Impact toughness of continuously cooled bainitic steels

H. Roelofs, S. Hasler, Swiss Steel AG, Switzerland
M. Lembke, Steeltec AG, Switzerland
F.G. Caballero, CENIM-CSIC, Spain
Classifying the bainite structure
„Swiss steels“

• Granular bainitic steel of C-Si-Mn-Cr type
  Rm = 1’100 – 1’300 MPa *(hot rolled)*
  excellent machinability

• Granular bainitic steel of C-Mn-B type
  Rm = 700 – 800 MPa *(hot rolled)*
  Z = 60 – 70% *(hot rolled)*
  excellent formability

• Lower bainitic steel of C-Mn-B type
  Rm = 900 – 1’100 MPa *(hot rolled)*
  Z = 60 – 70% *(hot rolled)*

Commercial grades

HSX®Z12
HSX®130
Swissbain-7MnB8
Granular bainitic steel of C-Si-Mn-Cr type

HSX®Z12

<table>
<thead>
<tr>
<th></th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>S</th>
<th>Cr</th>
<th>Mo</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>~0.23%</td>
<td>~1.0%</td>
<td>~1.55%</td>
<td>~0.15%</td>
<td>~1.5%</td>
<td>~0.15%</td>
</tr>
</tbody>
</table>
Granular bainitic steel of C-Si-Mn-Cr type

Steel microstructure

~70% bainite
~15% retained austenite
~15% martensite

HSX®130HD

HSX®Z12
Granular bainitic steel of C-Si-Mn-Cr type

Impact toughness depends on cooling rate

Charpy V-Notch at RT in J

bar diameter in mm

HSX®Z12
Granular bainitic steel of C-Mn-B type

<table>
<thead>
<tr>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>Al</th>
<th>V</th>
<th>Ti</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>~0.07%</td>
<td>~0.2%</td>
<td>~1.9%</td>
<td>~0.02%</td>
<td>~0.04%</td>
<td>~0.08%</td>
<td>~15ppm</td>
</tr>
</tbody>
</table>

Mainly granular bainite
15 mm wire rod

- austenite grain size ~25 μm
- cementite-free
- granular (dominant)
  + degenerate upper bainite
Granular bainitic steel of C-Mn-B type

Charpy V-notch impact strength in dependence of re-austenitization temperature and cooling rate

GB = granular bainite
DUB = degenerate upper bainite

Increase caused by finer austenite grain size
## Contributions of phases

<table>
<thead>
<tr>
<th>Austenite grains</th>
<th>Cooling Rate</th>
<th>$V_B$</th>
<th>$V_M$</th>
<th>$V_\gamma$</th>
<th>HV30</th>
</tr>
</thead>
<tbody>
<tr>
<td>large</td>
<td>1.5 °C/s</td>
<td>0.90 ± 0.03</td>
<td><strong>0.08 ± 0.02</strong></td>
<td>0.02 ± 0.01</td>
<td>257 ± 9</td>
</tr>
<tr>
<td>large</td>
<td>9 °C/s</td>
<td>0.89 ± 0.04</td>
<td><strong>0.09 ± 0.03</strong></td>
<td>0.02 ± 0.01</td>
<td>247 ± 5</td>
</tr>
</tbody>
</table>
Granular bainitic steel of C-Mn-B type

Bainite packet sizes (large angle boundaries)

ISO-V at 23°C in J/cm²

- 910°C
- 1200°C

<table>
<thead>
<tr>
<th>Speed</th>
<th>7.3±0.8</th>
<th>13.8±2.0</th>
<th>7.0±1.7</th>
<th>15.2±2.2</th>
</tr>
</thead>
<tbody>
<tr>
<td>hot rolled</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3K/s</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5K/s</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7K/s</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9K/s</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Number of Bainite Grains: ~400
Sizes of M/A-constituents

ISO-Y at 23°C in J/cm²

- 910°C
- 1200°C

- Hot rolled: 1.73±0.84
- 3K/s: 1.30±0.89
- 5K/s: 1.73±0.84
- 7K/s: 1.40±0.58
- 9K/s: 0.12±0.03
Controlling factors

- bainite packet sizes
- size of M/A constituents

Refining the microstructure by TMR techniques or by fast cooling is not always possible ......
## Lower bainitic steel of C-Mn-B type

<table>
<thead>
<tr>
<th></th>
<th>C</th>
<th>Mn</th>
<th>Mo</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>~0.10%</td>
<td>~3.1%</td>
<td>~0.2%</td>
<td>~15ppm</td>
</tr>
</tbody>
</table>
Lower bainitic steel of C-Mn-B type

Charpy ISO-V in J (room temp.)

bainite start temperature in K

<table>
<thead>
<tr>
<th>C</th>
<th>Mn</th>
<th>Mo</th>
<th>B</th>
<th>Bs</th>
</tr>
</thead>
<tbody>
<tr>
<td>%</td>
<td>%</td>
<td>%</td>
<td>ppm</td>
<td>°C</td>
</tr>
<tr>
<td>0.1</td>
<td>3.3</td>
<td>0.20</td>
<td>15</td>
<td>491</td>
</tr>
</tbody>
</table>
A „super-fine“ microstructure after air-cooling

>80% lower bainite, no retained austenite
Lower bainitic steel of C-Mn-B type from air cooling

\[ R_m = 1'068 \text{ MPa} \]
\[ \text{Rp0.2} = 777 \text{ MPa} \]
\[ \text{A5} = 14 \% \]
\[ Z = 69 \% \]
Toughness and machinability

**HSX130®HD**
- C = 0.17 %
- Rm = 983 MPa
- ISO-V (RT) = 20 J

**51CrV4 Q&T**
- C = 0.52 %
- Rm = 1'069 MPa
- ISO-V (RT) = 76 J

**lower bainite**
- C = 0.09 %
- Rm = 1'068 MPa
- ISO-V (RT) = 179 J

---

20 µm
Toughness and machinability

material: 51CrV4  
sample: Ø8 x 10 mm  
tool: VHM drill CD Ø4 mm (7xD)  
$\nu_c: 80\,\text{m/min}$  
$f: 0.2\,\text{mm}$

X-ray tomography
Toughness and machinability

position at the cutting edge

thicker chips ↔ increased forces ↔ higher temperatures

HSX130®HD
51CrV4Q&T
lower bainite
Conclusions

• Low and medium carbon carbide-free granular bainitic steels can exhibit Charpy ISO-V values at ambient temperature > 100J.

Impact toughness of a continuously air cooled lower bainitic steel even is comparable to that of 42CrMo4 Q&T.

• However highest impact toughness is not always needed. Finding the balance between working properties and material characteristics is more essential to realize applications with bainitic-martensitic steels.