Two Bainitic Pre-Tempered Steel Grades for Similar Spring Applications: A New Concept
Authors & Speaker* Information

Dr. Michael Hellmann, Dr. Jean-Marcel Jamet*

Materials Technology Dept.

WAELZHOLZ

jeanmarcel.jamet@waelzholz.com

www.waelzholz.com
Contents

• Cold Rolled Steel Strip
• Introduction to the World of Pre-Tempered Steels
• Materials and Processes: PT140 (AISI 1074 – C75S) vs. 27MnCrB5-2 (AISI 15B30)
• Results – Comparison
• Conclusions and Outlook
The Value Chain

Linking Raw Materials to Customer Needs in Target Markets
Facts & Figures

Business Year 2016/2017

- Employees: 2,100
- Sales Volume in €: 850 millions
- International Share of Sales: > 55%
Customized Material Properties

**Spring Power**
Young’s Modulus

**Magnetic Properties**
Low Core Losses

**Resistance to Wear**
Hardness
Core Processes

Tandem Rolling Mill
Cold rolling mill with the latest monitoring and control technologies

High Convection Annealing
Optimized annealing sequences for a precise set up of the microstructure

Austempering / Hardening and Tempering
Exact temperature control for an optimal flatness
A Global Footprint

USA

Germany

France

Austria

Brazil

China
Waelzholz North America

- A team of 25 employees in Cleveland, OH
- A Service Center with Warehouse activities
- More than 20,000 tons of steel strip, flat wire and profiles
- Dedicated to the North American market
The World of Pre-Tempered Steels

Materials Spectrum

- High strength / micro-alloyed
- Case hardening steels
- Non-earring
- Mild steels
- Steels for quenching & tempering / spring steels
- Texture rolled SORBITEX®
- Annealed +CR
- Soft-annealed +A
- Hardenes & tempered +QT
- PT strip

Tensile strength [ksi / MPa]

C-content [%]
The World of Pre-Tempered Steels

Carbon Steels in Various States

- Skin passed: 93 ksi
- Cold rolled as far as full hard: 170 ksi
- Anealed: 88 ksi
- Anealed dead soft: 83 ksi
- Hardened and tempered martensitic: 276 ksi
- Hardened and tempered bainitic: 225 ksi
- Texture rolled sorbitic: 435 ksi

↑ Tensile strength [ksi]  ➔ Delivery condition
The World of Pre-Tempered Steels

Cold Rolling: Process Stability
The World of Pre-Tempered Steels

TTT Diagram
The World of Pre-Tempered Steels

The Pre-Tempered Steel Grades

<table>
<thead>
<tr>
<th>Medium carbon and spring steel</th>
<th>Martensitic hardening and tempering (+QT)</th>
<th>Austempering / Bainitic hardening Pre-Tempered strip</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grade</td>
<td>Tensile Strength MPa</td>
<td>Grade</td>
</tr>
<tr>
<td>C45E/AISI 1050</td>
<td></td>
<td>PT 90 Mn</td>
</tr>
<tr>
<td>C55S/AISI 1055</td>
<td>1100 - 1700</td>
<td>PT 100</td>
</tr>
<tr>
<td>C60S/AISI 1060</td>
<td>1150 - 1750</td>
<td>PT 110</td>
</tr>
<tr>
<td>C67S/AISI 1070</td>
<td>1200 - 1900</td>
<td>PT 120</td>
</tr>
<tr>
<td>C75S/AISI 1074</td>
<td>1200 - 1900</td>
<td>PT 130</td>
</tr>
<tr>
<td>C85S/AISI 1086</td>
<td>1200 - 2000</td>
<td>PT 140</td>
</tr>
<tr>
<td>C90S</td>
<td>1200 - 2100</td>
<td>PT 150</td>
</tr>
<tr>
<td>C100S/AISI 1095</td>
<td>1200 - 2100</td>
<td></td>
</tr>
<tr>
<td>56Si7/AISI 9255</td>
<td>1200 - 1700</td>
<td></td>
</tr>
<tr>
<td>51CrV4/AISI 6150</td>
<td>1200 - 1800</td>
<td></td>
</tr>
</tbody>
</table>
The World of Pre-Tempered Steels

Stress / Strain Diagrams

Tensile Strength
[ksi / MPa]

PT 120 bainitic
PT 140 bainitic
1060 martensitic
1074 martensitic

15
The World of Pre-Tempered Steels

Applications Ready to use
The World of Pre-Tempered Steels

Bending Properties

TS mean value = 1350 MPa / 196 ksi

TS mean value = 1150 MPa / 167 ksi

\[ r = k \times t \]

90° - transvers
90° - longitudinal
The World of Pre-Tempered Steels

Bending Radii

Minimum Bending Radius for PT-Strip
Bending angle 90°, burr in inner radius

Thickness: .04 inch

<table>
<thead>
<tr>
<th></th>
<th>Transverse to Rolling Direction</th>
<th>Parallel to Rolling Direction</th>
</tr>
</thead>
<tbody>
<tr>
<td>PT120</td>
<td>1.026 mm</td>
<td>1.534 mm</td>
</tr>
<tr>
<td></td>
<td>.040 inch</td>
<td>.060 inch</td>
</tr>
<tr>
<td>PT140</td>
<td>1.940 mm</td>
<td>2.448 mm</td>
</tr>
<tr>
<td></td>
<td>.076 inch</td>
<td>.096 inch</td>
</tr>
</tbody>
</table>
The World of Pre-Tempered Steels

Principle Component Part: A Formability Summary

PT120 1,7 mm thickness and TS 1150 MPa

1. Bending radius in rolling direction
2. Collaring hole by drawing
3. Bending radius transverse to rolling direction
4. Notch
The World of Pre-Tempered Steels

Springback and compensation

Springback-angle [degrees]

0 2 4 6 8 10 12

0.5 1 1.5 2 2.5 Bending coefficient k

PT120

PT140
The World of Pre-Tempered Steels

Spring Production

conventional soft annealed steel strip

- blanking / bending
- hardening and tempering / austempering
- sorting
- reworking (levelling)

assembly

PT - strip

- blanking / bending
- stress relief ~570° F (300° C)

assembly
The World of Pre-Tempered Steels

Summary Bainitic Hardened and Tempered steel strip

• Obsolete piece hardening offers cost savings
• Cost savings due to significant reduction of rejections, reworking and sorting
• Production of parts with most sophisticated contours possible
• Hardness up to 45 HRc
• Wide range of thicknesses (.008 - .120“)
Materials and Processes

PT140 (C75S – AISI 1074): Chemical Composition

<table>
<thead>
<tr>
<th>C [%]</th>
<th>Si [%]</th>
<th>Mn [%]</th>
<th>P [%]</th>
<th>S [%]</th>
<th>Cr [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.70 - 0.80</td>
<td>max. 0.35</td>
<td>0.60 - 0.90</td>
<td>max. 0.025</td>
<td>max. 0.025</td>
<td>max. 0.40</td>
</tr>
</tbody>
</table>

Weight %

<table>
<thead>
<tr>
<th>Weight %</th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
<th>Cr</th>
<th>Mo</th>
<th>Ni</th>
<th>Al</th>
<th>Cu</th>
</tr>
</thead>
<tbody>
<tr>
<td>PT 140</td>
<td>0.70</td>
<td>0.202</td>
<td>0.64</td>
<td>0.011</td>
<td>0.004</td>
<td>0.031</td>
<td>0.002</td>
<td>0.16</td>
<td>0.015</td>
<td>0.01</td>
</tr>
</tbody>
</table>

**Carbon Equivalent**

\[ CE = C + \frac{Mn}{6} + \frac{(Cu + Ni)}{15} + \frac{(Cr + Mo + V)}{5} \]

**CE = 0.81 %**

→ Very poor weldability (CE >> 0.50%)
Materials and Processes

PT140 (C75S – AISI 1074): Austempering (TTT Curve)
Materials and Processes

PT140 (C75S – AISI 1074): Process

CR Strip 0,70 x 24,3 mm (.0275 x .957“)

Austenitization Furnace

S-Rolls

Pre heating canal

S-Rolls

Hardening furnace 11 heating zones

S-Rolls

Metal bath

S-Rolls

Skimmers

Welding machine

Decoiler

Coiler

Shears

Looper

S-Rolls and Air

Cooling after Austempering

Water cooled
Materials and Processes

PT140 (C75S – AISI 1074): Generic Mechanicals

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile strength</td>
<td>[MPa]</td>
<td>1,300 - 1,500</td>
</tr>
<tr>
<td>Yield / tensile ration</td>
<td>[%]</td>
<td>Ca. 80 - 85</td>
</tr>
<tr>
<td>Elongation A80</td>
<td>[%]</td>
<td>Min. 5</td>
</tr>
<tr>
<td>Microstructure</td>
<td></td>
<td>Intermediate stage structure (bainite)</td>
</tr>
</tbody>
</table>
Materials and Processes

PT140 (C75S – AISI 1074): Bending Radius
PT140 (C75S – AISI 1074): Flow Curves

Flow curve calculation acc. to Ludwik: \( k_r = R_m \left( \frac{\varepsilon}{n} \right)^n \cdot q'' \)
Materials and Processes

27MnCrB5-2 (1.7182) – AISI 15B30

Structural and construction steel
Boron Steel

<table>
<thead>
<tr>
<th>Weight %</th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
<th>Cr</th>
<th>Mo</th>
<th>Ni</th>
<th>Al</th>
<th>Cu</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>27MnCrB5-2</td>
<td>0,29</td>
<td>0,235</td>
<td>1,18</td>
<td>0,011</td>
<td>0,0027</td>
<td>0,334</td>
<td>0,001</td>
<td>0,008</td>
<td>0,043</td>
<td>0,009</td>
<td>0,0025</td>
</tr>
</tbody>
</table>

Carbon Equivalent
CE = 0,55 %
→ Still poor weldability (CE > 0,50%) but better than PT140
Materials and Processes

27MnCrB5-2 (1.7182) – AISI 15B30: TTC Curve
Materials and Processes

27MnCrB5-2 (1.7182) – AISI 15B30: Process

CR Strip 0.70 x 24.5 mm (.0279 x .964")
Materials and Processes

27MnCrB5-2 (1.7182) – AISI 15B30: Flow Curve

\[ k_f = R_m \left( \frac{\dot{\varepsilon}}{\dot{n}} \right)^n \cdot \varphi^n \]

\[ \varphi/t = \text{const.} \approx 0.5 \text{ 1/s} \]
Results - Comparison

Microstructure

PT140

100% Bainite

27MnCrB5-2

Bainite + Martensite + Ferrite
Materials and Processes

27MnCrB5-2 (1.7182) – AISI 15B30: TTC Curve
# Results - Comparison

## Tensile & Hardness Testing

<table>
<thead>
<tr>
<th></th>
<th>PT140</th>
<th>27MnCrB5-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>YS [MPa / ksi]</td>
<td>1161 / 168</td>
<td>1139 / 165</td>
</tr>
<tr>
<td>TS [MPa / ksi]</td>
<td>1351 / 196</td>
<td>1293 / 188</td>
</tr>
<tr>
<td>YS / TS</td>
<td>0,86</td>
<td>0,88</td>
</tr>
<tr>
<td>$A_{80}$ [%]</td>
<td>7,8</td>
<td>6,9</td>
</tr>
</tbody>
</table>

### C content
- PT140: 0,70 %
- 27MnCrB5-2: 0,29 %

### Similar Tensile Strengths

### Higher core hardness because of the microstructure (partly Martensite)

<table>
<thead>
<tr>
<th></th>
<th>PT140</th>
<th>27MnCrB5-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>VPN</td>
<td>411</td>
<td>439</td>
</tr>
</tbody>
</table>
Results - Comparison

3-Point-Bending Test

Springback angle = 90° - angle measured

\[ \alpha = 90° \]
### Results - Comparison

#### Bending Test - Springback

<table>
<thead>
<tr>
<th></th>
<th>PT140</th>
<th>27MnCrB5-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Springback angle r = 1mm</td>
<td>22,9 °</td>
<td>22,2 °</td>
</tr>
<tr>
<td>Springback angle r = 8mm</td>
<td>38,9 °</td>
<td>39,9 °</td>
</tr>
<tr>
<td>Springback angle r = 12mm</td>
<td>37,3 °</td>
<td>39,6 °</td>
</tr>
<tr>
<td>Springback angle r = 16mm</td>
<td>43,6 °</td>
<td>50,0 °</td>
</tr>
</tbody>
</table>
Results - Comparison

Bending Test - Springback

Core hardness has more influence on springback than tensile strength
Conclusions - Outlook

Conclusions

- Similar TS values, PT140 is more ductile (microstructure)
- Slightly different routings with Austempering (bainite+)
- Springback values move apart with increasing bending radius
- Spring related applications according to the characteristics
Conclusions - Outlook

Outlook

Use of decarburized surface of bainitic hardened steels for special applications requiring a better bending ability with a high core hardness → steel rule diecutting
Outlook

Steel Rules for Diecutting

Advantages of decarburized Strip

Cold rolled strip bainitic hardened

Cold rolled strip bainitic hardened with partial or total decarburization (Open Coil annealing step)
Outlook

Steel Rules for Diecutting
Carbon content and hardness adjusted to customer needs

Bainite (hard)
Decarburized (good formable)
Martensite (very hard)

Edge inductive hardened by customer
Outlook

Steel Rules for Diecutting

Strip Characteristics:

- Thickness (0.5 – 1.5 mm)
- Hardness (VPN 340 – 440)
- Bendability
- Steel grades (C 0.25-0.85%)
Thank you for your attention!

Dr. Jean-Marcel Jamet
Materials Technology Dept.
WAELZHOLZ
jeanmarcel.jamet@waelzholz.com
Reminders

Thursday, October 5
Exhibit Hall Open: 10:00AM – 2:30PM