# Hot rolled Steel Plates, Sheets and Coils

## Structural steels

Optim QC

Optim QC is a family of ultra high-strength steels that enables higher performance levels for vehicles and lifting equipment. The ultra-high strength, reasonable wear-resistance and the accuracy of dimensions and form of these steels open new possibilities for designers. Optim QC makes equipment manufacturing more efficient thanks to its good weldability, flangeability and lower unit weight. The properties of Optim QC promote environmentally friendly construction and sustainable development. Residual stress relief carried out by the efficient Dead Flat process (straightening rolling) ensures that cut lengths of strip are always flat and without any residual stress.

**Applications**

- Chassis and bodywork of commercial vehicles
- Booms of forest machinery
- Crane arms and other lifting equipment
- Load handling equipment
- Load support and fastening equipment
- Feeding and unloading hoppers
- Containers

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**Description of the steel grades**
Optim QC offers simultaneously very high strength, good workability in prefabrication and reasonable wear resistance. The surface quality of the steels, the accuracy of dimensions and form and consistency of properties include the best in the market. This allows lighter steel structures, higher payloads for machinery and equipment and a lower energy consumption.

**Designation**
This family of ultra high-strength steels includes the Optim 900 QC, Optim 960 QC and Optim 1100 QC grades. The figures in the designations refer to the minimum yield strength in MPa. The letter "Q" stands for quenching, which is the manufacturing method and delivery condition for these grades. The letter "C" stands for cold formability.

**Forms of delivery**
Cut lengths and coils.
Cut lengths and coils can also be delivered as pickled. Slit coils may be delivered by separate agreement.

**Dimensions**
Thickness: 2.5 – 6.40 mm; Optim 900 QC and Optim 960 QC grades.
Thickness: 2.5 – 6.00 mm; Optim 1100 QC grade.
Max. width: 1560 mm.
Length of cut lengths: 2000 – 12,000 mm.
Deliveries and dimensions of pickled products have to be agreed on separately.

**Tolerances on dimension and shape**
**Cut lengths**
Thickness, width and length: EN 10051.
Flatness: EN 10029 Class N, steel type H.
**Coils**
EN 10051.

**Delivery condition**
Quenched.

**Dead Flat process (straightening rolling) of cut lengths**
In the Dead Flat (DF) process, or straightening rolling, cut lengths are cold formed throughout their thickness resulting in a plastic, i.e. permanent deformation. At the same time, any residual stresses are relieved and the cut length receives excellent flatness. Controlling welding distortions becomes easier and repeatability in flanging is improved. When being cut, DF products will retain their flatness and no further straightening is required before the subsequent process stages. The DF process improves the surface quality of Optim QC cut lengths and lowers the roughness value of the surface finish. Flat and stress-relieved cut lengths will reduce the throughput time in sheet metal processing. The DF process will be noted in the inspection document.

**Compliance with standards**
The steels are not directly compliant to any standards of structural or other steels.

**Chemical composition**
The chemical composition is shown in Table 1.

**Microstructure**
Ultra high strength steels have a dual-phase microstructure consisting of bainite and martensite. The average grain size is in the order of magnitude of one micrometre (μm). The grades are classified according to the microstructure either as dual-phase (DP) or complex-phase (CP) steels, as the bainite consists of several phases in terms of metallography.

**Carbon equivalent value (CEV)**
Considering the high strength of the steels, the CEVs are low. Typical and maximum CEVs determined on the basis of the chemical composition are shown in Table 2.

**Mechanical properties**
The mechanical properties – yield strength, tensile strength, elongation and impact strength – are shown in Table 3. Typical strength properties are shown in Table 4.

**Wear resistance and hardness**
The average hardness of the quenched, bainitic-martensitic Optim QC steels is slightly over 300 HBW, in other words twice the hardness of S355 structural steels. The high hardness and tensile strength indicate good wear resistance.

**Materials testing**
The Optim 900 QC and Optim 960 QC grades are tested according to the EN 10149-1:1995 standard (Hot-rolled flat products made of high yield strength steels for cold forming. Part 1: General delivery conditions). The tensile test and impact tests are taken with test pieces longitudinal to the rolling direction.

For the Optim 1100 QC grade, the tensile test is taken with a transverse test piece, but the impact test with a longitudinal test piece. Flanging tests of all ultra high-strength steels are taken with transverse test pieces. Formability is tested with the flanging test because it better corresponds with flanging in workshop conditions than the bend test.

**Inspection documents**
Inspection certificate EN 10204-3.1.

## Welding

Ultra high-strength steels can be easily welded by all conventional methods as long as general welding instructions for steels and the specific recommendations in this data sheet are followed. Preheating is not normally required, as the steel plates are thin and their CEV values are reasonable. The hydrogen content of the weld must be kept very low due to the ultra-high strength of the steel. Groove surfaces must be dry and clean during welding. When welding ultra high-strength steels, particular attention must be paid to reasonable heat input values and proper selection of welding consumables.

### Welding methods

The most commonly used welding method is gas-shielded arc welding either with solid wire or a flux-cored electrode. Other recommendable methods include laser welding and the combination method of pulse MAG and laser MAG also known as laser-hybrid welding. All of these allow high-quality welding with low, concentrated heat input. Metal arc welding with covered electrodes may be used, particularly for minor repairs.

### Softened zone

Proper restriction of heat input is essential because high heat input in particular will create a zone softer than the parent metal in the welded joint. The zone is located in the heat affected zone (HAZ) of the joint. Even though this zone is narrow, it must be taken into account, when designing the structure and welding. Welded joints must be avoided in the most stressed parts of a structure.

### Selection of welding consumables

Welding consumables should be selected according to the requirements set by the structure to be welded. The type of joint and welding position also affect the selection. When welding ultra high-strength steels, either matching (high-strength) or undermatching (softer than the parent metal) consumables can be selected. Ultra high-strength steels require unusually low-weld hydrogen content, HD ≤ 5 ml/100 g. Due to this, only low-hydrogen type consumables may be used.

### Matching consumables for the Optim 900 QC and Optim 960 QC grades

Matching consumables must be used when a welded joint is to have strength properties close to those of the parent metal. Matching consumables have a standardised yield strength class of 89 (min. 890 N/mm$^2$). For the Optim 900/960 QC grades, the following matching consumables are recommended: covered electrodes as per EN 757 89 6 Z B 42 H5 and MAG consumables as per EN 12534 GMn4Ni2CrMo (mixed gas argon + $CO_2$). Matching consumables in compliance with the standards include the brands presented in Table 5.

### Slightly undermatching consumables for the Optim 1100 QC grade

There are few commercially available welding consumables for the stronger Optim 1100 QC grade. As slightly undermatching consumables as possible must be used when a welded joint is to have strength properties close to those of the parent metal. Such consumables are shown in Table 5.

### Instructions to achieve strong welded joints with the Optim 900 QC and Optim 960 QC grades

When a welded joint is to have an equal strength with the parent metal the tempering effect of the heat input caused by welding in the heat affected zone (HAZ) must be limited. The following measures are recommended to this end:

- Methods with a low heat input such as laser welding, pulse MAG and laser MAG are favoured.
- For a strip thickness of > 4 mm the max. arc energy should be 0.5 kJ/mm and for a thickness of less than 4 mm it should be 0.4 kJ/mm.
- The designed cooling time from 800°C to 500°C ($t_{8/5}$) should not exceed 4 seconds.
- The aim is to achieve as low a groove volume as possible. The lower the volume of molten material deposited in a single run the smaller the amount of heat and the resulting softening. For example, the bevel angle for a butt joint in single V and a single bevel (HV) grooves for thicknesses of > 4 mm should be max. 50°.
- In multi-run welding, room temperature (+20°C) is used as the interpass temperature.
- Surfaces to be welded should be kept clean, dry and at least at room temperature, to eliminate the need for preheating.
- For MAG welding, solid wire of the strength class 89 (min. 890 MPa) with a diameter of 1.0 mm as per EN 12534:2000 (Welding consumables. Wire electrodes, wires, rods and deposits for gas shielded metal arc welding of high strength steels. Classification) should be used.

### Undermatching consumables

The use of undermatching consumables produces a welded joint with a lower strength than that of the parent metal. Undermatching consumables may be used when, for example, the design allows this in terms of the location of joints and/or increase in the effective throat thickness. Undermatching consumables with a standardised yield strength class of 42 (min. 420 MPa) include the brands shown in Table 6.

It should be remembered that consumables in Table 5 may be used as slightly undermatching for the Optim 1100 QC grade.

**Handling of welding consumables**
Welding consumables are to be protected from moisture during transport, storage and use to prevent any condensation of water on them. If necessary they should be dried according to the manufacturer's instructions before welding.

**Joint preparation**
It is recommended that the preparation of joints for welding, i.e. bevelling, is carried out by machining. Generally the best type of joint preparation for a butt joint for strip thicknesses of ≤ 3 mm is the square butt preparation. For thicker strip, a single V-groove or a single V-groove with root face and a bevel angle of 40 – 70º as shown in Figure 1 is recommended. The type of joint preparation to be used for a fillet joint and the bevelling of web are to be determined according to the root penetration and weld thickness required of the welded assembly.

Groove surfaces must be dry and clean before welding to prevent the harmful hydrogen having any contact with the welded joint.

**Need for an elevated working temperature**
Preheating is a common way to elevate working temperature for welding. The need for an elevated working temperature is primarily determined on the basis of the chemical composition, i.e. hardenability, of the steel and welding consumables. The combined strip thickness, heat input by welding and the hydrogen content in the weld caused by welding consumables also must be taken into account. In normal workshop conditions, ultra high-strength steels can be welded without preheating thanks to the low CEVs relative to the high strength (Table 2) and small strip thicknesses.

- **Heat input**
A low heat input will minimise the impact of the welding heat cycle on the mechanical properties of the HAZ of the joint. Table 7 shows heat input values for butt and fillet joints, which will provide good mechanical properties for a welded joint. Softening of the HAZ will be pronounced if a large heat input value is used. Thanks to the relatively low alloying and hardenability, ultra high-strength steel will lend itself well to welding by methods with low heat input and a short cooling time $t_{8/5}$. Methods that provide a cooling time $t_{8/5}$ of less than 4 seconds include laser welding. It should be noted that in fillet welds made by metal arc welding with covered electrodes the maximum heat input value may easily be exceeded. This happens, for example, with 6-mm thick strip when the effective weld thickness exceeds 4 – 5 mm.

- **Forming**
The cold formability (i.e. at +20°C) of ultra high-strength steels is good, in regard to their high strength. They can be formed in any chamfering direction and the bend can be located independently from the rolling direction. The smallest inside bending radius in accordance with thickness is shown in Table 8. The formability of ultra high-strength steels is tested by the flanging test because it most realistically corresponds with flanging in workshop conditions. However, the bending force, springback effect and the bending radius are greater than those for softer structural steels due to the higher strength.

To obtain full advantage of the formability good engineering workshop techniques and careful design must be used. Worn tools, poor lubrication, surface defects and burrs on cut edges may all impair forming quality. Plates taken from a cold storage must be allowed to warm up to room temperature (+20°C) before forming.

- **Cutting**
Ultra high strength steels are well suited for thermal cutting. The cut surface will be smooth, which provides good fatigue resistance. Flame, plasma and laser cutting will leave a softened zone at the strip edge due to the heat, but selecting the proper cutting method will make this zone very narrow. When cutting high strength steels mechanically, particular attention must be paid to the stiffness of cutting equipment, blade condition and clearance and supporting of the work piece. Strip taken from a cold storage must be allowed to warm up to room temperature (+20°C) before cutting.

- **Hot-dip zinc coating**
Due to an optimised chemical composition, ultra high-strength steels provide a good substrate for hot-dip zinc coating. Proper control of the galvanizing parameters will produce an aesthetically pleasing, bright and durable coating. The coating thickness is regulated by controlling the galvanizing time and temperature. Unnecessarily long immersion should be avoided to ensure reasonable coating thickness and good adherence of the coating.

- **Heat treatment**
Ultra high-strength steels are not intended for heat treatment after welding or any other workshop operation. If stress relieving is required, however, it may be carried out in the temperature range 400–450°C. The soaking time is determined according to the material thickness

and the structure of the steel product. Slow cooling in the furnace is recommended. Annealing or working at a temperature above 450°C is not recommended because it may considerably reduce the strength of the steel.

- **Work safety**

Workshop processing of hardened steels, such as bending, flanging or cutting, requires special care. The instructions issued by the steel supplier and high-quality workshop practices are essential aspects of safety.

- **Further information**

The following data sheets are related to the subject: Coil products production programme, Dimensional and shape tolerances, Welding, Thermal cutting and flame straightening, Flanging and forming, Mechanical cutting.

## Chemical composition

*Table 1*

| | Maximum content % (ladle analysis) C | Si | Mn | P | S | P + S | Ti |
|---|---|---|---|---|---|---|---|
| Optim 900 QC | 0.10 | 0.25 | 1.15 | 0.020 | 0.010 | 0.030 | 0.07 |
| Optim 960 QC | 0.11 | 0.25 | 1.20 | 0.020 | 0.010 | 0.030 | 0.07 |
| Optim 1100 QC | 0.15 | 0.30 | 1.25 | 0.020 | 0.010 | 0.030 | 0.07 |

*In addition, aluminium (Al), niobium (Nb), vanadium (V), chromium (Cr), molybdenum (Mo) or boron (B) may be used either singly or in combination.*

## Carbon equivalent value (CEV)

*Table 2*

| | CEV typical | CEV maximum |
|---|---|---|
| Optim 900 QC | 0.51 | 0.56 |
| Optim 960 QC | 0.52 | 0.57 |
| Optim 1100 QC | 0.50 | 0.55 |

$CEV = C + Mn/6 + (Cr + Mo + V)/5 + (Ni + Cu)/15$

## Mechanical properties and thickness ranges

*Table 3*

| Steel grade | Thickness range mm | Yield strength $R_{p0,2}$ MPa Minimum | Tensile strength $R_m$ MPa Minimum | Elongation $A_5$ % Minimum | Impact strength t °C | Impact strength KV J Minimum |
|---|---|---|---|---|---|---|
| Optim 900 QC [1)] | 2.5 – 6.4 | 900 | 950 | 8 | -40 | 50 [3)] |
| Optim 960 QC [1)] | 2.5 – 6.4 | 960 | 1000 | 7 | -40 | 50 [3)] |
| Optim 1100 QC [2)] | 2.5 – 6.0 | 1100 | 1250 | 6 | -20 | 30 [3)] |

*1) The yield and tensile strength are tested longitudinal to the rolling direction, but guaranteed both in the longitudinal and transverse direction. The elongation is tested longitudinal to the rolling direction.*
*2) The yield strength and tensile strength and the elongation are tested transverse to the rolling direction. The impact strength (KV) is tested by the Charpy V impact test using a longitudinal test piece.*
*3) The guaranteed impact energy values refer to the impact strength tested with 10-mm thick standard test piece.*
*When testing cut lengths thinner than 10 mm, the width of the test piece corresponds with the strip thickness and, accordingly, the guaranteed impact strength value decreases linearly. For example, two thirds of the guaranteed 50 Joule value, i.e. 33 J, is guaranteed for a 5-mm thick cut length. No impact tests are carried out for less than 5-mm thick cut lengths, but the impact strength is guaranteed nevertheless.*

## Typical strength properties

*Table 4*

| | Yield strength $R_{p0,2}$ MPa | Tensile strength $R_m$ MPa | Elongation $A_5$ % |
|---|---|---|---|
| Optim 900 QC | 900 – 1000 | 1050 – 1150 | 11 |
| Optim 960 QC | 960 – 1060 | 1080 – 1180 | 10 |
| Optim 1100 QC | 1100 – 1200 | 1280 – 1380 | 8 |

*The values shown in this table are results from longitudinal tensile tests (Optim 900/960 QC grades) or transversal tensile tests (Optim 1100 QC).*

## Optim 900 QC and Optim 960 QC grades, matching or nearly matching welding consumables Optim 1100 QC grade, slightly undermatching consumables

*Table 5*

| Steel grade | Welding process | Consumables |
|---|---|---|
| Optim 900 QC | Gas shielded arc welding (MAG) | OK Autrod 13.31/M21 [1], Union X90/M21 [1] and X90-IG/ M21 [1] |
| | Flux-cored electrodes | PZ 6149 and Stein Megafil 1100 M |
| | Covered electrodes | OK 75.78, SH NNI 2 K 130 and Fox EV 90 |
| Optim 960 QC | Gas shielded arc welding (MAG) | OK Autrod 13.31/M21 [1], Union X90/M21 [1], X90-IG/ M21 [1] and Union X96/M21 [1] |
| | Flux-cored electrodes | PZ 6149 and Stein Megafil 1100 M |
| | Covered electrodes | OK 75.78, SH NNI 2 K 150 and Fox EV 90 |
| Optim 1100 QC | Gas shielded arc welding (MAG) | OK Autrod 13.31/M21 [1], Union X90/M21 [1], X90-IG/ M21 [1] and Union X96/M21 [1] |
| | Flux-cored electrodes | PZ 6149 and Stein Megafil 1100 M |
| | Covered electrode | OK 75.78, SH NNI 2 K 150 and Fox EV 90 |

*Similar welding consumables from other suppliers/manufacturers are equally recommended.*
*The validity of any recommendations should be verified with the manufacturer before welding.*
*[1] M21: Shielding gas approx. 80% argon + 20% $CO_2$. A lower $CO_2$ content may also be used.*

## Optim 900 QC, Optim 960 QC and Optim 1100 QC grades, undermatching welding consumables

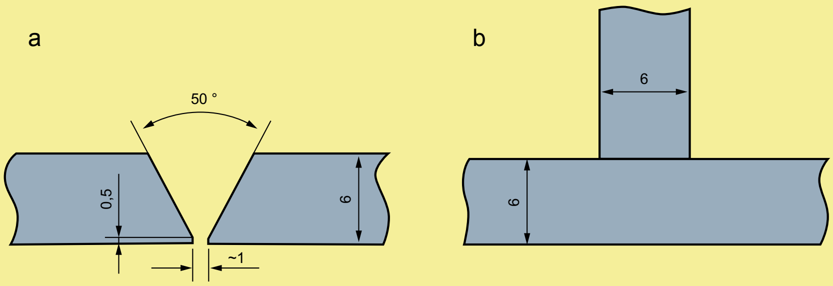
*Table 6*

| Welding process | Consumables |
|---|---|
| MAG [1] | OK Autrod 12.51, DB-20, Elga-Matic 100, LNM 26 or EMK 6. |
| MAG w/flux-cored electrodes | OK Tubrod 14.12, OK Tubrod 15.14, PZ 6102, PZ 6113, MXA 100 or DWA 50. |
| Submerged arc | OK Autrod 12.22 + OK Flux 10.71, L-61 + FX860 or Union S 2 + UV 400. |
| Covered electrodes | 48.00 or P48 S or similar. |

*Similar welding consumables from other suppliers/manufacturers are equally recommended.*
*The validity of any recommendations should be verified with the manufacturer before welding.*
*[1] Shielding gas approx. 80% argon + 20% $CO_2$. A lower $CO_2$ content may also be used.*
*The use of undermatched consumables produces a tough, flexible weld, which tolerates weld stress and impact loads better than a weld produced with high-strength consumables. Longitudinal joints of crane arms, for example, are often welded with undermatching consumables to achieve a tough overall structure. The applicability of consumables and conformity of welded joints with the requirements are best ensured by a welding procedure test.*

## Welding of the ultra high-strength Optim QC steels
## Examples of a butt joint (a) and a fillet joint (b)

*Figure 1*




## Optim 900 QC, Optim 960 QC and Optim 1100 QC grades
## Approximate arc energies for welding

*Table 7*

| Steel grade | Strip thickness mm | Arc energy kJ/mm [1] Butt joint | Fillet joint |
|---|---|---|---|
| Optim 900 QC, Optim 960 QC | 2.5 – 4 | 0.25 – 0.6 | 0.4 – 0.7 |
| Optim 900 QC, Optim 960 QC | (4) – 6.4 | 0.35 – 0.8 | 0.5 – 1.1 |
| Optim 1100 QC | 2.5 – 4 | 0.25 – 0.4 | 0.4 – 0.7 |
| Optim 1100 QC | (4) – 6.4 | 0.25 – 0.6 | 0.5 – 0.9 |

*[1] Arc energy = E = 60 x U x I / 1000 x v, in which E = (kJ/mm), U = arc voltage (V), I = welding current (A) and welding speed v = (mm/min).*
*As cooling times of a welded joint through the temperature range 800–500ºC, the heat input recommendations shown in Table 7 comply with the following cooling times: Optim 900 QC and Optim 960 QC grades: $t_{8/5}$ = 4 – 15 seconds and Optim 1100 QC grade: $t_{8/5}$ = 4 – 10 seconds.*
*N.B: Cooling times shorter than these $t_{8/5}$ values can also be used in welding.*

## Minimum bending radii for cut lengths of various thicknesses, bending angle 90°

*Table 8*

| | Thickness mm 3 | (3) – 4 | (4) – 5 | (5) – 6 |
|---|---|---|---|---|
| | Min. internal bending radius mm | | | |
| Optim 900 QC | 9.0 | 12.0 | 15.0 | 19.0 |
| Optim 960 QC | 10.5 | 14.0 | 17.5 | 22.0 |
| Optim 1100 QC | 12.0 | 16.0 | 20.0 | 25.0 |

There are no restrictions for the location of the bend.
The formability of ultra high-strength steels is tested with the flanging test.

## Our Customer Service is happy to give you further information

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