Steel

Carbon steels for heat treatment

Product information for case-hardening, tempering, and spring steels

thyssenkrupp

Issue: June 23, 2021, version 0

Brief profile

Unalloyed and alloyed carbon steels from thyssenkrupp are intended for heat treatment, in which important properties such as hardness, wear resistance and toughness are controlled. A distinction is made between case-hardening, tempering, and spring steels.

In heat treatment a fundamental distinction can be made between the hardening and tempering processes. Hardening comprises the heating and quenching of a workpiece in order to increase its hardness and strength. In tempering, the quenched and hardened workpiece is reheated in order to increase ductility.

Content

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Overview of carbon steels

Case-hardening steels

Case-hardening steels are within the carbon range of 0.07 to 0.31%. They are intended for case hardening, which uses a diffusion process (case-hardening, carburizing, carbonitriding) to introduce carbon into the surface layer up to a C content of approximately 0.8%. After hardening, there is a hard, wear-resistant surface layer present, and a comparatively tough core which is able to withstand impact stresses without fracture.

Case-hardening steels are standardized in DIN EN ISO 683-3 (previously DIN EN 10084) and in DIN EN 10132-2, which is relevant for cold-rolled strip. In DIN EN ISO 683-3, 34 steel grades are standardized, from C10E to 18CrNiMo7-6. In practice, three steel grades – C10E, C15E and 16MnCr5 – have become standard for flat material, and are also included in DIN EN 10132-2. These steel grades are supplied by thyssenkrupp as hot-rolled wide strip, pickled and unpickled. Typical applications include gear wheels, shafts, bolts and clutch parts.

Tempering steels

Tempering steels are within the carbon range of 0.17 to 0.65%. They are intended for tempering, which involves hardening and reheating. In the hardening process, the maximum hardness level (up to approximately 65 HRC) is reached according to the carbon content; during the subsequent tempering process the hardness is reduced to achieve an optimum combination of hardness and toughness.

Tempering steels are standardized in DIN EN ISO 683, part 1 and 2 (previously DIN EN 10083, parts 1 to 3), and in DIN EN 10132 part 3, which is relevant for cold-rolled strip. Steel grades covered by this standard include unalloyed carbon steels, C22E to C60E and alloyed grades with alloying elements such as manganese, chromium, nickel, molybdenum, vanadium and boron, added alone or in combination. Typical applications include clutch parts, roller chains, shafts, crankshafts, axles and connecting rods.

Spring steels

Spring steels from thyssenkrupp are within the carbon range of 0.55 to 1.00%. These steels are subjected to different heat treatments (hardening, tempering, isothermal transformation) to achieve the optimum spring properties required in each case. They are standardized in DIN EN 10132-4 and include grades C55S to C100S as well as 51CrV4 and 80CrV2. They are typically used for industrial springs.

Available forms

thyssenkrupp supplies hot-rolled strip or slit strip with tolerances to DIN EN 10051 in unpickled, pickled, or pickled and annealed finishes in the sizes listed in the section "Available dimensions". The listed sizes are indications of technical feasibility.

Other thickness and width combinations and minimum order quantities upon request.

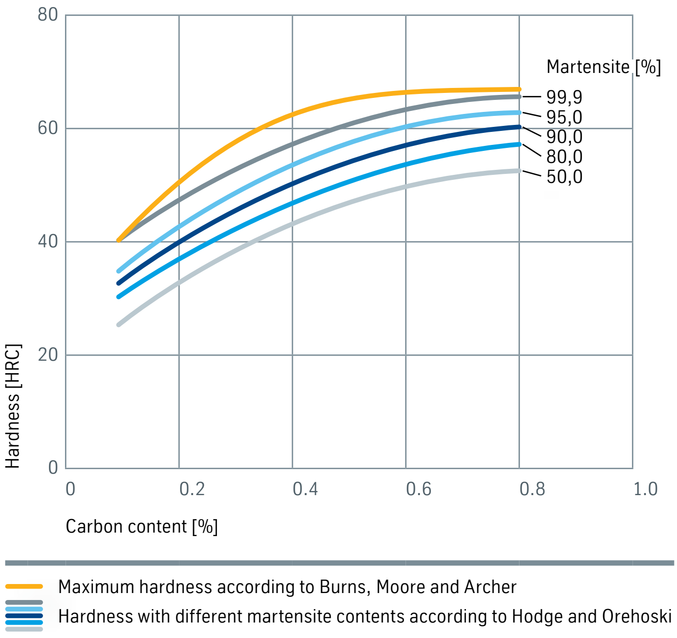
In pickled finish the coils are normally oiled prior to delivery (anticorrosion oil or emulsion-based oil for re-rollers).

Material characteristics

thyssenkrupp generally supplies carbon steels in line with analysis specifications with no guarantees regarding mechanical properties in as-delivered condition, as the final mechanical properties of the workpiece are significantly influenced by the heat treatment. The chemical composition forms the basis for the hardness values that can be achieved after heat treatment.

The carbon content influences the martensite hardness that can be achieved after hardening, and the alloying elements (Si, Mn, Cr, Mo) affect through-hardenability. The achievable martensite hardness is shown in Fig. 1 according to Burns, Moore and Archer.

Fig. 1: Correlation between carbon content and hardness

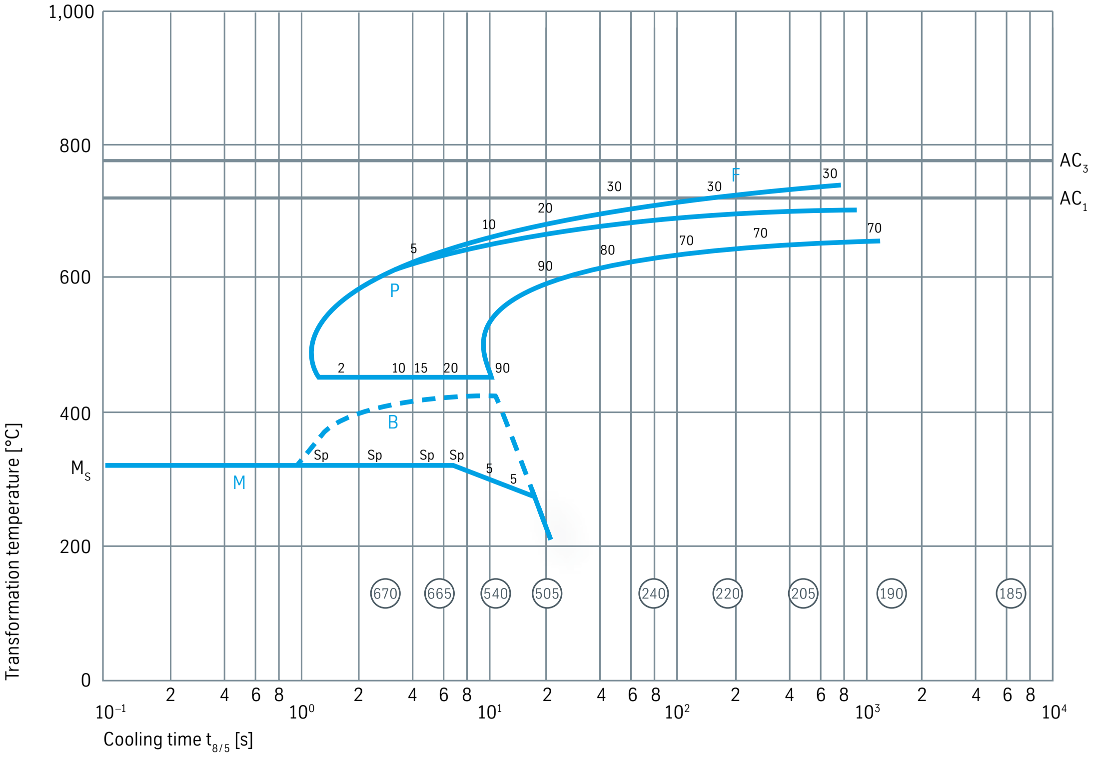


Source: Wirtschaftsvereinigung Stahl, Merkblatt 450

Where good through-hardenability is also required with greater thicknesses, alloyed steel grades are used. The microstructure and hardness values after heat treatment are shown in Fig. 2, TTT diagram (Time-Temperature-Transformation) for steel C45.

The diagram shows the transformation behavior at an austenitizing temperature of 870°C and a holding time of 15 minutes.

Fig. 2: TTT diagram of transformation behavior of C45 [1)]



○ Hardness value HRC/HV
M_S Martensite temperature 320 °C
AC_1 = Start of austenitizing 720 °C
AC_3 = End of austenitizing 780 °C

F Ferrite
P Pearlite
B Bainite
M Martensite

[1)] Austenitizing temperature 870 °C, holding time 15 minutes

There is a risk of graphite formation during recrystallization annealing of steel grades with high carbon contents which are intended for high cold rolling reduction ratios. Aluminum alloying elements promote the degradation of the cementite, while chromium alloys prevent this degradation.

By agreement with our customers, if they have such requirements, Cr/AL ratios > 10 are used in the chemical composition, which inhibits the tendency for graphitization. Please contact our technical customer support team if you require any further information.

With carbon steel, the mechanical properties of hot-rolled wide strip mainly depend on the pearlite content and its formation. Increasing carbon content results in higher pearlite content and thus also higher strength. thyssenkrupp's cooling strategy is aimed at forming pearlite which is as finely lamellar as possible. Fine lamellar pearlite is advantageous for soft annealing, which is frequently carried out by our customers, for example re-rollers. The aim here is to improve cold rollability while also offering an end product which has the best possible cold forming properties.

With increasing thicknesses, larger proportions of lamellar pearlite can be expected because cooling speeds are lower than with thin dimensions. Lamellar pearlite is softer than fine lamellar pearlite (sorbite), but also more brittle.

Similarly, longer soft annealing times can be expected to achieve pearlite spheroidization. Strengths for carbon steel in the hot-rolled condition are typically between 400 MPa for C10 and 1000 MPa for C100S, although on the outer windings, values of up to approximately 1200 MPa are also possible. Values listed in DIN EN ISO 683 (previously DIN EN 10083) for mechanical properties relate to the normalized condition and are not applicable to hot-rolled wide strip in the hot-rolled condition (U = untreated). Hot-rolled wide strip can also be delivered in soft-annealed condition. The mechanical properties that can be achieved are to be agreed.

Normally only pickled materials are delivered in the soft-annealed condition as otherwise the scale layer is reduced during annealing and scale swarf is produced. This scale swarf can cause contamination of the equipment during further processing. No guarantees for edge decarburization can be provided for this delivery condition.

Microstructure of carbon steel as a function of carbon content < 0.8%

0.1% C
12.5% Pearlite

0.4% C
50.0% Pearlite

0.6% C
75.0% Pearlite

0.8% C
100.0% Pearlite

Technical features

Carbon steels from thyssenkrupp are produced as special steels in accordance with DIN EN 10020 with significantly reduced levels of phosphorus and sulfur. On request an additional reduction is possible. Further analysis restrictions may be possible and must be agreed with the Technical Customer Service before ordering.

Subject to completion, steel grades are available in dimensions shown from page 10 onwards. Please contact the Technical Customer Service before ordering.

Chemical composition

Case-hardening steels according to DIN EN ISO 683-3 (previously DIN EN 10084), DIN EN 10132-2

Mass fractions in ladle analysis – Steel grade	Material No.	C [%]	Si [%] max.	Mn [%]	P [%] max.	S [%] max.	Cr [%] max. / –
● C10	1.1121	0.07 – 0.13	0.40	0.30 – 0.60	0.025	0.010	0.30
● C15	1.1141	0.12 – 0.18	0.40	0.30 – 0.60	0.025	0.010	0.30
● 16MnCr5	1.7131	0.14 – 0.19	0.40	1.00 – 1.30	0.025	0.010	0.80 – 1.10
● 20MnCr5	1.7147	0.17 – 0.22	0.40	1.10 – 1.40	0.025	0.010	1.00 – 1.30

● Hot-rolled flat products

Chemical composition

Unalloyed tempering steels according to DIN EN ISO 683-1 (previously DIN EN 10083-2), DIN EN 10132-3

Mass fractions in ladle analysis – Steel grade	Material No.	C [%]	Si [%] max.	Mn [%]	P [%] max.	S [%] max.	Cr [%] max.	Mo [%] max.	Ni [%] max.	Cr + Mo + Ni [%] max.
● C22	1.1151	0.17 – 0.24	0.40	0.40 – 0.70	0.025	0.010	0.40	0.10	0.40	0.63
● C25	1.1158	0.22 – 0.29	0.40	0.40 – 0.70	0.025	0.010	0.40	0.10	0.40	0.63
● C30	1.0528	0.27 – 0.34	0.40	0.50 – 0.80	0.025	0.010	0.40	0.10	0.40	0.63
● C35	1.1181	0.32 – 0.39	0.40	0.50 – 0.80	0.025	0.010	0.40	0.10	0.40	0.63
● C40	1.1186	0.37 – 0.44	0.40	0.50 – 0.80	0.025	0.010	0.40	0.10	0.40	0.63
● C45	1.1191	0.42 – 0.50	0.40	0.50 – 0.80	0.025	0.010	0.40	0.10	0.40	0.63
● C50	1.1206	0.47 – 0.55	0.40	0.60 – 0.90	0.025	0.010	0.40	0.10	0.40	0.63
● C55	1.1203	0.52 – 0.60	0.40	0.60 – 0.90	0.025	0.010	0.40	0.10	0.40	0.63
● C60	1.1221	0.57 – 0.65	0.40	0.60 – 0.90	0.025	0.010	0.40	0.10	0.40	0.63

● Hot-rolled flat products

Chemical composition

Mass fractions in ladle analysis		C [%]	Si [%] max.	Mn [%]	P [%] max.	S [%] max.	Cr [%]	Mo [%] –/max.	V [%]	B [ppm]
Alloyed tempering steels according to DIN EN ISO 683-2 (previously DIN EN 10083-1, DIN EN 10083-3), DIN EN 10132-3										
Steel grade	Material No.									
● 25CrMo4	1.7218	0.22–0.29	0.40	0.60–0.90	0.025	0.010	0.90–1.20	0.15–0.30	–	–
● 34CrMo4	1.7220	0.30–0.37	0.40	0.60–0.90	0.025	0.010	0.90–1.20	0.15–0.30	–	–
● 42CrMo4	1.7225	0.38–0.45	0.40	0.60–0.90	0.025	0.010	0.90–1.20	0.15–0.30	–	–
● 50CrMo4	1.7228	0.46–0.54	0.40	0.50–0.80	0.025	0.010	0.90–1.20	0.15–0.30	–	–
● 51CrV4	1.8159	0.47–0.55	0.40	0.70–1.10	0.025	0.010	0.90–1.20	0.10	0.10–0.25	–
● 58CrV4	1.8161	0.54–0.62	0.40	0.70–1.10	0.025	0.010	0.90–1.20	–	0.10–0.20	–
● 20MnB5	1.5530	0.17–0.24	0.40	1.10–1.40	0.025	0.010	–	0.10	–	8–50
● 30MnB5	1.5531	0.27–0.33	0.40	1.10–1.45	0.025	0.010	–	0.10	–	8–50
● 39MnB5	1.5532	0.36–0.42	0.40	1.15–1.45	0.025	0.010	–	0.10	–	8–50
● 27MnCrB5-2	1.7182	0.24–0.30	0.40	1.10–1.40	0.025	0.010	0.30–0.60	0.10	–	8–50
● 33MnCrB5-2	1.7185	0.30–0.36	0.40	1.20–1.50	0.025	0.010	0.30–0.60	0.10	–	8–50
● 39MnCrB6-2	1.7189	0.36–0.42	0.40	1.40–1.70	0.025	0.010	0.30–0.60	0.10	–	8–50

● Hot-rolled flat products

Chemical composition

Mass fractions in ladle analysis		C [%]	Si [%]	Mn [%]	P [%] max.	S [%] max.	Cr [%] max./–	Mo [%]	Ni [%] max.	V [%]
Spring steels according to DIN EN 10132-4										
Steel grade	Material No.									
● C55S	1.1204	0.52–0.60	0.15–0.35	0.60–0.90	0.025	0.010	0.40	0.10	0.40	–
● C60S	1.1211	0.57–0.65	0.15–0.35	0.60–0.90	0.025	0.010	0.40	0.10	0.40	–
● C67S	1.1231	0.65–0.73	0.15–0.35	0.60–0.90	0.025	0.010	0.40	0.10	0.40	–
● C75S	1.1248	0.70–0.80	0.15–0.35	0.60–0.90	0.025	0.010	0.40	0.10	0.40	–
● C85S	1.1269	0.80–0.90	0.15–0.35	0.40–0.70	0.025	0.010	0.40	0.10	0.40	–
● C90S	1.1217	0.85–0.95	0.15–0.35	0.40–0.70	0.025	0.010	0.40	0.10	0.40	–
● C100S	1.1274	0.95–1.05	0.15–0.35	0.30–0.60	0.025	0.010	0.40	0.10	0.40	–
● 51CrV4	1.8159	0.47–0.55	≤ 0.40	0.70–1.10	0.025	0.010	0.90–1.20	0.10	0.40	0.10–0.25
● 75Cr1	1.2003	0.70–0.80	0.25–0.50	0.60–0.80	0.025	0.010	0.30–0.45	–	–	–
● 80CrV2	1.2235	0.75–0.85	0.15–0.35	0.30–0.50	0.025	0.010	0.40–0.60	0.10	0.40	0.15–0.25

● Hot-rolled flat products

Notes on applications and processing

Heat treatment

The aim of heat treatment is to influence the microstructure and thus the mechanical properties of a workpiece in line with requirements by heating and then cooling it. A detailed insight into the topics of “hardening”, “reheating”, “quenching and tempering” and “austempering” can be found in the bulletin “Merkblatt 450 – Heat treatment of steel” from The German Steel Federation. Merkblatt 452 provides valuable information on case hardening.

Joining

Joining unalloyed and alloyed carbon steels is generally possible in the as-delivered condition and after heat treatment. Weldability and mechanical properties – essentially the hardness, strength and toughness of the joints – mainly depend on the carbon equivalent and the heat-treated condition. For this reason, when it comes to joining methods it is necessary to distinguish between case-hardening steels, tempering steels and spring steels. For welding, the welding parameters must be matched to the material. In particular, resistance spot, shield gas, arc, laser-beam welding, adhesive bonding and mechanical joining methods can be used.

Resistance spot welding

In principle, case-hardening steels, unalloyed and alloyed tempering steels, as well as spring steels, can be conductively heated using conventional resistance pressure welding equipment, and can therefore also be welded.

For all grades any oxidation residues from heat treatment or secondary heat treatment – depending on the process (with/without shield gases, transfer times to the atmosphere etc.) – will have to be removed, preferably by sandblasting (also by pickling if necessary), before resistance spot welding can be carried out. Even case-hardening steels with carbon contents of only up to 0.20% by mass carry a risk after case-hardening that near-surface recarburization up to approximately 0.8% will cause the resistance spot welds to become extremely hard and thus fracture under excessive stresses – even in the low load range – unless they undergo further post-treatment.

This also applies to the other steel grades that have not only carbon contents of approx. 0.2 to over 1%, but also other hardening elements such as manganese or chromium in higher quantities.

For these grades it should be determined whether, after welding, the microstructure of the weld can be made tougher by reheating with electrodes so as to improve the service properties of the welds. Subsequent reheating using an external source (e.g. HF induction) may also be a way of achieving such weld optimization; in this case, however, there is always the possibility of distortion in the welded components. With process-hardened materials from the grades described in this product datasheet, softening within the heat-affected zone (HAZ) of a spot weld must be expected from certain final strengths of the base material; this softening results from reheating processes during or immediately after welding. A similar softening zone will also be created if spot welds are reheated, although it will be superimposed with the previous initial softening zone and the HAZ of the joint will be enlarged overall.

Laser beam welding

In general it should be borne in mind that when hardened components are welded a decrease in hardness in the HAZ cannot be avoided. This decrease in hardness represents a weakness in the joint, which has to be taken into account in the design of the component. If post-weld heat treatment is carried out, the properties of the HAZ may also be affected.

Case-hardening steels: Based on their chemical composition, case-hardening steels should be readily weldable by laser beam. This should be validated before use by component-specific trials.

Unalloyed tempering steels: Based on their chemical composition, case-hardening steels should be readily weldable by laser beam. Due to the high cooling rates in the laser process, a high level of hardness can be expected in the heat-affected zone and in the weld metal, depending on the carbon equivalent. If necessary, this can be reduced or eliminated by subsequent heat treatment. Prior to use, component-specific trials should be carried out in each case.

Alloyed tempering steels: Based on their chemical composition (high carbon equivalent), alloyed tempering steels show only limited suitability for laser-beam welding. Due to the high cooling rates in the laser process, a high level of hardness can be expected in the heat-affected zone and in the weld metal. If necessary, this can be reduced or eliminated by subsequent heat treatment. Prior to use, component-specific trials should be carried out in each case.

Spring steels: Based on their chemical composition (high carbon equivalent), spring steels are not suitable for laser welding. Due to the high cooling rates in the laser process, a high level of hardening and crack formation in the heat-affected zone and in the weld metal must be expected.

Arc welding

The suitability of carbon steels for arc welding generally depends on the carbon equivalent. The heat input during welding can result in the formation of martensite, which is very hard and is consequently susceptible to cold cracking or hardening cracking in the material. This crack susceptibility depends not only on the alloy composition of the base material but also the filler metal, the geometry of the weld and the heat control. Suitability for welding must therefore be checked in component-specific trials in each case.

Within the validity limits, an initial assessment of cold cracking susceptibility can be carried out using the leaflet Stahl-Eisen-Werkstoffblatt SEW 088. In addition thyssenkrupp offers the web-based software ProWeld (free registration at: https://online.thyssenkrupp-steel.com/ecmlogin/proweld_register.do), which can be used to assess cold cracking susceptibility and estimate pre-heating requirements.

To reduce susceptibility to cracking in critical materials, the use of low-alloy filler metals with low yield strength is recommended; when using the submerged arc and manual arc welding processes, care must be taken to ensure the welding powder and filler metals are dry enough. In individual cases it may be useful to use austenitic filler metals, as their low yield strength and high formability can help reduce stress peaks during forming. Pre-heating the workpiece can prevent or delay the formation of martensite. To reduce residual stresses from welding and to reheat a hardened heat-affected zone, post-weld heat treatment may be useful; the impact of this measure on the base material must be taken into account.

Note: Reheating effects on welded components in the tempered/hardened condition can cause a change to the mechanical values in the affected area.

Adhesive bonding

Generally, in adhesive bonding the adhesion of the respective adhesive and the stability of the bond almost always depend on the surface of the parts to be joined. As a wide range of adhesives are available, each optimized for use with different surfaces and applications, exploratory trials should always be carried out in order to determine the bonding behavior of the specific combination of material and adhesive.

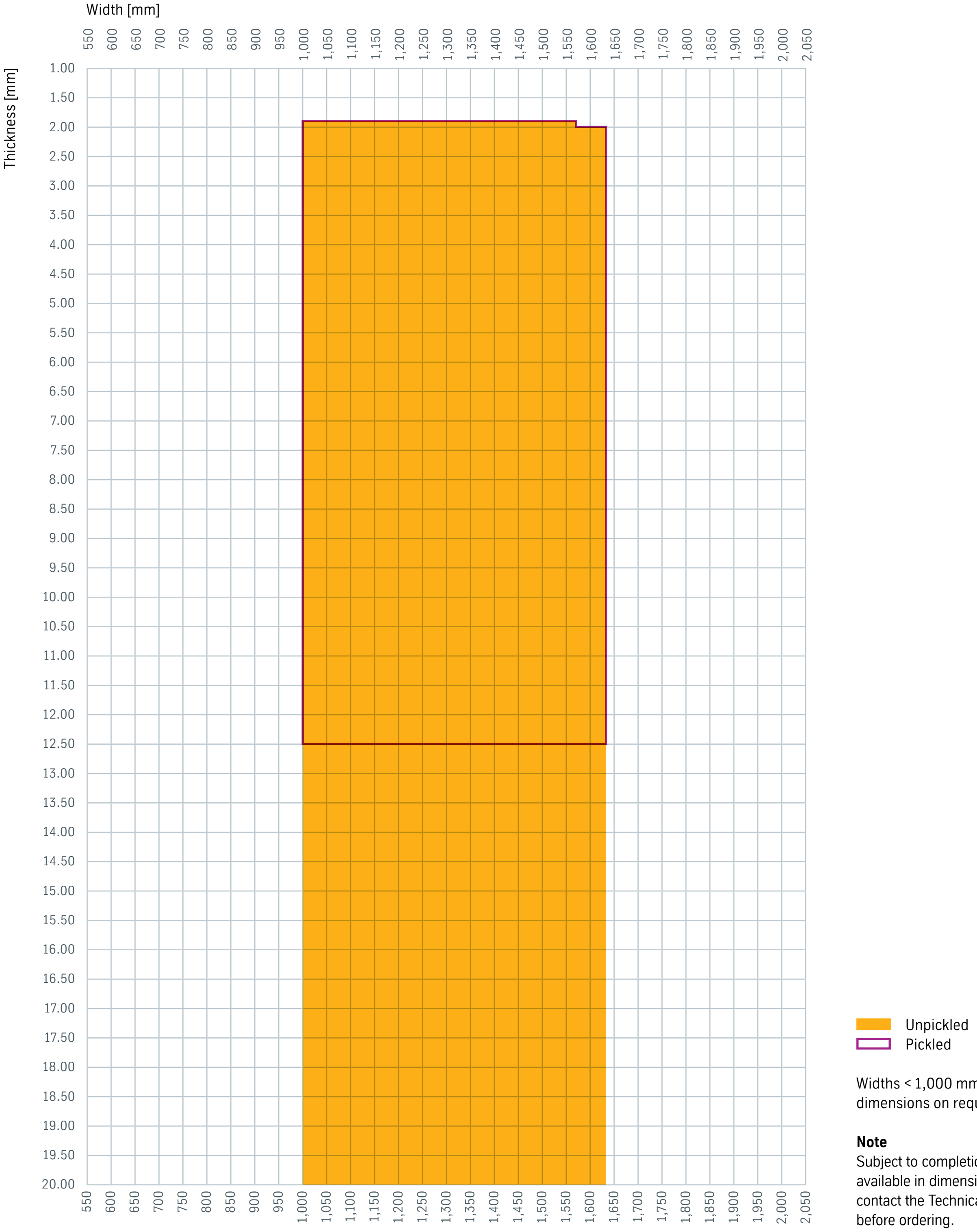
General guidelines for all materials described in the production information:

- Unpickled surfaces have an oxide layer which can vary locally and therefore result in variances in adhesion. The adhesion of the oxide layer to the metallic material can also be weaker than its adhesion to the adhesive, so the bond may fail due to the oxide layer tearing off.
- Pickled surfaces have a more uniform surface
- Oiling may impair the adhesion of adhesives, especially cold-curing adhesives. By contrast, thermosetting adhesives generally continue to display good adhesion even with the standard light application of anticorrosion oil.

Available dimensions

Wide hot strip

C10, C15

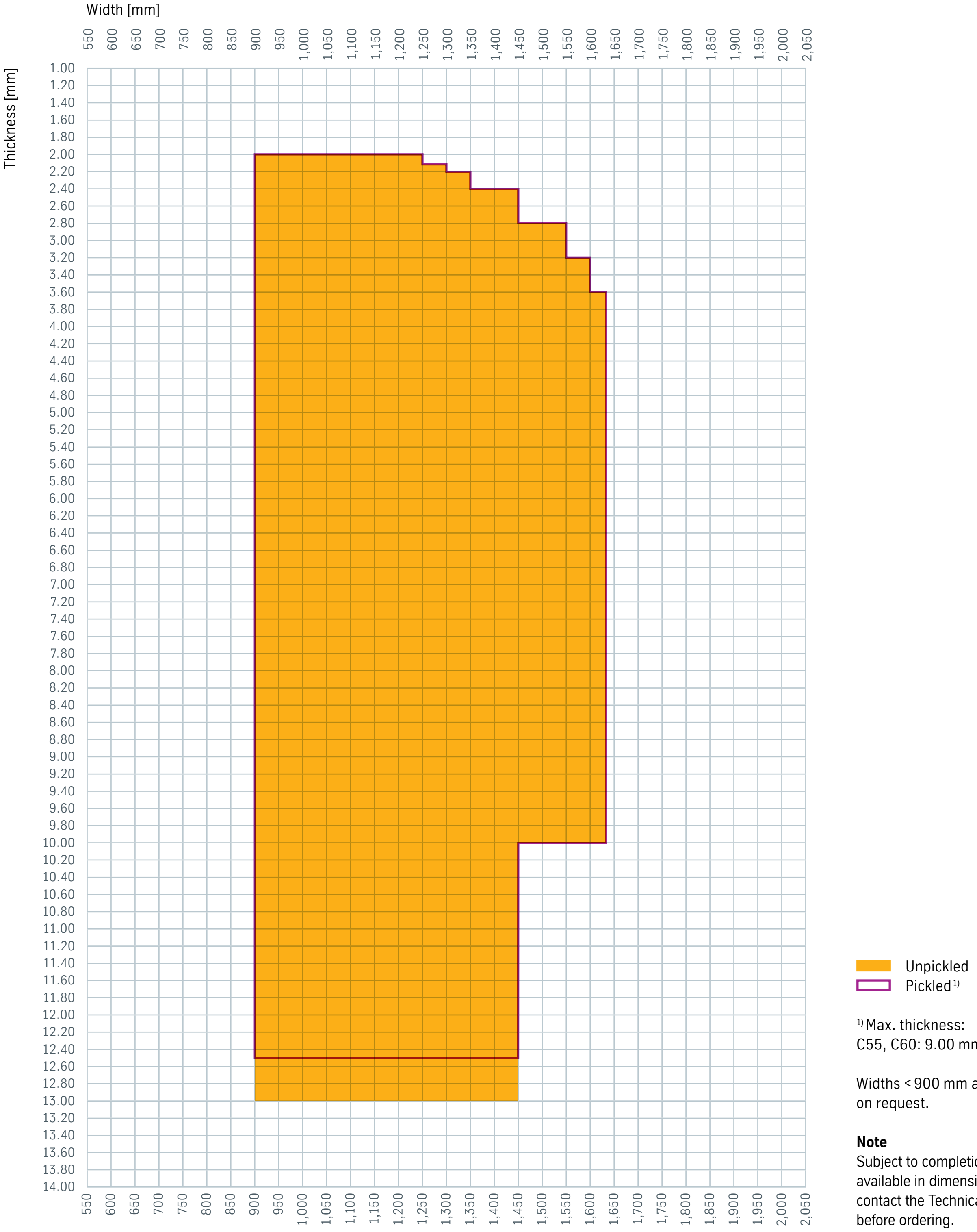


Widths < 1,000 mm and further dimensions on request.

Note
Subject to completion, steel grades are available in dimensions shown. Please contact the Technical Customer Service before ordering.

Wide hot strip

C22 – C60



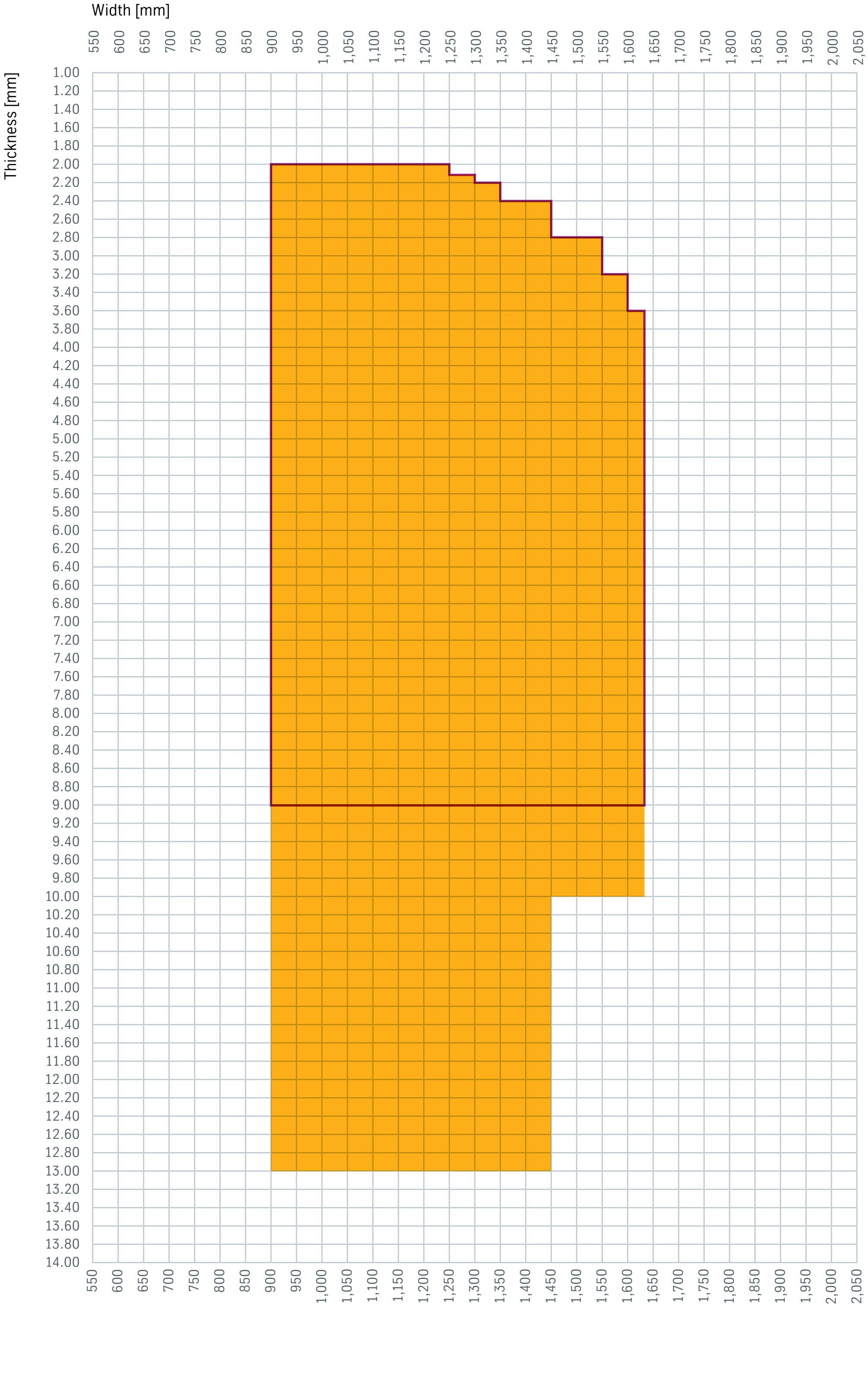
[1] Max. thickness:
C55, C60: 9.00 mm

Widths < 900 mm and further dimensions on request.

Note
Subject to completion, steel grades are available in dimensions shown. Please contact the Technical Customer Service before ordering.

Wide hot strip

C55S, C60S, C67S, C75S, C85S, C90S, C100S



Unpickled
Pickled[1)]

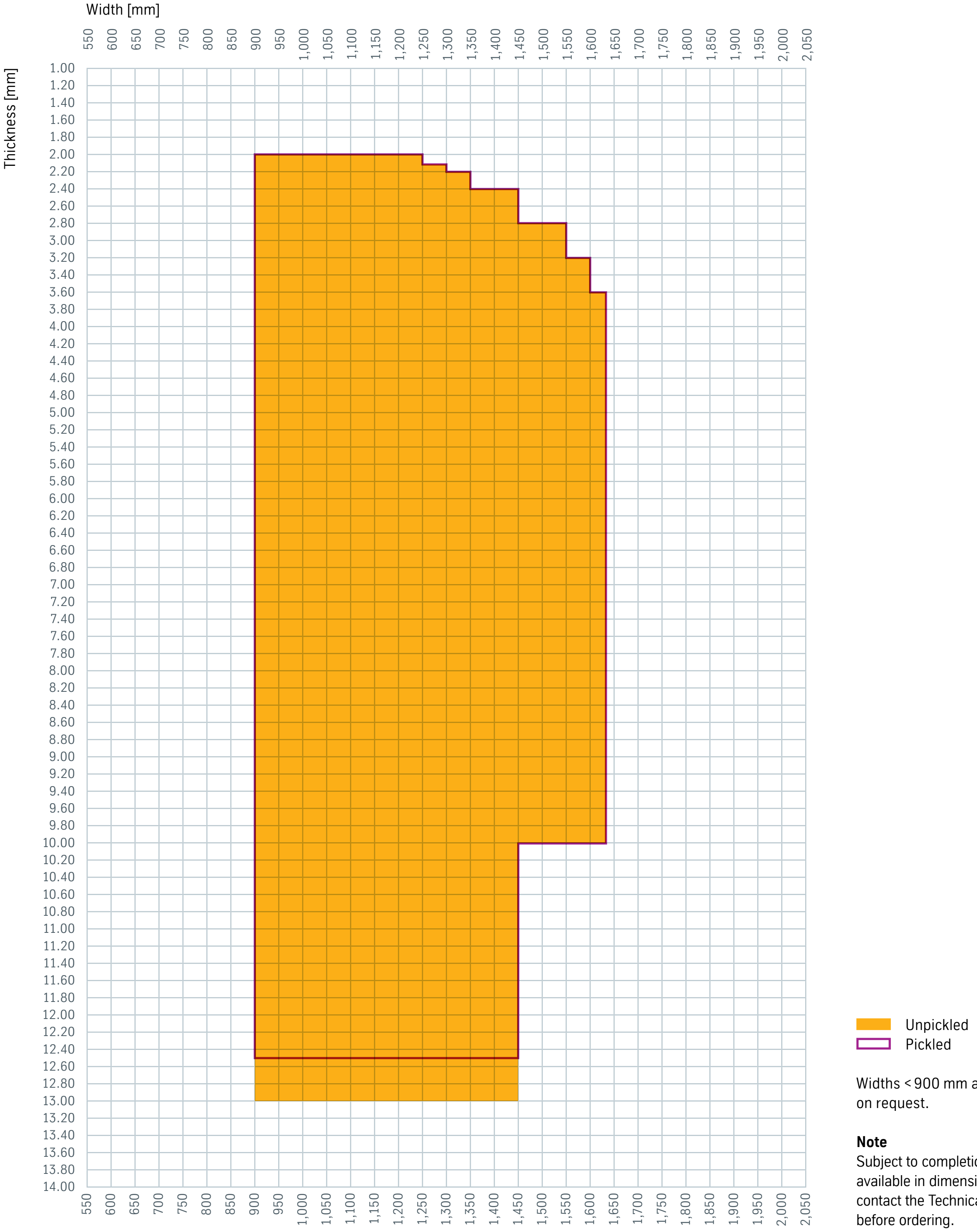
[1)] Max. tickness:
C100S: 6.25 mm

Widths < 900 mm and further dimensions on request.

Note
Subject to completion, steel grades are available in dimensions shown. Please contact the Technical Customer Service before ordering.

Wide hot strip

16MnCr5, 20MnCr5



Widths < 900 mm and further dimensions on request.

Note
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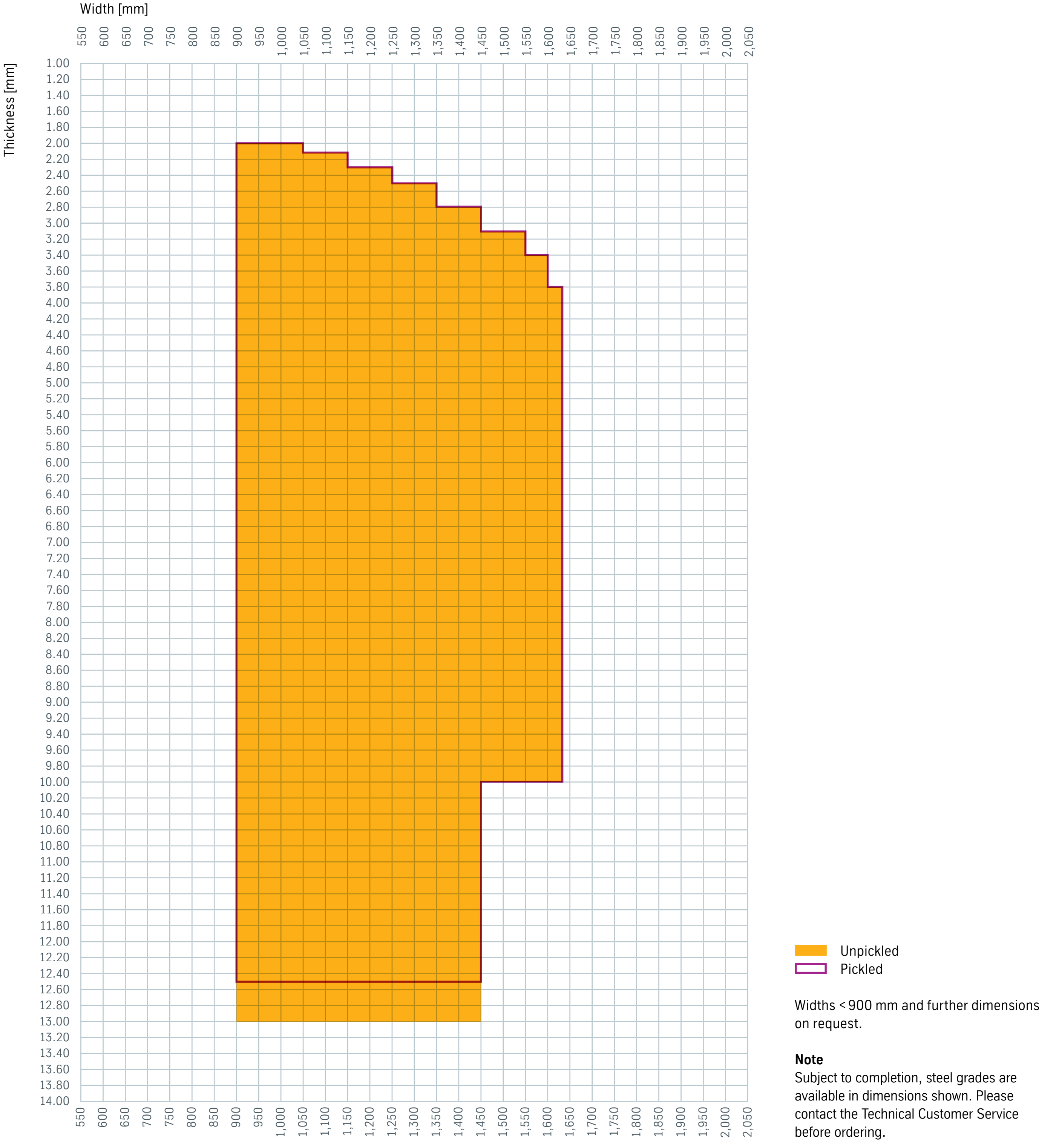
Wide hot strip

20MnB5, 30MnB5, 39MnB5, 27MnCrB5-2, 33MnCrB5-2, 39MnCrB6-2



Widths < 900 mm and further dimensions on request.

Note
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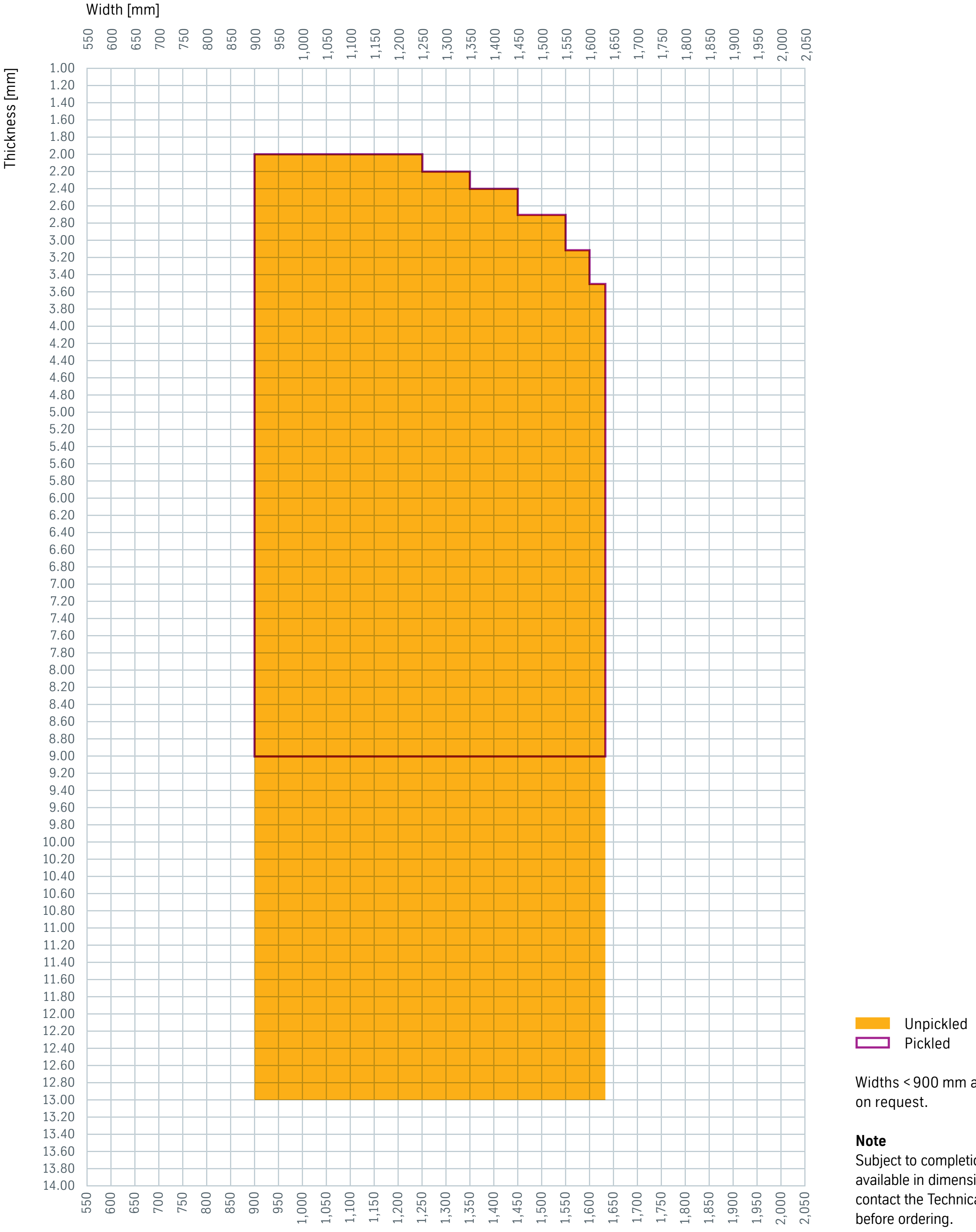
Wide hot strip

25CrMo4, 34CrMo4, 42CrMo4, 50CrMo4

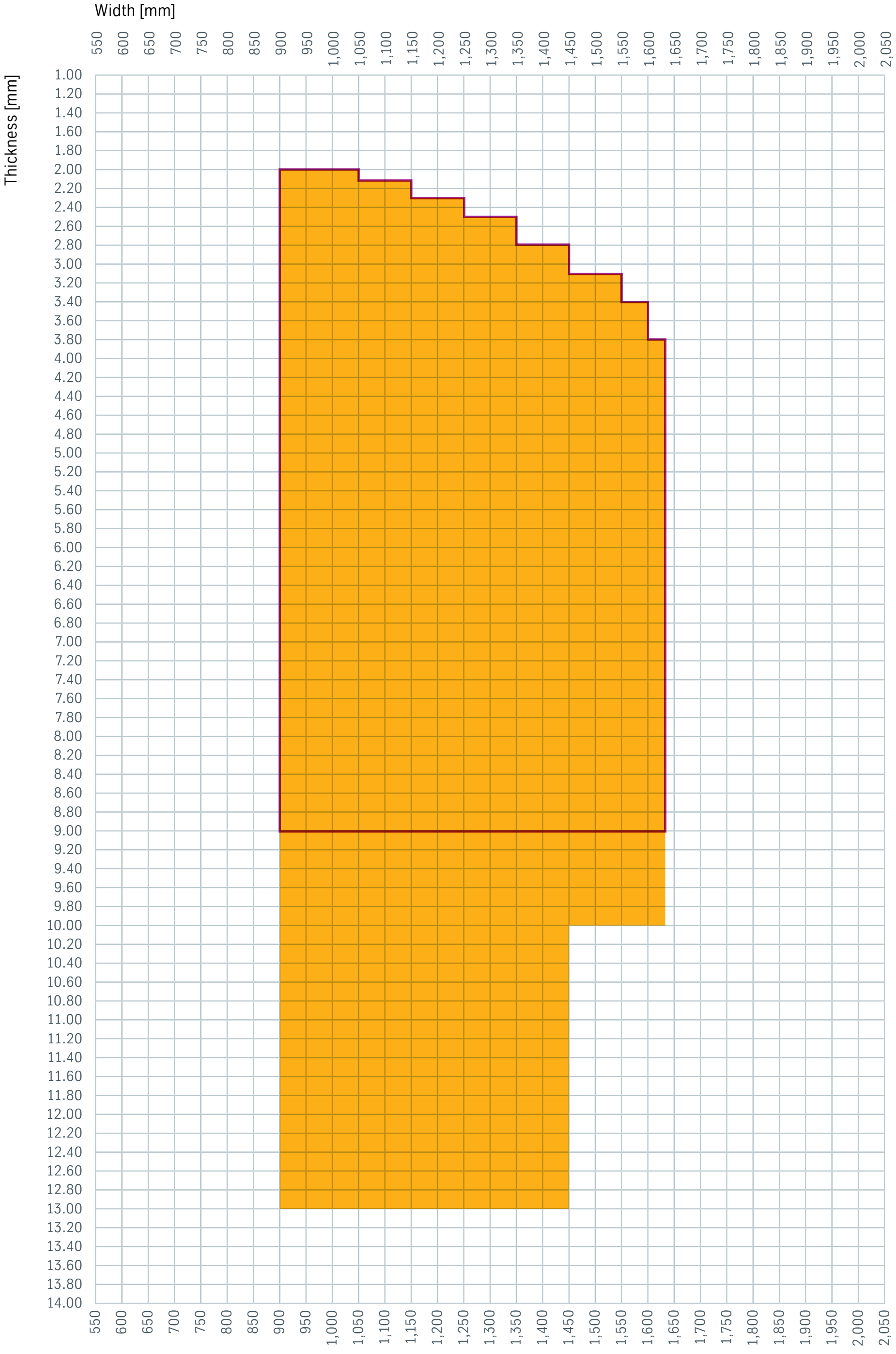


Widths < 900 mm and further dimensions on request.

Note
Subject to completion, steel grades are available in dimensions shown. Please contact the Technical Customer Service before ordering.

Wide hot strip

51CrV4, 58CrV4



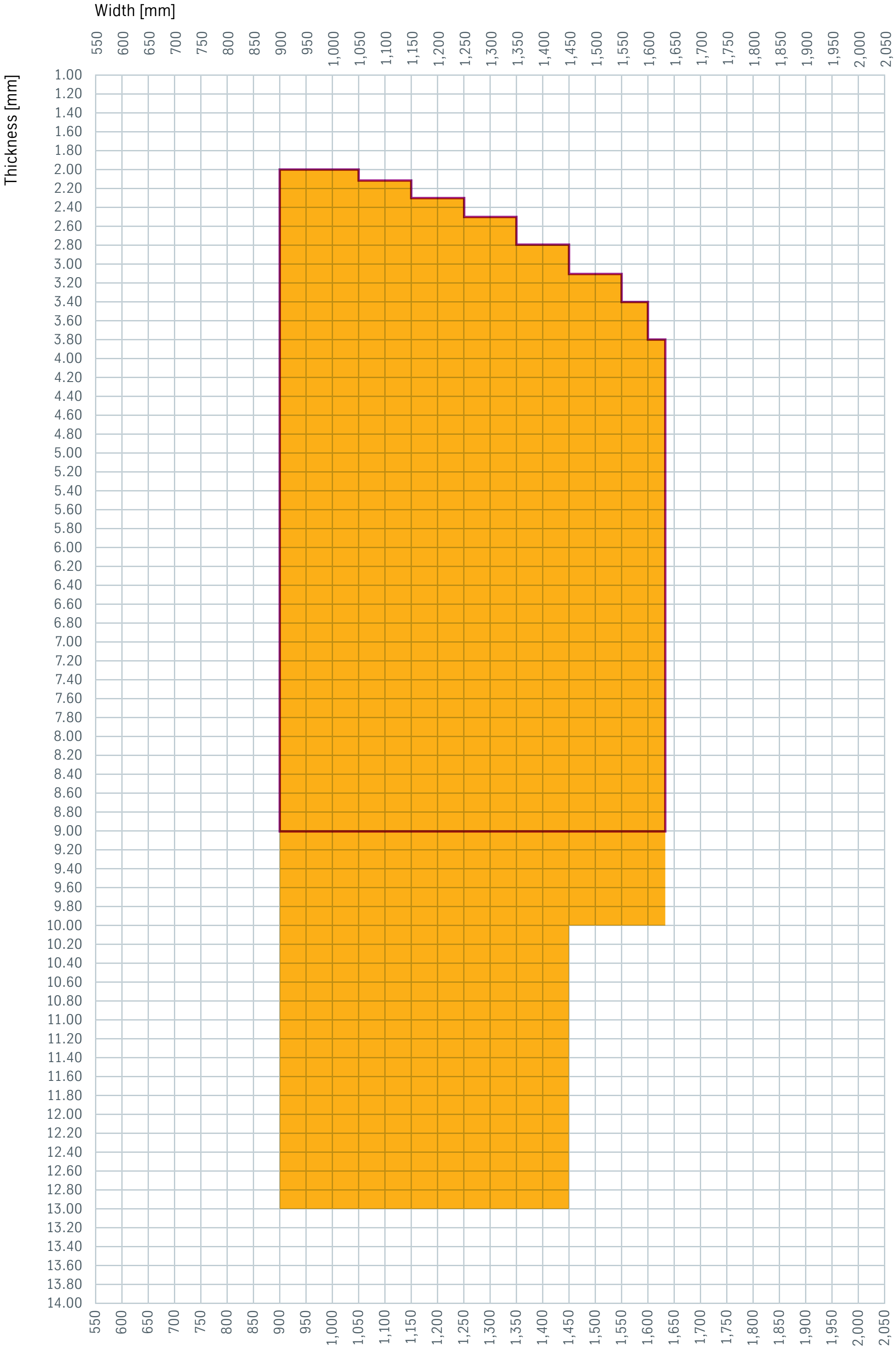
Unpickled
Pickled

Widths < 900 mm and further dimensions on request.

Note
Subject to completion, steel grades are available in dimensions shown. Please contact the Technical Customer Service before ordering.

Wide hot strip

75Cr1, 80CrV2



Unpickled
Pickled

Widths < 900 mm and further dimensions on request.

Note
Subject to completion, steel grades are available in dimensions shown. Please contact the Technical Customer Service before ordering.

Sample applications

Circular saw blade.

Roller chains.

Seat adjuster unit.

Gear wheels.

Special mill grades are supplied subject to the special conditions of thyssenkrupp. Other delivery conditions not specified here will be based on the applicable specifications. The specifications used will be those valid on the date of issue of this product information brochure.

General information

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