Hot rolled steel sheets, plates and coils

Processing of material

Welding

In this data sheet, we collected information on the welding of our hot rolled steel products, for example:

- Selecting the welding process
- Selecting the welding consumables
- Increased working temperature
- Flame straightening
- Weld inspection
- Post treatment and heat treatment

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- **Selecting the welding process**
  The choice of the welding process must include the consideration of any steel-specific limitations of heat input and the method of welding. The higher the strength of the steel and the required impact strength, the more important is the proper choice of welding process, welding method and arc energy. Proper impact strength of the weld can be achieved by any common welding process provided that arc energy is kept within the limits recommended for the steel in question.

- **Selecting the welding consumables**
  Welding consumables for hot rolled steel are chosen based on the requirements for the weld. Strength and toughness are important selection criteria for the filler metal. The availability and the price of the filler metal should also take into account. Catalogues giving recommended consumables for various steel grades are available from welding material manufacturers.

  Welding consumables are classified for example in the EN standards. The classification is based on the welding process used, with specific standards for the different processes – for example, EN ISO 2560 “Welding consumables. Covered electrodes for manual metal arc welding of non-alloy and fine grain steels.” Welding consumable manufacturers have their own product names and markings for consumables corresponding to the standards.

  Welding consumables include:
  a) filler metals, such as wire electrodes and covered electrodes,
  b) fluxes and
  c) shielding gases.

  For hot rolled steels, it is recommended to use a filler metal with the same or only slightly higher strength than the base material. The strength of filler metals for pressure equipment steels, however, should meet the requirements of a strength coefficient for pressure equipment. The use of overmatching filler metals results in high residual stresses.

  When welding the strongest steel grades, such as Optim 550 MC, Optim 600 MC, Optim 650 MC, Optim 700 MC, Optim 900 QC, Optim 960 QC, B 13S, B 24, B 27, Raex 400, Raex 450 and Raex 500, it is in many cases beneficial to use so-called undermatching fillers that are softer than the base material. At the same time, the structures should be designed to avoid welds in places where they are exposed to the highest stresses or heavy abrasion. With the most alloyed steels, the dilution of the base material with the weld metal increases the strength of the filler up to approximately 100 MPa compared with the catalogue values of all weld metal.

  The choice of filler metal for boron steel depends on whether the welding is carried out before heat treatments or only after hardening and, possibly, tempering. When abrasion resistance is not required for the filler, non-alloy or low-alloy “soft” fillers may be used with boron steels (for example OK 48.00, OK Autrod 12.51 or similar). Soft filler metals make welds that are less sensitive to cracking and require less preheating. With soft filler metals the surface of the weld metal becomes as hard as with hard filler metals when hardened, only with lower hardening depth.

  Higher-alloyed filler metals (such as OK 75.75, OK Autrod 13.12 or similar) can be used if the weld metal must be easily hardenable and hardening is not followed by tempering, or if a high strength (hardness) is required of the weld metal in the as-welded condition. Normally, the use of such high-alloy filler metals can be limited to the surface passes.

  When welding extra high strength S700 M and S700 ML steel grades, it is generally recommended to follow the welding instructions for strength class 690 MPa quenched and tempered steels given in the EN 10025-6 standard. The welding instructions are available in the standard EN 1011-2:2001 “Welding. Recommendations for welding of metallic materials. Part 2: Arc welding of ferritic steels.” To eliminate the possibility of hydrogen cracking, the hydrogen content of the weld metal must be kept as low as possible, which means that only low-hydrogen welding consumables can be used. Recommended welding consumables for steels are given in Table 1. The filler metals in the table are so-called matching filler metals, providing the same strength level in the weld joint as in the base material.

  Filler metals that are clearly softer than the base material (undermatching) may be used under certain conditions. They are suitable for joints subjected to lower loads than designed. Undermatching consumables may also be used for the root passes of butt welds and single-pass fillet welds. In these cases the weld metal is alloyed through a dilution with the base plate, which has a strengthening effect on the weld metal. The benefit of undermatching welding consumables is that the formability and toughness of the weld metal is improved in comparison with matching consumables.

  The Guideline 7/12 “Welding consumables”, an annex to the Pressure Equipment Directive PED 97/23/EC, clarifies the approvals of welding consumables. The Guideline refers to Annex I Section 4 of PED concerning materials used for the manufacture of pressure equipment. The section states that welding consumables or other joining materials do not need to comply with harmonised standards, European approvals of materials or particular material appraisal. PED, however, requires that welding consumables are suited for the base material, the welding process and the manufacturing conditions.

When welding together different types of steels, such as P265GH/16Mo3, 16Mo3/13CrMo4-5 etc, the main principle is to choose the filler metal according to the less alloyed steel. The filler metal may also be chosen halfway between the chemical compositions of the base metals or even according to the more alloyed base metal.

Welding consumables for shipbuilding steels require Classification Society's approval.

Welding consumables for weathering steels should be selected in the way that the welds will also be weather-resistant. This requires that the filler metal is weather-resistant. Nickel and copper are the most common alloy elements in filler metals for these steels. Unalloyed filler metal may be used where the joint design (square groove, fillet weld) and the degree of penetration (submerged arc welding) provide ample blending of the base material into the filler metal. In such cases, the filler metals takes up the necessary alloying elements from the molten base material. In multi-run welding of weathering steels, the final runs should always be made with weather-resistant filler metal.

Steel grouping system

Metallic materials have been grouped for welding procedure testing and welder qualification approvals.

Table 2 shows the grouping of steels according to the CEN ISO/TR 15608 report and the CEN ISO/TR 20172:2004 report on European materials. The grouping in the table is for welder qualification approval (EN 287-1:2004) and welding procedure testing (EN ISO 15614-1:2004).

The qualification range for base materials according to EN 287-1:2004 is shown in Table 3. The qualification ranges of steel groups and subgroups according to EN ISO 15614-1:2004 are shown in Table 4.

Reports CEN ISO/TR 20173 and CEN ISO/TR 20174 for American and Japanese materials are in a preparation. They group the materials according to the ISO/TR 15608 report.

- **Increased working temperature**

In welding the steel grade S235JR and ordinary grade A shipbuilding steel, increased working temperature is not required for plate thicknesses less than 60 – 80 mm.

For pressure equipment steel P265GH the need for increased working temperature begins at slightly lower thicknesses.

The preheating requirement for weathering COR-TEN® steels is somewhat higher with higher plate thicknesses than that for ordinary structural steels with the same thickness.

The molybdenum and chromium-molybdenum alloyed heat resistant steels are generally welded with preheating appropriate for the steel grade in question. After welding, these steels usually need to be annealed.

Optim steels produced in coils do not require an increased working temperature in engineering workshop conditions. Prior to welding, however, it should be ensured that the grooves to be welded are dry and clean. For storage and drying of welding consumables, follow the manufacturers' instructions.

When welding high strength steels, it should be noticed that the filler metal may be clearly more alloyed and more hardening than the base metal. As a result, the filler metal may be the decisive factor in determining the working temperature when welding the high strength thermomechanically rolled steels, such as Optim 500 ML, S460M and S460ML.

It should be noted that even the thermal cutting of weldable parts made of Raex steels may require preheating. Preheating the plate prevents hydrogen cracking in the heat affected zones of the welds.

When the carbon equivalents of the steels to be welded and the combined thickness of the joint are known, the need for increased working temperature and preheating can be determined on the basis of recommended working temperatures.

The preheating requirement for extra high strength steels S700 M and S700 ML is determined mainly based on the chemical composition of the steel and the filler metal. The hardening tendency caused by alloying is described with carbon equivalent values, such as P_{cm} and CET. The P_{cm} equivalent for extra high strength steels is typically 0.21, with a maximum P_{cm} value of 0.26. The CET carbon equivalent of these steels is 0.32. The required preheating is usually determined by the filler metals as they are generally more alloyed than the base metal. The typical CET carbon equivalent of filler metals is in the range of 0.33 – 0.40. In addition to alloying, the preheating need is affected by plate thickness, heat input and the hydrogen content of the filler metals. In normal engineering workshop conditions, the extra high strength steels S700 M and S700 ML can be welded without preheating up to a plate thickness of 15 – 20 mm.

The need for preheating is determined according to the general instructions in EN 1011-2. Preheating is especially important when welding with low heat input, e.g. in tack welding. Always make sure that moisture and other sources of hydrogen, such as grease, oil and other impurities, have been removed from the surface of the groove before welding.

Carbon equivalents of steel grades

The carbon equivalent is determined on the basis of the chemical composition of the steel. The value is used for estimating the hardenability and susceptibility to cold cracking in welding.

There are several designations for the carbon equivalent as well as formulae for calculating the value. The most common is the CEV formula by the International Institute of Welding (IIW):

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

As for the cold cracking risk, steel is highly weldable when its CEV is less than 0.41. CEVs between 0.41 and 0.45 guarantee good weldability with dry consumables with a low hydrogen content. Table 5 shows the CEV for some steel grades.

Another commonly used carbon equivalent formula is P_{cm}:

$$P_{cm} = C + Si/30 + (Mn + Cu + Cr)/20 + (Ni)/60 + (Mo)/15 + (V)/10 + 5B$$

A carbon equivalent formula popular in Germany is the CET:

$$CET = C + Mn/10 + Mo/10 + Cr/20 + Cu/20 + Ni/40$$

Working temperature recommendations

Figure 1 shows how the combined plate thickness is determined.

Table 6 presents the working temperature recommendations for some steels with specific elevated temperature properties. Tables 7 and 8 show working temperature recommendations based on the CE carbon equivalents of steels to be joined and the combined plate thickness of the joint.

When welding extra high strength steels S700 M and S700 ML, the required heat input depends on the strength and toughness requirements of the joint. The thermal cycle of the weld is determined by the cooling time of the joint $t_{8/5}$. The recommended $t_{8/5}$ cooling time for steel grades S700 M and S700 ML is approximately 5 – 20 seconds. This approximately corresponds to arc energies of 1.0 – 2.3 kJ/mm for 15 – 30 mm plate thicknesses. The ideal heat input range depends on the plate thickness and the requirements for the joint. The longest permissible $t_{8/5}$ cooling time (corresponding to maximum permissible heat input) is determined by the impact toughness requirement of the Heat Affected Zone (HAZ) of the joint. Impact toughness is impaired if $t_{8/5}$ and/or heat input exceed their permissible values. On the other hand, the shortest recommended $t_{8/5}$ cooling time (corresponding to minimum permissible heat input) is determined by the susceptibility of the weld metal and the HAZ to hydrogen cracking. If $t_{8/5}$ is too short and/or the heat input too slight, the risk of hydrogen cracking increases.

- **Flame straightening**

Flame straightening may be used to form a steel object as required. Flame straightening is also used for returning a worked steel object to its original form if the object deviates from the desired shape after working. The heating may affect only the surface of the object or penetrate deeper, up to the entire depth of the object. The heating depth should be selected based on the intended amount of straightening.

The straightening flame must be sharp, local and short in duration. In addition to the sharpness of the flame, its accurate pointing increases the straightening effect. Beware of using an unnecessary hot flame. The surface of the steel will overheat and become upset without improving the straightening effect. Straightening with excess heat may also deteriorate the properties of the steel.

European structural steels are defined in the standard EN 10025/Parts 2, 3, 4, 5 and 6. High strength cold formable steels are presented in the standard EN 10149/Parts 2 and 3. All these standard steels may be flame straightened under certain conditions. The peak temperature must remain below the limit given in Table 9. This ensures that the properties of the steel remain unchanged even after flame straightening. The straightening may be enhanced by limiting the thermal expansion caused by heating, for example with hydraulic or mechanical presses.

Normalised steels may usually be flame straightened at higher temperatures than extra high strength thermomechanically rolled or quenched and tempered steels. Traditional hot rolled (i.e. as rolled) steels behave as normalised or normalised rolled steels in flame straightening.

- **Weld inspections**

Post-welding inspections should be evaluated already when making a welding plan. The scope of the inspections depends on the regulations governing the different businesses, designer requirements, engineering shop quality standards or customers' requirements. All inspections are documented in inspection reports, which are attached to the documents to be delivered to the customer, if necessary.

Hydrogen cracking, also known as cold cracking, is often called "delayed cracking" in literature. Because hydrogen cracking may occur after welding, a minimum time lapse of 16 hours is usually required from the finishing of the welding to the final inspection. This time can be shortened with low material thicknesses and when the yield strength of the steel is less than 500 MPa. Correspondingly, if the plate thickness is greater than 50 mm and the yield strength of the steel is greater than 500 MPa, the elapsed time should be increased. The time between welding and inspection must be stated in the inspection report. A time lapse is not needed for welds that have been annealed for hydrogen removal or stress relief.

- **Post treatment and heat treatment**

The fatigue strength of welds may be improved through a variety of post treatments. These have to be defined in the welding plan. Typical post treatments include the grinding of the toe of the weld, or remelting the toe with TIG treatment.

Example of TIG treatment values:

- current	200 A
- electrode	Ø 3.2 mm
- shield gas	Argon, 20 l/minute
- transfer speed	300 mm/minute.

The most important post-weld heat treatments are stress relieving and normalising. The heat treatment may be performed on a whole structure or only for the welded joint.

The purpose of heat treatments is to:
- Increase the fatigue strength of the structure by reducing residual stresses.
- Remove major residual stresses to prevent cracking in use or to reduce susceptibility to brittle fracture.
- Improve the stress corrosion resistance of the structure.

Stress relieving is carried out at a temperature between 550 – 600°C. The appropriate soaking time in minutes is 2 x t, where t = max. plate thickness of the steel structures in millimetres. For plates less than 15 mm thick, the min. allowable soaking time is 30 minutes. The recommended heating rate (°C/h) from room temperature to the stress relieving temperature depends on the max. plate thickness. The heating rate is calculated using the formula (1250 ... 5000)/t. However, the heating rate must not exceed 200°C/h even for small plate thicknesses. The cooling rate (°C/h) of stress-relieved steel must not exceed the calculated value 6875/t. Regardless of the calculated value, however, the max. allowable cooling rate is 275°C/h, which is equal to the calculated value for a 25 mm thick plate.

Examples:
- For plate thickness 20 mm, the recommended soaking time is 40 min, heating rate 63 – 200°C/h and highest cooling rate 275°C/h.
- For plate thickness 40 mm, the recommended soaking time is 80 min, heating rate 31 – 125°C/h and highest cooling rate 172°C/h.

Stress relieving reduces the state of stress in a welded structure to a safe level in use. In addition to reducing the state of stress, stress relieving reduces the hardness and improves the impact strength and ductility of the welded joint.

The strength of normalised, normalised rolled and hot rolled steels is retained best in heat treatments, because the strength is a result of alloying. The basic strength of thermomechanically rolled steel comes from alloying, but additional strength is achieved through the rolling technique and cooling after rolling. The effect of alloying on the strength of TM steels is reduced when the strength of the steel increases. The production process of quenched and tempered steel includes annealing in austenitising temperature, followed by quenching (Q) and finally tempering (T). When quenched and tempered steel is tempered for added toughness, it is annealed in the so-called tempering temperature, which is lower than the austenitising temperature.

Hardened steels are manufactured in the same way as quenched and tempered steels. The final production stage of hardened steels is quenching, or hardening, from which the designation is derived. Thus, hardened steel is not actually tempered, which accounts for its different properties from quenched and tempered steel.

Normalising is carried out at 900 – 940°C. The soaking time is 1 minute per mm of plate thickness, however, at least 20 min and free cooling in ambient air. Normalising achieves the same advantages as stress relieving. Additionally, normalising reduces the increased grain size resulting from welding and hot working, leading to properties that are at least the same as in delivery condition (TM rolled steels excepted). Normalising also restores the impact strength impaired by cold forming and strain ageing. Typical structures requiring normalising are pressure vessels where the steel has been cold formed more than 5% during manufacturing.

Extra high strength steels S700 M and S700 ML should not be heat treated at all, because the long-term high temperatures present in heat treatments may impair the properties of the steel. If heat treatment for a steel structure or a part of it is deemed necessary, the effect of the heat treatment on the properties of the steel has to be determined in a separate welding procedure test. Hardened wear resistant Raex steels should not be subjected to post-weld heat treatment. A long exposure to temperatures higher than 250°C impairs the properties of the steel.

When heat treating welded structures, the following should be taken into account:

- Yield strength and impact strength may deteriorate in heat treatments involving temperatures higher than 600°C. For example, the strength of thermomechanically rolled Optim steels is impaired when the temperature exceeds 650°C. This is why heat treatments in over 650°C temperatures, such as normalising, are not recommended for these steels.

- The strength of the weld metal may decrease in normalising, compared to the as-welded condition. That is why the welding consumables for structures to be normalised should be selected to give a weld metal that meets the specified strength even after normalising.

- When the weld metal is subjected to intensive cold forming before heat treatment, its strength and impact toughness may not meet requirements after stress relieving and normalising.

- All steels may be flame straightened if the maximum temperature does not exceed 650°C.

A welding procedure test is always recommended to ensure the mechanical properties in the heat treated structure.

Extra high strength S700 M and S700 ML steels
Recommended welding consumables

Table 1

Welding process	Welding consumables [1]
Manual metal arc welding (SMAW)	ESAB OK 75.75 SH Ni 2 K 90 SH Ni 2 K 100 Fox EV 85 Fox U 100 N
Gas-shielded metal arc welding (GMAW)	ESAB OK Autrod 13.29 / M21 [2] Union NiMoCr / M21 [2] Union X85 / M21 [2] X70-IG / M21 [2]
Submerged arc welding (SAW)	ESAB OK Autrod 13.43 + OK Flux 10.62 Union S 3 NiMoCr / UV 421 TT Fluxcord 42 / OP 121 TT

[1] *Or corresponding.*
[2] *The shielding gas contains approximately 80% argon (Ar) and 20% carbon dioxide (CO_2). Shielding gas with lower than 20% CO_2 content may also be used.*

Material grouping according to the reports CEN ISO/TR 15608:fi and CEN ISO/TR 20172:2004 for welder approval test (EN 287-1:2004) and welding procedure test (EN ISO 15614-1:2004)

Table 2

Group	Steel grade. CEN ISO/TR 15608:fi and CEN ISO/TR 20172:2004	
1	Steels with minimum specified yield point R_{eH} ≤ 460 MPa and with analysis in %: C ≤0,25, Si ≤0,60, Mn ≤1,80, Mo ≤0,70, S ≤0,045, P ≤0,045, Cu ≤0,40, Ni ≤0,5 %, Cr ≤0,3, Nb ≤0,06, V ≤0,1, Ti ≤0,05	
1.1	Steels with minimum specified yield point R_{eH} ≤275 MPa	
	- Ruukki	**Laser 250 C**
	- EN 10025-2	**S235JR, S235J0, S235J2, S275JR, S275J0, S275J2**
	- EN 10025-3	**S275N, S275NL**
	- EN 10025-4	**S275M, S275ML**
	- EN 10149-3	**S260NC, P265NB**
	- EN 10028-2	**P235GH, P265GH, 16Mo3**
	- EN 10028-3	**P275NH, P275NL1, P275NL2**
	- EN 10207	**P235S, P265S, P275SL**
		Grade A shipbuilding steels
	- EN 10120	P245NB
	- EN 10208-1	L210GA, L235GA, L245GA
	- EN 10208-2	L245NB, L245MB, 16Mo3
	- EN 10210-1	S235JRH, S275J0H, S275J2H, S275NH, S275NLH
	- EN 10213-2	GP240GR, GP240GH
	- EN 10213-3	G17Mn5
	- EN 10219-1	S235JRH, S275J0H, S2752H, S275NH, S275NLH, S275MH, S275MLH
	- EN 10248-1	S240GP, S270GP
	- EN 10216-1	P195TR1, P195TR2, P235TR1, P235TR2, P265TR1
	- EN 10216-2	P195GH, P235GH, P265GH, 16Mo3
	- EN 10216-3	P275NL1, P275NL2
	- EN 10217-1	P195TR1, P195TR2, P235TR1, P235TR2, P265TR1, P265TR2
	- EN 10217-2	P195GH, P235GH, P265GH, 16Mo3
	- EN 10217-3	P275NL1, P275NL2
	- EN 10217-4	P215NL, P265NL
	- EN 10217-5	P235GH, P265GH, 16Mo3.
	- EN 10217-6	P215NL, P265NL
1.2	Steels with minimum specified yield point 275 MPa < R_{eH} ≤ 360 MPa	
	- Ruukki	**Multisteel, Multisteel N**
	- Ruukki	**Laser 355 MC**
	- EN 10025-2	**S355JR, S355J0, S355J2, S355K2**
	- EN 10025-3	**S355N, S355NL**
	- EN 10025-4	**S355M, S355ML**
	- EN 10149-2	**S315MC, S355MC**
	- EN 10149-3	**S315NC, S355NC**
	- EN 10028-2	**P295GH, P355GH**
	- EN 10028-3	**P355N, P355NH, P355NL1, P355NL2**
	- EN 10028-5	**P355M, P355ML1, P355ML2**
	- EN 10225	**The nickel (Ni) content of steel grades S355G9N, S355G9M, S355G10N and S355G10M according to standard EN 10225 ≤ 0.70%**
		Strength class 32, 36 shipbuilding steels
	- API	**2W GR 50, 2H GR 50**
	- EN 10028-6	P355Q, -QH, -QL1, -QL2
	- EN 10120	P310NB, P355NB
	- EN 10208-1	L290GA, L360GA
	- EN 10208-2	L290NB, L290MB, L360NB, L360MB, L360QB
	- EN 10210-1	S355J0H, S355J2H, S355NH, S355NLH, S460NH, S460NLH
	- EN 10213-2	GP280GH
	- EN 10213-3	G20Mn5, G18Mo5
	- EN 10216-2	20MnNb6
	- EN 10216-3	P355N, P355NH, P355NL1, P355NL2
	- EN 10217-3	P355N, P355NH, P355NL1, P355NL2
	- EN 10219-1	S355J0H, S355J2H, S355NH, S355NLH, S355MH, S355MLH, S460NH, S460NLH
	- EN 10222-4	P285NH, P285QH, P355NH, P355QH
	- EN 10224	L355
	- EN 10248-1	S320GP, S355GP
1.3	Normalised fine grain steels with minimum specified yield point R_{eH} > 360 MPa	
	- EN 10025-3	S420N, S420NL, S460N, S460NL
	- EN 10028-3	P460NH, P460NL1, P460NL2
		Strength class 40 shipbuilding steels
	- EN 10149-3	S420NC
	- EN 10208-2	L415NB
	- EN 10216-2	8MoB5-4
	- EN 10216-3	P460N, P460NH, P460NL1, P460NL2
	- EN 10217-3	P460N, P460NH, P460NL1, P460NL2
	- EN 10248-1	S390GP, S430GP
1.4	Weathering steels the analysis of which may exceed the content specified for Group 1 alloying elements	
	- Ruukki	**COR-TEN® B, COR-TEN® B-D**
	- EN 10025-5	**S235J0W, S235J2W, S355J0W, S355J2W, S355K2W**

Group	Steel grade. CEN ISO/TR 15608:fi and CEN ISO/TR 20172:2004	
2	Thermomechanical rolled fine grain steels and cast steels with minimum specified yield point R_{eH} > 360 MPa	
2.1	Thermomechanical rolled fine grain steels and cast steels with minimum specified yield point 360 MPa < R_{eH} ≤ 460 MPa	
	- Ruukki	**Laser 420 MC**
	- EN 10025-4	**S460M, S460ML**
	- EN 10149-2	**S420MC, S460MC**
	- EN 10149-3	**S420NC**
	- EN 10028-5	**P420M, P420ML1, P420ML2, P460M, P460ML1, P460ML2**
	- EN 10225	**S420G1M, S420G2M, S460G1M, S460G2M**
		420 (43)-, 460 (47)-shipbuilding steels
	- API	**2W GR 60**
	- EN 10208-2	L415MB, S450MB
	- EN 10219-1	S420MH, S460MLH, S460MH, S460MLH
	- EN 10222-4	P420NH
2.2	Thermomechanical rolled fine grain steels and cast steels with minimum specified yield point R_{eH} > MPa	
	- Ruukki	**Optim 500 MC, Optim 550 MC, Optim 600 MC, Optim 650 MC, Optim 700 MC, Optim 500 ML**
	- EN 10149-2	**S500MC, S550MC, S600MC, S650MC, S700MC**
		Strength class 500 shipbuilding steels
	- EN 10208-2	L485MB, L555MB
3	Quenched and tempered steels and precipitation hardening steels, except stainless steels, with minimum specified yield point R_{eH} ≥ 360 MPa	
3.1	Quenched and tempered steels with minimum specified higher yield point 360 MPa < R_{eH} ≤ 690 MPa	
	- EN 10028-6	P460Q, P460QH, P460QL1, P460QL2, P500Q, P500QH, P500QL1, P500QL2, P690Q, P500QH, P500QL1, P500QL2
		S460Q, S460QL, S460QL1, S500Q, S500QL, S500QL1, S550Q, S550QL, S550QL1, S620Q, S620QL, S620QL1, S690Q,
	- EN 10137-2	S690QL1, S690QL2
		L415QB, L450QB, L485QB, L550QB
	- EN 10208-2	P420QH
	- EN 10222-4	G20Mo5
	- EN 10213-2	25CrMo4, 20CrMoV13-5-5
	- EN 10216-2	P620Q, P620QH, P620QL, P690Q, P690QH, P690QL1, P690QL2
	- EN 10216-3	
3.2	Quenched and tempered steels with minimum specified higher yield point R_{eH} ≥ 690 MPa	
	- Ruukki	**Optim 900 QC, Optim 960 QC, Optim 1100 QC. Normal delivery condition hardened.**
	- Ruukki	**Raex 400, Raex 450, Raex 500. Normal delivery condition hardened.**
	- Ruukki	**B 13S, B 24, B 27. Normal delivery condition hot rolled with strengths < 690 MPa.**
	- EN 10137-2	S890Q, S890QL, S890QL1, S960Q, S960QL

Base metal approval range
Welder approval test EN 287-1:2004

Table 3

Test piece base metal group [1)]		Approval range 1.1 1.2 1.4	1.3	2	3	4	5	6	7	8	9 9.1	9.2 + 9.3	10	11
1.1, 1.2, 1.4		X	–	–	–	–	–	–	–	–	–	–	–	–
1.3		X	X	X	X	–	–	–	–	–	X	–	–	X
2		X	X	X	X	–	–	–	–	–	X	–		X
3		X	X	X	X	–	–	–	–	–	X	–	–	X
4		X	X	X	X	X	X	X	X	–	X	–	–	X
5		X	X	X	X	X	X	X	X	–	X	–	–	X
6		X	X	X	X	X	X	X	X	–	X	–	–	X
7		X	X	X	X	X	X	X	X	–	X	–	–	X
8		–	–	–	–	–	–	–	–	X	–	X	X	–
9	9.1	X	X	X	X	–	–	–	–	–	X	–	–	X
	9.2 + 9.3	X	–	–	–	–	–	–	–	–	–	X	–	–
10		–	–	–	–	–	–	–	–	X	–	X	X	–
11		X	X	–	–	–	–	–	–	–	–	–	–	X

[1)] Base metal group according to report CR ISO 15608.
X Base metal groups for which the welder is approved.
– Base metal groups for which the welder is not approved.

Approval ranges for steel groups and subgroups
Procedure test EN ISO 15614-1:2004

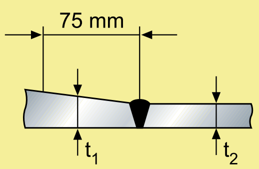
Table 4

Test piece base metal (sub)group	Approval range
1 - 1	1[a] - 1
2 - 2	2[a] - 2, 1 - 1, 2[a] - 1
3 - 3	3[a] - 3, 1 - 1, 2 - 1, 2 - 2, 3[a] - 1, 3[a] - 2
4 - 4	4[b] - 4, 4[b] - 1, 4[b] - 2
5 - 5	5[b] - 5, 5[b] - 1, 5[b] - 2
6 - 6	6[b] - 6, 6[b] - 1, 6[b] - 2
7 - 7	7[c] - 7
7 - 3	7[c] - 3, 7[c] - 1, 7[c] - 2
7 - 2	7[c] - 2[a], 7[c] - 1
8 - 8	8[c] - 8
8 - 6	8[c] - 6[b], 8[c] - 1, 8[c] - 2, 8[c] - 4
8 - 5	8[c] - 5[b], 8[c] - 1, 8[c] - 2, 8[c] - 4, 8[c] - 6.1, 8[c] - 6.2
8 - 3	8[c] - 3[a], 8[c] - 1, 8[c] - 2
8 - 2	8[c] - 2[a], 8[c] - 1
9 - 9	9[b] - 9
10 - 10	10[b] - 10
10 - 8	10[b] - 8[c]
10 - 6	10[b] - 6[b], 10[b] - 1, 10[b] - 2, 10[b] - 4
10 - 5	10[b] - 5[b], 10[b] - 1, 10[b] - 2, 10[b] - 4, 10[b] - 6.1, 10[b] - 6.2
10 - 3	10[b] - 3[a], 10[b] - 1, 10[b] - 2
10 - 2	10[b] - 2[a], 10[b] - 1
11 - 11	11[b] - 11, 11[b] - 1

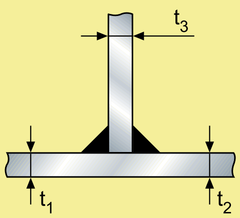
[a] *Covers those steels in the group with the same or lower minimum specified yield point.*
[b] *Covers steels in the same subgroup and all lower subgroups within the group.*
[c] *Covers steels in the same subgroup.*

Combined plate thickness

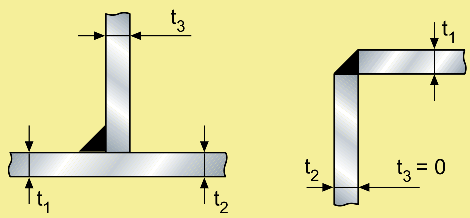
Figure 1



t_1 = average thickness over 75 mm distance
Combined plate thickness $t = t_1 + t_2$



Both sides welded simultaneously
Combined plate thickness
$t = ½ \cdot (t_1 + t_2 + t_3)$



Combined plate thickness $t = t_1 + t_2 + t_3$

Carbon equivalent values CEV

Table 5

	Carbon equivalent CEV Average Plate thickness mm					Maximum Plate thickness mm									
		≥2 ≤13	≥5 ≤20	>20 ≤40	>40 ≤150		≥2 ≤13	≤40	≥5 ≤20	≥5 ≤16	>16 ≤40	>20 ≤40	>40 ≤150	≤63	>63 ≤100
Plate and strip products															
EN 10025-2 S235JR. S235J2								0.35					0.38		
EN 10025 2 S355J2. S355K2								0.47					0.47		
EN 10025-3 S355N. S355 NL														0.43	0.45
EN 10025-3 S420N. S420NL														0.48	0.50
Strip products															
Multisteel		0.40					0.43								
Laser 250 C						0.24									
Laser 355 MC						0.24									
Laser 420 MC						0.28									
Optim 500 MC	0.32					0.36									
Optim 550 MC	0.33					0.38									
Optim 600 MC	0.40					0.41 [1)]									
Optim 650 MC	0.35					0.41									
Optim 700 MC	0.37					0.41									
Optim 900 QC	0,51					0.56									
Optim 960 QC	0,52					0,57									
Optim 1100 QC	0,50					0,55									
Plate products															
Laser 250 C						0.30									
Laser 355 MC						0.34									
Laser 420 MC						0.38									
Multisteel			0.39	0.41	0.43				0.41			0.43	0.45		
Multisteel N			0.39	0.41	0.43				0.41			0.43	0.45		
Multisteel W	0.39					0.41									
EN 10025-4 S355 ML										0.39	0.39				
EN 10025-4 S420 ML										0.43	0.45				
EN 10025-4 S460 ML										0.45	0.46				
Optim 500 ML	0.41					0.43									

1) In thickness range 2.2 – 4.6 mm CEV ≤ 0.45.
CEVs for abrasion-resistant steels depend on the plate thickness and product form.
Typical CEV ranges for various steel grades: Raex 400; 0.45–0.56, Raex 450; 0.49–0.58 and Raex 500; 0.54–0.64.
Typical CEVs for hardenable boron steel grades for the entire thickness range: B 13S, B 24; 0.51 and B 27; 0.54.

Recommended working temperatures for steels with specific elevated temperature properties

Table 6

	Plate thickness mm	Preheating and interpass temperatures, minimum °C Weld hydrogen content HD			Interpass temperature, maximum °C
		HD ≤5	HD >5 ≤10	HD >15	
16Mo3	≤15	20	20	20	250
	≥15 ≤30	75	75	75	250
	>30	75	100	100	250
13CrMo4-5	<15	20	100	100	300
	>15	100	150	150	300
10CrMo9-10	<15	75	150	150	350
11CrMo9-10	>15	100	200	200	350

Recommended working temperatures

Table 7

CEV Part 1	CEV Part 2	Working temperature °C. Arc energy E ≥1.0 kJ/mm EN 1011-2 Combined plate thickness mm											
		10	20	30	40	50	60	70	80	90	100	110	120
0,44	0,39	20										75	
0,45	0,40	20									75		
0,46	0,41	20								75			
0,47	0,42	20						75			100		
0,48	0,43	20			50	75				100			
0,49	0,44	20			75			100				125	
0,50	0,45	20			75		100			125			
0,51	0,46	20		75		100			125			150	
0,52	–	20		75	100		125				150		
0,53	0,47	20		75	100		125			150			

CEV Part 3	Working temperature °C. Arc energy E ≥1.0 kJ/mm EN 1011-2 Combined plate thickness mm											
	10	20	30	40	50	60	70	80	90	100	110	120
0,39	20										75	
0,40	20								50		75	
0,41	20							50			75	
0,42	20						50		75		100	
0,43	20						75			100		
0,44	20					75		100			125	
0,45	20				75		100			125		
0,46	20			75		100			125			
–	20		50	75	100				125			
0,47	20		75	100			125				150	

Part 1 MIG/MAG solid wire, basic flux and metal-cored wire, weld hydrogen content HD ≤ 5 ml/100 g (ISO 3690).
Part 2 Basic flux and rutile covered electrode, weld hydrogen content 5 ml/100 g < HD ≤10 ml/100 g (ISO 3690).
Part 3 Submerged arc welding, weld hydrogen content 5 ml/100 g < HD ≤10 ml/100 g (ISO 3690).

Recommended working temperatures

Table 8

<table>
<tr><td rowspan="3">CEV
Part 1</td><td rowspan="3">CEV
Part 2</td><td colspan="12">Working temperature °C. Arc energy E ≤ 2.0 kJ/mm EN 1011-2</td></tr>
<tr><td colspan="12">Combined plate thickness mm</td></tr>
<tr><td>10</td><td>20</td><td>30</td><td>40</td><td>50</td><td>60</td><td>70</td><td>80</td><td>90</td><td>100</td><td>110</td><td>120</td></tr>
<tr><td>0,49</td><td>0,44</td><td colspan="9">20</td><td colspan="2">75</td><td></td></tr>
<tr><td>0,50</td><td>0,45</td><td colspan="6">20</td><td>50</td><td colspan="4">75</td><td></td></tr>
<tr><td>0,51</td><td>0,46</td><td colspan="5">20</td><td>50</td><td colspan="2">75</td><td colspan="2">100</td><td>125</td><td></td></tr>
<tr><td>0,52</td><td>–</td><td colspan="5">20</td><td colspan="2">75</td><td colspan="2">100</td><td colspan="2">125</td><td></td></tr>
<tr><td>0,53</td><td>0,47</td><td colspan="5">20</td><td>75</td><td colspan="3">100</td><td colspan="2">125</td><td></td></tr>
<tr><td>0,54</td><td>0,48</td><td colspan="5">20</td><td>75</td><td colspan="2">100</td><td colspan="3">125</td><td></td></tr>
<tr><td>0,55</td><td>0,49</td><td colspan="4">20</td><td>75</td><td colspan="2">100</td><td colspan="4">125</td><td></td></tr>
<tr><td>0,56</td><td>0,50</td><td colspan="3">20</td><td>75</td><td colspan="2">100</td><td colspan="3">125</td><td colspan="2">150</td><td></td></tr>
<tr><td>0,58</td><td>0,51</td><td colspan="3">20</td><td>75</td><td>100</td><td colspan="3">125</td><td colspan="3">150</td><td></td></tr>
<tr><td>0,59</td><td>0,52</td><td colspan="3">20</td><td>100</td><td colspan="3"></td><td colspan="4">150</td><td></td></tr>
</table>

<table>
<tr><td rowspan="3">CEV
Part 3</td><td colspan="12">Working temperature °C. Arc energy E ≤ 2.0 kJ/mm EN 1011-2</td></tr>
<tr><td colspan="12">Combined plate thickness mm</td></tr>
<tr><td>10</td><td>20</td><td>30</td><td>40</td><td>50</td><td>60</td><td>70</td><td>80</td><td>90</td><td>100</td><td>110</td><td>120</td></tr>
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<tr><td>0,45</td><td colspan="8">20</td><td>50</td><td colspan="2">75</td><td></td></tr>
<tr><td>0,46</td><td colspan="7">20</td><td colspan="2">50</td><td colspan="2">75</td><td></td></tr>
<tr><td>0,47</td><td colspan="6">20</td><td>50</td><td colspan="2">75</td><td colspan="2">100</td><td></td></tr>
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Part 1 MIG/MAG solid wire, basic flux and metal-cored wire, weld hydrogen content HD ≤ 5 ml/100 g (ISO 3690).
Part 2 Basic flux and rutile covered electrode, weld hydrogen content 5 ml/100 g < HD ≤10 ml/100 g (ISO 3690)
Part 3 Submerged arc welding, weld hydrogen content 5 ml/100 g < HD ≤10 ml/100 g (ISO 3690).

Flame straightening
Hot rolled steels, maximum recommended temperatures by delivery condition
Source CEN/TR 10347:2006 (E)

Table 9

<table>
<tr><td rowspan="2">Delivery condition</td><td rowspan="2">Delivery condition designation</td><td colspan="3">Maximum recommended flame straightening temperatures</td></tr>
<tr><td>Short-term surface heating</td><td>Short-term full thickness heating</td><td>Long-term full thickness heating</td></tr>
<tr><td>Normalised,
normalised rolled</td><td>N
N</td><td>≤ 900°C</td><td>≤ 700°C</td><td>≤ 650°C</td></tr>
<tr><td>Thermomechanical rolled up to strength class S460</td><td>TM</td><td>≤ 900°C</td><td>≤ 700°C</td><td>≤ 650°C</td></tr>
<tr><td>Thermomechanical rolled S500 – S700</td><td>TM</td><td>≤ 900°C</td><td>≤ 600°C</td><td>≤ 550°C</td></tr>
<tr><td>Quenched and tempered</td><td>QT</td><td colspan="3">Tempering temperature used in manufacture of quenched and tempered steel lowered by 20°C. Maximum temperature usually ≤ 550°C.</td></tr>
</table>

Our Customer Service is happy to give you further information

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