High-strength heavy plates for modern European medium and large span bridges

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ABSTRACT
The application of modern high-strength steel plates enables bridge designers to an efficient cost- and time-saving construction of steel and composite bridges which may also satisfy the highest architectural demands on aesthetics and elegance. In particular heavy steel plates with their wide range of currently available steel grades and dimensions fulfil an important role in the future advancement of steel and composite bridges. These products offer very efficient technical solutions for modern medium and large span bridges. This will presented in several examples.

1. USER-ORIENTED DEVELOPMENT OF HEAVY PLATES
At present heavy plates are widely used in constructional steelwork. Among these in particular the steel grades between S235, S275 and S355 (that means a yield stress of 235, 275 and 355 MPa respectively) are very popular. These steel grades are defined by the standards EN 10 025 and EN 10 113-2 for special normalized fine-grained grades fulfilling higher toughness requirements.
The further development of steel products for bridges was driven by the aim of enhancing the workability of the steel, that means in particular the weldability in order to reduce fabrication costs in the bridge workshop and at site and to ensure high operating safety in particular by disposing outstanding thougness values against brittle fracture.
By the thermomecanical (TM) rolling process [1] adapted from the linepipe production the alloying content, which is often summarized by the various carbon equivalents, could be reduced (Figure 1).
Low alloying contents and especially a low carbon content reduce the tendency of cold cracking and hardening during the welding process. Section 2 deals with the properties of TM-steel in detail.
Furthermore by the TM-process higher yield strength grades with a yield stress of up to S460M are today possible for bridgebuilding – offshore construction uses already grades up to S550M. The main point is that additionally to the high strength an acceptable carbon content
is simultaneously guaranteed. This high-strength grade has been used for plenty of bridges in Europe. However, even higher-strength steel grades are today available and used for special bridge components. For instance, the steel S690Q, which is produced by a combined quenching and tempering process, allows a design of parts fulfilling the highest requirements on esthetics and "slimness". Though in Germany this steel grade is allowed for constructional steelwork in thicknesses up to 50 mm, it is very rarely used at the moment. On the contrary, the US and Japanese bridge markets show a significant market share for these highest-strength steel grades.

Another development should not be neglected. The weather-resisting steel, which was already developed in the 1930s, forms a dense patina by alloying elements such as nickel, chromium, copper and molybdenum. This patina stops the further corrosion process so that a painting of the steel structure can be avoided. Only a few design rules have to be obeyed to ensure this advantageous material behaviour [2]. Unfortunately this group has not found much attention in Europe. Contrarily, US bridge designers have recognized the costs benefits of this steel group. Thus, the market share for weathering steel in bridgebuilding is about 50 % there.

2. TM-ROLLED STEEL GRADES

Use of the TM-process first of all requires a very precise adaptation of the chemical composition to the subsequent rolling process. Typical chemical analyses for heavy plates with a yield strength of 355 are given in the Table 1. The comparison with normalized steel grades shows the strong reduction of the carbon content and the addition of so called microalloying elements such as niobium. These low alloying contents reduce the values of the various carbon equivalents used to describe the suitability for welding. Classical steel normally reaches CE-values of about 0.1% higher compared with values for TM-rolled plates of the same thickness.

The TM-rolling process includes a large variety of realization possibilities from the manufacturers point of view. In any case the desired properties are achieved by a special time and temperature sequence including a defined number of rolling stages at prescribed temperature ranges interrupted by cooling periods and cooling after finish rolling either on air or in a water cooling line. The metallurgical result is a reduction of the austenitic grain size resulting also in a fine final ferritic grain size giving the product excellent toughness as well as high strength values.
The most significant advantage of TM-plates compared with normalized plates of equal thickness is their suitability for welding characterized by two main features: on the one hand, preheating of thicker TM-plates can be significantly reduced or omitted completely, which allows considerable savings in fabrication time and costs. On the other hand, TM-plates exhibit high toughness values and low hardening values in the heat affected zone (HAZ) after welding.

<table>
<thead>
<tr>
<th></th>
<th>S 355 J2G3</th>
<th>S 355 ML</th>
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<tr>
<td></td>
<td>according</td>
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<tr>
<td>C</td>
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</tr>
<tr>
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<tr>
<td>CET</td>
<td>0,32</td>
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Carbon equivalents:

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

Pcm = C + \( \frac{Si}{30} \) + \( \frac{Mn + Cu + Cr}{20} \) + \( \frac{Ni}{60} \) + \( \frac{Mo}{15} \) + \( \frac{V}{10} \) + 5B

CET = C + \( \frac{Mn + Mo}{10} \) + \( \frac{Cr + Cu}{20} \) + \( \frac{Ni}{40} \)

![Fig. 2. Preheating temperatures for S355ML according to SEW 088](image)

Due to the risk of hydrogen-induced cold cracking common grades such as S355J2G3 have to be preheated for welding in thicknesses thicker than 30 mm. In dependence of the constraint in the structure an S460N has already be preheated in thicknesses from 10 or 12 mm. On the contrary, Figure 2 exhibits the preheating temperatures for S355M plates according to the SEW 088 [3] for different heat input energies. A 50 mm thick S355M-plate can be welded, e.g. with a filler metal consumable with a hydrogen content lower than 5 ml/100g deposit metal without preheating. Lower hydrogen contents allow an omitting of preheating even for
larger thicknesses. For submerged arc welding the maximum acceptable plate thickness for welding with such a hydrogen content is even larger. Even S460ML can mostly be welded without any preheating up to thicknesses of 80 mm.

Strong toughness requirements for the heat affected zone have often been a problem for normalized grades, in particular when high heat inputs have been applied. TM-plates offer the possibility of using a high heat input and simultaneously obtaining excellent toughness values in the HAZ. So in weldings of S460ML the impact energy measured in HAZ exceeds mostly 100 J, so that best toughness requirements are fulfilled.

3. DIMENSIONAL OPPORTUNITIES

The efficiency of a steel or composite construction is not only affected by the steel grade used. Nowadays, steel products, and in particular heavy plates, can be delivered in a wide range of dimensions. Employing this full range of dimensional possibilities structural safety can be enhanced and fabrication costs can be minimised due to the reduced number of weldings.

For instance heavy plates in common steel grades are today available in the following dimensions: width up to 5200 mm, length up to 36000 mm and thickness up to 250 mm. The big lengths and widths available enable the minimisation of cost- and time-intensive longitudinal and transverse weldings in particular for deck components of the bridge. By taking advantage of the full thickness range offered, the well know lamellae packets for flanges of common bridge girders made by welding together two or three single lamellae of up to 50 mm thickness can be avoided. It is clearly understood that the minimisation of the welding procedure also reduces fabrication costs.

![Fig. 3. Various shapes of LP-plates available](image)

Also the deliverable range of TM-rolled products is steadily increasing. Today, plates of S460M have already been applied in bridgebuilding in thicknesses up to 120 mm. The demand to reduce weight, i.e. the reduction of the dead weight of the structure and the reduction of the total volume of steel required, was the starting point for the development of the longitudinally profiled plates (LP-plates) [4]. By a special control of the rolling gaps during the rolling process a longitudinal profile with a continuously varying thickness along the length can be given to a heavy plate. Thus, various types of LP-plates with various geometries can be produced (Figure 3). Such plates allow an optimised adaptation of the plate thickness to the actual stress in the structure. Today, LP-plates are applied in bridgebuilding
all over Europe. Besides reducing the weight, the application of LP-plates saves also fabrication costs and time due to the possibility of avoiding complicated weldings.

4. EXAMPLES

As far as medium-span bridges are concerned, that means by definition bridges with a span between 30 and 150 m, the application of steel has significantly increased during the past decade in particular due to the development of very cost-efficient composite bridge designs. These bridges consist of a steel carrying structures in the lower tension zone, closed box girders, welded or rolled I-girders or open box girders, and a concrete deck in the pressure zone. In this way the specific advantages of the materials steel and concrete are combined in an optimized and, therefore, cost-efficient way.

These structures can strongly profit from the wide range of deliverable heavy plates. For example Figure 4 shows the bridge of Rémoulins in the south of France. For this double-girder constructions a combination of the TM-steels S355ML and S460ML was used. The high-strength S460ML was especially applied in the highly stressed areas near the piles to reduce the maximum thickness. So only a maximum thickness of 80 mm instead of 120 for the solution purely in S355ML was necessary resulting in weight reduction and an easier fabrication and erection procedure.

Fig. 4. Bridge of Rémoulins and repartition of steel grades in the main girders

Figure 5: Bridge of Schengen and Application of LP-plates in the upper flange

An example for the usage of LP-plates gives Figure 5, the Schengen-viaduct across the river Mosel. From the 3900 t of structural steel, 1200 t were rolled as LP-plates. The right picture shows the application of the wedge-shaped plates in the upper-flanges of this bridge.
Nevertheless, bridges with a big span are still the domain of steel products. Furthermore it is now nearly unthinkable, that these outstanding bridges can be built without high-strength grades. An example for this is the well-known Erasmus-bridge in Rotterdam of a total length of 499 m consisting of an 410 m-span cable-stayed bridges with a 89 m-span flap bridge and a 139 m-high pylon. For the whole construction, which is a really outstanding landmark for the city of Rotterdam 4200 t of S355M (thickness up to 100 mm), 2000 t of S460L (thickness up to 80 mm) and some S460 QL (thickness up to 125 mm) had been used [5].

Another example is still in the construction. The bridge Ilverich (Figure 6) across the river Rhine near Düsseldorf will be opened for traffic according to the schedule in the middle of 2002. Due to the situation in the landing zone of the near airport the constructions height of this cable-stayed bridges with a main span of 275 m had to be hold as small as possible. Therefore, the pylons were designed in the shape of a V, whose legs are connected by a cross beam at the top. In order to ensure that the pylon can bear the high arising charge, the pylon heads were performed in a modified S460ML with thickness up to 100 mm. For this steel the controlling institution demanded for special toughness values which had to be proven by a successful impact test at -80°C. Altogether 700 t of S460ML were used for the pylons plus more than 4.000 t of S355J2G3 for the bridge deck.

![Fig. 6: Animation of the futurus Ilverich-bridge](image)

5. CONCLUSION
The steelmakers offer presently a wide range of products suitable for modern bridgebuilding. Among these, heavy plates offer nearly unlimited design opportunities by a wide range of dimensions and steel grades.

However, the full potential of modern steel products is still rarely used. Therefore, further work will be necessary to inform bridge designers about the advantageous construction methods offered by these steel products.

6. REFERENCES
2. Fischer M., Stahl, 1992, Dez., 63-68