</tr>
<tr>
<td>+ Production Volume (&gt;10,000 runs)</td>
<td>- Installation costs</td>
</tr>
<tr>
<td>+ Economical (no waste)</td>
<td></td>
</tr>
<tr>
<td>+ Relatively low maintenance costs</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>
HOT ISOSTATIC PRESSING (HIP)

Tool Steels
Special requirements for tool steels and high speed steels demand a fine and homogenous microstructure.

These steels have a high C-content (1.3 - 2.3%) as well as other alloying elements and form Ledeburite during solidification.

Conventional methods lead to coarse Ledeburite network and inhomogenieties.

Carbides are wear carriers but break during rolling and forging.

With powder metallurgy finest dendritical carbides are achieved.

With the same chemical analysis much better properties are achieved.

Carbides have the same effect as NMI, for small critical defect sizes the degree of purity becomes more important than the carbide size.
HOT ISOSTATIC PRESSING

Tool Steels – Production Route

Source: Böhler Edelstahl

Source: Erasteel
**HOT ISOSTATIC PRESSING**

Development of Today’s State of the Art HSS Process

### 1980’s

### 1991
Installation of the first ESH plant with a heat size of 7 ton at ERASTEEL KLOSTER AB, Söderfors, *by INTECO*.

- Development of the ERASTEEL ASP® Process

### 1999
Installation of the second ESH plant with a heat size of 8 ton at BÖHLER Edelstahl, Kapfenberg, *by INTECO*.

- Development of the BÖHLER microclean® Process

### 2011
Installation of the third ESH plant with a heat size of 14 ton at ERASTEEL KLOSTER AB, Söderfors, *by INTECO*.

- Development of the ERASTEEL Dvalin™ Process
HOT ISOSTATIC PRESSING

Near Net Shaped

NEAR NET SHAPED
HSS Powder Production - Start 2019

3t HSS Powder Production Line

8t HSS Powder Production Line
ADDITIVE MANUFACTURING

Specialty Powder

SPECIALTY POWDER
**ADDITIVE MANUFACTURING**

**Powder ≠ Powder**

**Powder Characteristics:**
- Compositional Homogeneity
- Particle Size Distribution
- Flowability
- Powder Cleanliness
- Powder Shape & Morphology
- Etc.

<table>
<thead>
<tr>
<th>PRODUCTION METHOD</th>
<th>APPLICATION</th>
<th>SIZE FRACTION</th>
<th>SHAPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vacuum Inert Gas Atomization</td>
<td>Additive Manufacturing</td>
<td>15 – 45 µm</td>
<td>Spherical</td>
</tr>
<tr>
<td>Nitrogen Gas Atomization (Tool Steels)</td>
<td>Hot Isostatic Pressing</td>
<td>&lt; 800 µm</td>
<td>Spherical</td>
</tr>
</tbody>
</table>

**Acronyms:**
- **MIM:** Metal Injection Molding
- **HVOF:** High-Velocity Oxygen-Fuel Spray
- **3D:** Additive Manufacturing
- **MMS:** MMS-Scanpac Process
- **PTA:** Plasma Transferred Arc
- **HIP:** Hot Isostatic Pressing
ADDITIVE MANUFACTURING

Vacuum Inert Gas Atomization – Powder Production
Benefits of the (re)melting process (cleanliness level, homogeneous distribution of alloying elements, ingot structure, yield) have been shown and lead to superior quality compared to the conventional ingot casting process.

Optimized (re)melting procedures and controls are necessary to obtain highest ingot quality and needed to exceed current limitation.

Process Modelling as the key tool for a better understanding of the process and a valuable support to achieve a repeatable production.

Development of additional technologies and new products in the field of Metal Powders might disrupt certain conventional technologies and but will also open new manufacturing technologies.

Summary, Conclusion & Outlook
INTECO melting and casting technologies GmbH

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Have an eye on our technology www.inteco.at

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