How Modern Steel Development Can Help Optimizing Cost and Sustainability of Bridge Constructions

Dr. Tobias Lehner
Bridge construction today

Drivers in modern bridge construction:

- Fabrication cost: cost reduction puts high pressure on fabricator
- Sustainability: environmental aspects are gaining more and more weight
- Architectonical...
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HOW CAN MODERN STEEL CONCEPTS HELP?

- High recyclability ⇒ general advantage of steel ⇒ resource-conserving

- Modern steel concepts can significantly reduce cost and energy of fabrication and transport
  - Reduced energy consumption, e.g. better weldability ⇒ no preheating energy
  - Higher Safety e.g. steels with high toughness level ⇒ faster welding possible
  - Weight reduction, e.g. higher strength material ⇒ thinner cross-sections
  - Less maintenance, e.g. weathering steel and combinations, e.g. weathering steel with improved weldability

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Modern Steel Concepts

I. Thermomechanically rolled steel

II. High strength steel

III. Weathering steel

IV. Longitudinally profiled (LP)
**General heavy plate production – from ore to steel plate**

- **Cooking plant**
- **Blast furnace**
- **Sintering plant**
- **Steel plant**
- **Ingot casting**
- **Pig iron desulphurisation**
- **Converter**
- **Secondary metallurgy**
- **Continuous casting**
- **Rolling mill**
Modern steel concepts

Different Rolling Procedures

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Modern steel concepts – thermomechanically rolled plates

TM CP PRODUCTION PROCESS

Verfasser/Dokument: 11.08.2014 Istanbul Bridge Conference
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TMCP → Grain Refining

\[ \gamma \text{ crystallized} \quad \gamma \text{ not crystallized} \quad \gamma + \alpha \quad \alpha \]

Heating

Phase 1: grain refining (2)

Phase 2: New-rolling (3)

Accelerated Cooling (4)

Cooling on air

Annealing

Typical steel grades for steel construction =

S 355ML and S 460ML

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**Modern steel concepts – thermomechanically rolled plates**

**TM CP ⇒ GRAIN REFINING**

- Normalized
- TM (air)
- TM (ACC)

**Hall-Petch:**

- **Grain size**: $\downarrow$
- **Strength**: $\uparrow$
- **Toughness**: $\uparrow$
- **Excellent weldability**

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Typical TMCP Grades

European Standards EN 10025-4
  e.g. S 355M /M L
  S 460 M /M L

ASTM Standards
  e.g. A 1066 Gr. 50
  A 1066 Gr. 65

Dillinger Hütte
  e.g. D I - M C 355T (acc. to EN 10025-4)
  D I - M C 460 B (acc. to EN 10025-4)

DILLIMAX 500 M L

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Modern steel concepts – thermomechanically rolled plates

Benefits – low alloying content

![Graph showing yield strength vs. carbon equivalent (IIW) CE %]
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Benefits – Reduction of preheating according to EN 1011-2 method B

- Reduced fabrication time
- Less energy needed
- High cost-effectiveness

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Modern steel concepts – thermomechanically rolled plates

Cost/time savings by using TM-Steels

Same strength grade (S355N ⇒ S355M - S460N ⇒ S460M):

Avoidance of preheating

- Less consumption of electric power for preheating
- Time heating up
- Shorter setup times due reduced cooling times is the main saving
- Also in terms of job safety, low preheating temperatures are beneficial
  - No hot surfaces and no handling with gas
  - Better working conditions

High toughness values

- In 11.08.2014 Istanbul Bridge Conference choosing a faster welding process
Modern steel concepts – thermomechanically rolled plates

ADVANTAGES OF TM CP STEEL

TM ➔ lower carbon equivalent
  ➔ excellent weldability
  ➔ no or less preheating
  ➔ cost as well as time savings

TM ➔ high toughness
  ➔ toughness buffer for secure fabrication
  ➔ additional construction safety

TM ➔ improved surface quality
Modern steel concepts – thermomechanically rolled plates

RECORD-BREAKING – with TMCP
Viaduc de Millau, France

- ca. 18,000 t D I - M C 4 6 0
  (o f 4 3 , 0 0 0 t total delivery)
- at present longest cable

Makkah Royal Clock Tower Hotel, Saudi Arabia

- ca. 1,000 t S 4 6 0 M L
- at present longest cable

Verasser/Dokument
Modern steel concepts – higher strength steel

Different routes to obtain higher strength steel:

- **Alloying**
  - Higher carbon equivalent, decreasing weldability
  - Increasing brittle fracture tendency

- **Thermo-Mechanically Rolling**
  - Mainly up to S460M
  - Low carbon equivalent ⇒ excellent weldability

- **Quenching and Tempering**
  - Most commonly used method to produce high strength steel
  - Additional heat treatment
  - Applied after hot rolling
  - Up to 1300 MPa, in steel construction up to S690QL
  - Good weldability

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Modern steel concepts – higher strength steel

Typical steel grades for steel construction = S 460QL and S 690QL

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Modern steel concepts – higher strength steel

Normalising + Thermo-Mechanically Rolled

Normalising Quenching + Tempering

up to 460 MPa
up to 960 MPa
up to 460 MPa

standardised in standardised in standardised in

EN10025-3 EN10025-4 EN10025-6

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Modern steel concepts – higher strength steel

Benefits

- Slender, filigree construction
  - Enabling of architectural specialities
  - Thinner cross-sections possible
  - e.g. S355-S460 \( \Rightarrow \) Reduction of thickness: app. - 30 %

- Multiple effects on the cost and eco-balance
  - Less material needed
  - Lower transport weight
  - Bigger assembly units
  - Less transport cost

- Sustainable and economical
**Modern steel concepts – higher strength steel**

**BENEFITS**

- thinner cross-sections possible
- reduced weld volume
- less filler metal
- less fabrication
  - reduced welding time
  - reduced testing time

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**Figure 2: Material and fabrication costs for welding:**

DILLIMAX steels in comparison to conventional S355 steel

<table>
<thead>
<tr>
<th>Plate Thickness</th>
<th>S355</th>
<th>DILLIMAX S550</th>
<th>DILLIMAX S690</th>
<th>DILLIMAX S890</th>
<th>DILLIMAX 965</th>
<th>DILLIMAX 1100</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>100%</td>
<td>80%</td>
<td>60%</td>
<td>53%</td>
<td>47%</td>
<td>43%</td>
</tr>
</tbody>
</table>

Relative total costs in %

- 65 mm
- 42 mm
- 33 mm
- 26 mm
- 24 mm
- 21 mm

*Plate thickness*

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*Extracted from “DILLIMAX – Technical Information”*
Modern steel concepts – higher strength steel

REFERENCES – Samuel Beckett Bridge, Dublin, Ireland

Top of the pylon due to its exceptional stress situation from high strength quenched and tempered fine grain steel DILLIMAX 690T (plate thickness 180 mm)
Modern steel concepts – higher strength steel

COMBINATION – High strength + TM CP

Typical Carbon Equivalents for different steel grades (plate thickness 50 mm)

<table>
<thead>
<tr>
<th>Steel grade</th>
<th>typical CET/%</th>
<th>typical CEV/%</th>
<th>max. CEV/% acc. EN 10025</th>
</tr>
</thead>
<tbody>
<tr>
<td>S 355J2 +N</td>
<td>0.31</td>
<td>0.42</td>
<td>0.45</td>
</tr>
<tr>
<td>S 355M L</td>
<td>0.24</td>
<td>0.36</td>
<td>0.40</td>
</tr>
<tr>
<td>S 460M L</td>
<td>0.25</td>
<td>0.39</td>
<td>0.47</td>
</tr>
</tbody>
</table>

CE ↓ ⇒ cold cracking tendency ↓  ⇒ toughness in HAZ ↑

Low alloying ⇒ Excellent weldability

TM Steels = higher strength while maintaining excellent weldability !!!
Modern steel concepts – Weathering Steels

PROPERTIES
- different grades according to EN und ASTM available
- alloying elements build an oxidic protection layer, which increases the resistance against atmospheric corrosion (Patina)

Significant lower rusting rate
Modern steel concepts – Weathering Steels

BENEFITS

- Corrosion protection can be omitted
  ⇒ Reduction of fabrication time
- No need for repainting
  ⇒ Optimized maintenance costs
  ⇒ Bigger maintenance intervals
- Better lifecycle cost and sustainability
  (investigated in different research projects, e.g. SBRi, NaBrü)
  ⇒ e.g. reduced global warming potential (NaBrü)
  ⇒ Reduced lifecycle cost (SBRi)
Modern steel concepts – Weathering Steels

Limits of Application

- Special care in construction necessary
- Avoid details which cannot sufficiently dry

Different guidelines available

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Modern steel concepts – Weathering Steels

LIMITS OF APPLICATION

Not applicable:

– Next to the sea (chloride): distance of 2 km

– In regions and places with constant high humidity (e.g. in short distances to water)

– In regions with a high SO₃-level (2.1 mg/100 cm³)
Modern steel concepts – Weathering steel

COMBINATIONS – Weathering steel + High strength + TM CP

Typical Carbon Equivalents for different steel grades:

<table>
<thead>
<tr>
<th>Steel grade</th>
<th>typical CET/%</th>
<th>typical CEV/%</th>
</tr>
</thead>
<tbody>
<tr>
<td>A 709-345W</td>
<td>0.35</td>
<td></td>
</tr>
<tr>
<td>(normalized)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A 709-485W (TM CP)</td>
<td>0.28</td>
<td>0.47</td>
</tr>
</tbody>
</table>

Carbon equivalents:

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

\[ CE\ T = C + \frac{(Mn + Mo)}{10} + \frac{(Cr + Cu)}{20} + \frac{Ni}{40} \]

TM Steels = higher strength + weathering steel while maintaining good weldability !!!

New European standard EN 10025 will introduce S460 Weathering Steel !!!

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Modern steel concepts – Weathering steel

REFERENCES:
Golden Horn Metro Bridge, Istanbul, Turkey
- ca. 13,000 tonnes
- A709M HPS 345W
- A709M HPS 485W (TMCP)
Modern steel concepts – LP-plates

PROFILEs
- every constructional steel up to S460 in delivery condition as rolled or normalised
- Software tool to prove feasibility available at www.dillinge-r.de /E-Service
M odern s teel c oncepts – LP -pl ates

A D VA NTA G E S

- O ptimization of fatigue behavior
  - optimizing the cross-sectional area to the effective stress profile
  - moving the welds in less stressed regions
  ⇒ Improved safety for construction

- C o st s a vings
  - Lower weight of construction
  - Lower transport and assembly weights
  - Reduced number of welds

⇒ Reduction in fabrication/testing time as well as fabrication cost
**Modern steel concepts – LP-plates**

**Example for cost reduction**

**Optimum Structure**

<table>
<thead>
<tr>
<th>Possible solution</th>
<th>Weight</th>
<th>Number of welds</th>
<th>Total costs</th>
<th>Relative costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>120</td>
<td>12 t.</td>
<td>1</td>
<td>7,900 €</td>
<td>100</td>
</tr>
<tr>
<td>120</td>
<td>18 t.</td>
<td>0</td>
<td>8,300 €</td>
<td>105</td>
</tr>
<tr>
<td>120, 80</td>
<td>15 t.</td>
<td>1</td>
<td>8,150 €</td>
<td>103</td>
</tr>
<tr>
<td>120, 93, 67</td>
<td>14 t.</td>
<td>2</td>
<td>8,940 €</td>
<td>113</td>
</tr>
</tbody>
</table>

*Grade S 355 J2 G2, Assumed price: 460 €/t, surcharge LP: 75 €/t*

*Costs MAG-welding: 67 mm = 20 h; 80 mm = 25 h; 93 mm = 30 h; 120 mm = 40 h*
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How can modern steel concepts help?

Economic and ecologic usage of raw material and energy

- Less transport energy
- Less raw material (e.g., steel and filler metal)
- Less fabrication energy
- Weight reduction
- Reduced weld volume
- No or less preheating
- High strength steel or LP plates
- TMCP
Thank you very much for your attention