Melting and casting technologies for the production of tool steels

Dr. Harald Holzgruber, CEO
DI Alexander Scheriau, CSO

Tool 2016, Bratislava, October 5th 2016
Global Alloy Tool Steel Products 2015 [‘000 metric tonnes]

<table>
<thead>
<tr>
<th>TOTAL BARS</th>
<th>Total World: 1,320</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOTAL</td>
<td></td>
</tr>
<tr>
<td>Forged Bars*</td>
<td>690</td>
</tr>
<tr>
<td>Hot Rolled Bars</td>
<td>210</td>
</tr>
<tr>
<td>Cold Finished Bars</td>
<td>420</td>
</tr>
<tr>
<td>Other Products</td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>460</td>
</tr>
<tr>
<td>Flat Products</td>
<td>300</td>
</tr>
<tr>
<td>Others</td>
<td>160</td>
</tr>
</tbody>
</table>

*incl. die blocks

<table>
<thead>
<tr>
<th>TOTAL</th>
<th>Total World: 1,930</th>
</tr>
</thead>
<tbody>
<tr>
<td>NAFTA</td>
<td>250</td>
</tr>
<tr>
<td>Other America</td>
<td>60</td>
</tr>
<tr>
<td>Europe</td>
<td>600</td>
</tr>
<tr>
<td>Asia</td>
<td>900</td>
</tr>
<tr>
<td>Others</td>
<td>120</td>
</tr>
</tbody>
</table>

Total ATS: 1,780

Total HSS: 150

Picture credits: Böhler Edelstahl GmbH & Co KG

Picture credits: Böhler Bleche GmbH & Co KG

Picture credits: Deutsche Edelstahlwerke

Data provided by SMRI!
Alloy Tool Steel Structure 2015

**Europe**
- PM: 42%
- HW: 27%
- CW: 24%
- HSS: 7%

**Rest of the World**
- PM: 38%
- HW: 27%
- CW: 26%
- HSS: 9%

**Tool steel grades:**
- Hot work steel (HW)
- Cold work steel (CW)
- Plastic mould steel (PM)
- High speed steel (HSS)

Data provided by [SMRei!](http://www.smrail.com)
TOP 20 tool steel producers

- voestalpine special steel
- Schmolz & Bickenbach
- Dongbei Special Steel
- Tiangong Group
- Qilu Special Steel
- SeAH Special Steel
- Baosteel Special Steel
- Daido Steel
- Baosteel Special Materials
- Metal Ravne
- Hitachi Metals
- Changcheng
- NLMK
- Doosan
- IndusSteel
- Eramet Alliage
- Heve Special Steel (HSS)

* excluding trade volumes (externally sourced)

Data provided by SMRül
Properties and influence factors

Chemistry
- Hardness
- Red hardness
- Wear resistance
- Polishability
- Low levels of inclusion
- Cleanliness
- Hot toughness
- Retention of hardness
- Hot strength
- Thermal shock resistance
- Thermal conductivity

Heat/surface treatment
- Forging

Melting

Refining
- Remelting
- Casting
Typical process route for tool steels
Typical process route for tool steels
EAF – Electric Arc Furnace
EAF – Main tasks and trend

› Primary melting unit in alloy steel making process
› Melting of various kinds of scraps and ferro-alloys
› Dephosphorisation and decarburisation using oxygen and lime

Trend towards …

› Improved productivity
› Decreased energy consumption
› Increased flexibility
The EAF Melting Process requires the combination of 2 main energy sources:

- **Chemical Energy** (burners, oxygen lances, carbon injectors)
- **Electrical Energy** (electric arc)

The optimum control of the two power input together with all the activities needed for process and turnaround is the KEY for EAF process optimization.
EAF – Melting optimisation

Case study of 55t EAF for Tool Steels:

• Upgrade of existing EAF to decrease energy consumption and tap-to-tap-time
• Installation of SwingDoor and chemical energy Package
EAF – Achieved savings

Electric energy reduction:
- 94 kWh/t (-16.2 %)

Power ON reduction:
- 10 min (-13.5 %)
EAF – Telescopic Furnace

› Increased yield due to low oxidation
› Increased productivity due to one scrap bucket charging
› High flexibility (one bucket is one steel grade)
Typical process route for tool steels
Refining - Typical units

- Ladle Furnace
  - Heating
  - Trimming
  - Desulphurisation

- VD/VOD
  - Degassing
  - Decarburisation
## Refining - Tasks

- Final adjustment of chemical composition
- Decreasing gas content in the melt
- Improved steel cleanliness

<table>
<thead>
<tr>
<th></th>
<th>AOD</th>
<th>LF</th>
<th>VD</th>
<th>VOD</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Temperature adjustment</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Red. of tapping temp.</td>
<td>green</td>
<td>green</td>
<td>black</td>
<td>orange</td>
</tr>
<tr>
<td>Re-heating</td>
<td>orange</td>
<td>orange</td>
<td>black</td>
<td>orange</td>
</tr>
<tr>
<td>holding temp.</td>
<td>black</td>
<td>black</td>
<td>black</td>
<td>black</td>
</tr>
<tr>
<td><strong>Degassing</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reduction of H2</td>
<td>orange</td>
<td>black</td>
<td>black</td>
<td>orange</td>
</tr>
<tr>
<td>Reduction of O2</td>
<td>black</td>
<td>green</td>
<td>orange</td>
<td>orange</td>
</tr>
<tr>
<td>Reduction of N2</td>
<td>orange</td>
<td>orange</td>
<td>orange</td>
<td>orange</td>
</tr>
<tr>
<td><strong>Decarburisation</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steel with lowest C content</td>
<td>green</td>
<td>black</td>
<td>black</td>
<td>green</td>
</tr>
<tr>
<td><strong>Desulfurisation</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Desulfurisation</td>
<td>orange</td>
<td>orange</td>
<td>orange</td>
<td>black</td>
</tr>
<tr>
<td><strong>Trimming to final Analysis</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yield optimisation</td>
<td>orange</td>
<td>orange</td>
<td>orange</td>
<td>orange</td>
</tr>
<tr>
<td>Red. of EAF working load</td>
<td>black</td>
<td>green</td>
<td>green</td>
<td>green</td>
</tr>
</tbody>
</table>
Refining - Challenges

› Many steelgrades with challenging target values ...

<table>
<thead>
<tr>
<th>Grade</th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
<th>Cr</th>
<th>Ni</th>
<th>V</th>
<th>Al</th>
<th>W</th>
<th>Ti</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.13</td>
<td>0.20</td>
<td>0.05</td>
<td>0.015</td>
<td>0.001</td>
<td>0.25</td>
<td>0.08</td>
<td>0.25</td>
<td>0.05</td>
<td>0.16</td>
<td>0.025</td>
</tr>
<tr>
<td>B</td>
<td>0.32</td>
<td>0.62</td>
<td>1.00</td>
<td>0.000</td>
<td>0.045</td>
<td>0.25</td>
<td>0.05</td>
<td>0.15</td>
<td>0.12</td>
<td>0.005</td>
<td>0.031</td>
</tr>
<tr>
<td>C</td>
<td>0.39</td>
<td>1.30</td>
<td>0.35</td>
<td>0.015</td>
<td>0.001</td>
<td>5.50</td>
<td>1.21</td>
<td>0.25</td>
<td>0.91</td>
<td>0.000</td>
<td>0.20</td>
</tr>
<tr>
<td>D</td>
<td>0.82</td>
<td>0.25</td>
<td>1.10</td>
<td>0.029</td>
<td>0.020</td>
<td>0.50</td>
<td>0.30</td>
<td>0.30</td>
<td>0.10</td>
<td>0.010</td>
<td>0.66</td>
</tr>
<tr>
<td>E</td>
<td>1.20</td>
<td>0.25</td>
<td>0.30</td>
<td>0.023</td>
<td>0.023</td>
<td>1.40</td>
<td>0.07</td>
<td>0.25</td>
<td>0.05</td>
<td>0.015</td>
<td>0.05</td>
</tr>
<tr>
<td>F</td>
<td>0.20</td>
<td>0.40</td>
<td>1.55</td>
<td>0.010</td>
<td>0.016</td>
<td>0.20</td>
<td>0.08</td>
<td>0.15</td>
<td>0.20</td>
<td>0.020</td>
<td>0.05</td>
</tr>
<tr>
<td>G</td>
<td>0.83</td>
<td>0.20</td>
<td>0.95</td>
<td>0.029</td>
<td>0.030</td>
<td>0.20</td>
<td>0.08</td>
<td>0.12</td>
<td>0.03</td>
<td>0.000</td>
<td>0.05</td>
</tr>
<tr>
<td>H</td>
<td>0.18</td>
<td>0.17</td>
<td>0.50</td>
<td>0.020</td>
<td>0.030</td>
<td>1.64</td>
<td>0.30</td>
<td>1.50</td>
<td>0.013</td>
<td>0.003</td>
<td>0.10</td>
</tr>
<tr>
<td>I</td>
<td>0.35</td>
<td>0.30</td>
<td>0.69</td>
<td>0.005</td>
<td>0.003</td>
<td>1.90</td>
<td>0.50</td>
<td>3.10</td>
<td>0.11</td>
<td>0.015</td>
<td>0.18</td>
</tr>
<tr>
<td>J</td>
<td>0.34</td>
<td>0.30</td>
<td>0.95</td>
<td>0.012</td>
<td>0.005</td>
<td>1.05</td>
<td>0.30</td>
<td>5.50</td>
<td>0.06</td>
<td>0.015</td>
<td>0.20</td>
</tr>
<tr>
<td>K</td>
<td>0.34</td>
<td>0.15</td>
<td>0.015</td>
<td>0.005</td>
<td>0.15</td>
<td>0.22</td>
<td>0.25</td>
<td>0.08</td>
<td>0.025</td>
<td>0.05</td>
<td>0.20</td>
</tr>
<tr>
<td>L</td>
<td>0.35</td>
<td>0.20</td>
<td>0.60</td>
<td>0.010</td>
<td>0.040</td>
<td>1.60</td>
<td>0.20</td>
<td>1.50</td>
<td>0.05</td>
<td>1.000</td>
<td>0.05</td>
</tr>
<tr>
<td>M</td>
<td>0.24</td>
<td>0.10</td>
<td>1.00</td>
<td>0.010</td>
<td>0.003</td>
<td>1.05</td>
<td>0.10</td>
<td>0.15</td>
<td>0.05</td>
<td>0.000</td>
<td>0.05</td>
</tr>
</tbody>
</table>

› Various combination of different process units ...

› …requires clever process modelling
The integrated metallurgical models dynamically (cyclic) calculate the temperature, the mass and the chemical composition of the steel bath and the slag along the whole process route.
Typical results of degassing model

Results presented at AISTech2016 together with DEUTSCHE EDELSTAHLWERKE
Typical process route for tool steels
Casting - Trends

- Bottom pouring is still the dominant process
- Two major trends can be observed:
  1. Mechanisation / automation of ingot casting
  2. Continuous casting
ATS – advanced teeming system
Segment Casting

› Tool steels usually cannot be cast on a bow type caster. Vertical CC have enormous investment cost. Therefore new plant concepts have to be developed.

› **Features**
  › Semi-continuous vertical casting process
  › Combination of advantages of vertical ingot casting with continuous casting
  › Casting steel grades that cannot be cast on a conventional bow-type caster (i.e. alloyed and special steels)
  › Suited for all casting shapes (round, square, rectangular, slab)
  › Up to 1200 mm diameter
Segment Casting – Client (Europe)
Typical process route for tool steels
Why 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

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
Comparison NMI conventional route VS remelted material

Source: G. Reiter (Böhler special steel), LMPC 2013, Austin Texas
One main objective in ESR is a constant stable remelting rate (given in orange) in order to achieve consistent product quality.
Surface quality ESR

ø1000mm ESR ingot 1.2083
250,000 tons remelted
Typical process route for tool steels
World Market

PM Industry Supply 2014(e) by Steel Type

World Fe-based PM Production 2005 to 2014 (e)

Data provided by SMRI!

www.inteco.at
In the traditional method, pre-alloyed metal is poured into a funnel, acting as a fairly small tundish; no temperature control and high risks of entrainment of slag.

The 1st generation is a development of the traditional method to produce powder in an atomizing chamber utilizing a tundish (approx. 1 t), requiring frequent refilling which leads to entrainment of slag.

The 2nd generation is applied for the ERASTEEL ASP® and DvalinTM process, where a larger tundish (7 t and 14 t) is utilized in combination with Argon stirring and INTECO’s electro-slag heating (ESH) system, leading to higher powder cleanliness with reduced slag entrainment.

The 3rd generation is applied for the BÖHLER UDDEHOLM microclean® process, where a larger tundish (approx. 8 t) in combination with INTECO’s ESH and electromagnetic stirring system is used, leading to extremely high powder cleanliness, optimized atomization and closed powder handling.
HSS Powder Production - Today

MicroClean® Process
8 t Tundish & Electromagnetic Stirring & ESH

PM Herstellungsverfahren
PM Production Route

Source: Böhler Edelstahl

INTECO
INTECO IHEC

www.inteco.at
HSS Powder Production - Today

Dvalin™ Process:
14 t Tundish & Argon Stirring & ESH

Graphite electrodes for heating and temperature regulation
Slag cover
Molten steel
N2 - Gas

Atomization of molten steel with nitrogen gas

Hot isostatic pressing
Forging
Rolling

Encapsulation of powder in steel cylinder
Welding together of cylinder after vacuum evacuation

Finished capsules of homogeneous steel

PM
ESH
Dvalin™
with ESH

Inclusions/cm³

Inclusion size (µm)

PM
ESH
Dvalin™
with ESH

90% reduction in number of large non-metallic inclusions

Bend strength [kN/mm²]

M 42
ASP 30
ASP 2030
ASP 2030 with ESH and Dvalin™

Improved bend strength
+20% over our previous ESH technology
+40% over standard powder products (without ESH)
+220% over HSS

Source: ERASTEEL
Outlook: General trends in tool steel melting and casting

Productivity & yield

Production costs

Automation & mechanisation

Product quality

Introduce completely new alloy concepts
THANK YOU