

VDM® Crofer 22 H

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VDM® Crofer 22 H is a high-temperature ferritic stainless steel especially developed for application in solid oxide fuel cells (SOFC). It has good creep strength because of Laves phase precipitates. At temperatures up to 900 °C (1,652 °F) a chromium-manganese oxide layer is formed on the surface of Crofer 22 H, which is thermodynamically very stable and possesses high electrical conductivity. The low coefficient of thermal expansion matches to the one of ceramics typically used for high-temperature fuel cells in the range of room temperature up to 900 °C (1,652 °F).

VDM® Crofer 22 H is characterized by:

- excellent corrosion resistance at high temperatures in anode gas and cathode gas,
- good creep properties,
- low rate of chromium vaporization,
- ease of working and processing,
- low coefficient of thermal expansion,
- good electrical conductivity of the oxide layer.

Designations and standards

Standard	Material designation
DIN EN	1.4755 - X1CrWNbTiLa22-2

Table 1 – Designations and standards

Chemical composition

	Cr	Fe	C	N	S	Mn	Si	Al	W	Nb	Ti	La	P	Ni	Cu
Min.	20.0	bal.					0.10		1.0	0.20	0.02	0.04			
Max.	24.0		0.030	0.04	0.006	0.80	0.60	0.10	3.0	1.00	0.20	0.20	0.050	0.50	0.50

Table 2 – Chemical composition (%)

Physical properties

Density	Melting range
7.8 g/cm ³ 0.278 lb/in ³	1452 °C (Solidus) - 1503 °C (Liquidus) 2646 °F (Solidus) - 2737 °F (Liquidus)

Temperature		Specific heat		Thermal conductivity		Electrical resistivity	Modulus of elasticity		Coefficient of thermal expansion	
°C	°F	$\frac{\text{J}}{\text{kg} \cdot \text{K}}$	$\frac{\text{Btu}}{\text{lb} \cdot \text{°F}}$	$\frac{\text{W}}{\text{m} \cdot \text{K}}$	$\frac{\text{Btu} \cdot \text{in}}{\text{sq. ft} \cdot \text{h} \cdot \text{°F}}$	$\mu\Omega \cdot \text{cm}$	GPa	10 ³ ksi	$\frac{10^{-6}}{\text{K}}$	$\frac{10^{-6}}{\text{°F}}$
20	68	469	0.112	20.0	139	56	208	30.2		
100	212	494	0.118	20.6	143	65	207	30.0	9.8	5.5
200	392	532	0.127	21.5	149	74	203	29.3	10.1	5.7
300	572					82	196	28.4	10.5	5.8
400	752	615	0.147	22.6	157	89	190	27.6	10.8	6.0
500	932					96	182	26.4	11.0	6.1
600	1112	948	0.226	25.4	176	103	175	25.4	11.2	6.2
700	1292					107			11.4	6.3
800	1472	660	0.158	26.1	181	109			11.8	6.6
900	1652					111			12.3	6.8
1000	1832	674	0.161	29.9	207	113			12.8	7.1

Table 3 – Typical physical properties at room and elevated temperatures

Microstructural properties

VDM® Crofer 22 H has a body-centered-cubic structure. During annealing at temperatures up to about 1,000 °C (1,832 °F) a Laves phase is formed which increases creep strength.

Mechanical properties

Form	Yield strength R _{p 0.2}		Tensile strength R _m		Elongation A	Hardness (For information only)
	MPa	ksi	MPa	ksi	%	HV
Strip	320	46.4	450	65.3	A ₅₀ = 18	160 – 200
Sheet & Plate	320	46.4	450	65.3	A ₅ = 18 A ₅ = 8*	

*Thickness > 16 mm (0.630 in)

Table 4 – Minimum mechanical properties in the solution annealed condition for all product forms at room temperature

Form	Dimension	Yield strength R _{p 0.2}		Tensile strength R _m		Elongation A
		MPa	ksi	MPa	ksi	%
Strip		390	65.6	560	81.2	23 (A ₅₀)
Sheet & Plate	≤ 16mm	390	65.6	520	75.4	25 (A ₅)
	> 16mm	390	65.6	490	71.1	10 (A ₅)

Table 5 – Typical mechanical properties for different product forms at room temperature

Temperature		Yield strength R _{p 0.2}		Tensile strength R _m		Elongation A
°C	°F	MPa	ksi	MPa	ksi	%
600	1112	160	23.2	333	48.3	25
700	1292	119	17.3	147	21.3	24
800	1472	49	7.1	55	8.0	80

Table 6 – Typical mechanical properties for plate (12 mm) at high temperatures

Figure 1 shows that VDM® Crofer 22 H clearly has a higher tensile strength than Crofer 22 APU. VDM® Crofer 22 H also has an increased creep resistance as shown by stress-rupture tests in Figure 3.

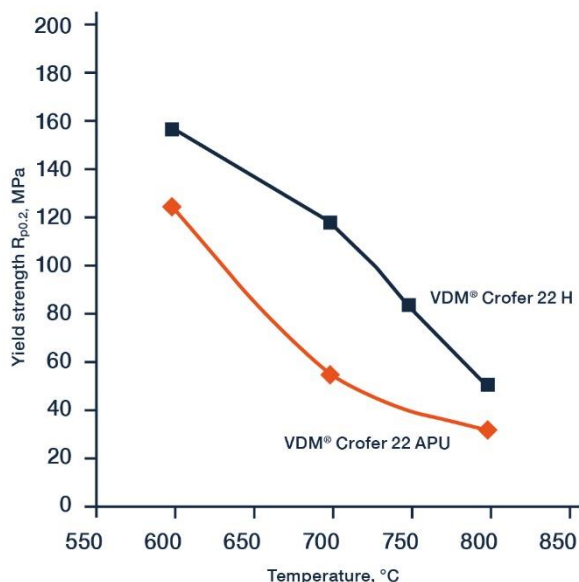


Figure 1 – Typical short-time mechanical properties VDM® Crofer 22 H, 12 mm plate, as a function of temperature (solution annealed and about 2 hours at testing temperature before the test) in comparison to Crofer 22 APU

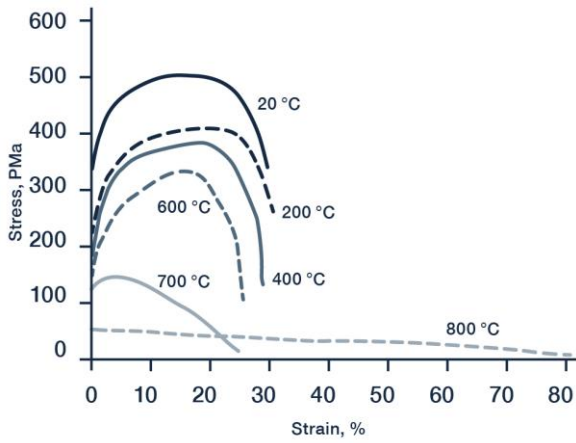


Figure 2 – Stress-Strain curves for Crofer 22 H at various temperatures

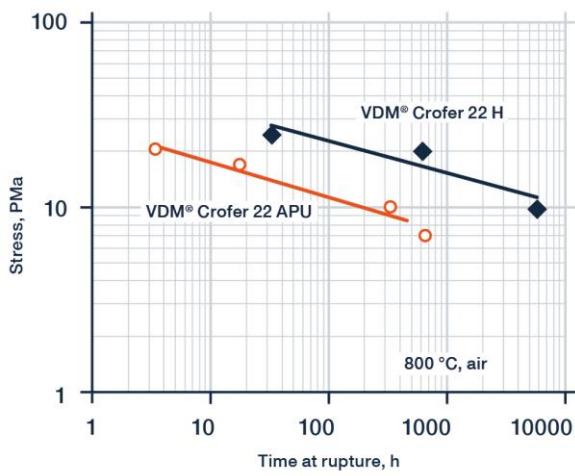


Fig. 3 – Typical creep-rupture strength of solution annealed Crofer 22 H, 12 mm plate, in air in comparison to Crofer 22 APU (After B. Kuhn et al., Forschungszentrum Jülich)

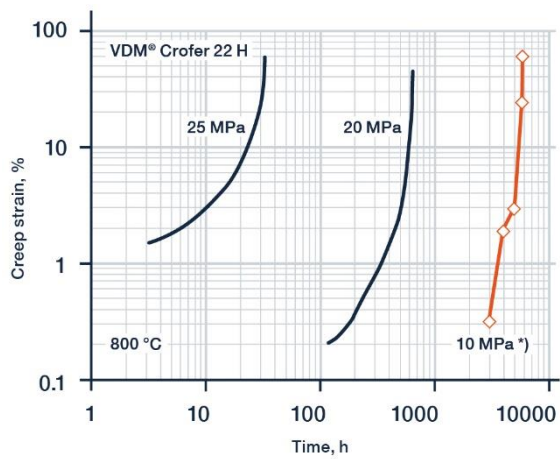


Figure 4 - Typical creep strain - time curves of solution annealed Crofer 22 H in air. All curves are from a continuous elongation measurement at the sample except *), which is from discontinuous elongation measurement (After B. Kuhn et al., Forschungszentrum Jülich)

Corrosion resistance

VDM® Crofer 22 H shows excellent corrosion resistance in atmospheres relevant to SOFC applications up to 900 °C. The oxide layer of VDM® Crofer 22 H consists of a fine grained inner scale which is predominantly Cr₂O₃ and a columnar (Mn, Cr)₃O₄ spinel outer oxide layer.

Figure 5 shows the corrosion resistance of VDM® Crofer 22 H in air at 800 °C for a commercial heat. For comparison the results of a laboratory heat melted with high-purity prematerials prior to the commercial heat are also included in Figure 5.

Figure 6 clearly shows that the thickness of sheet material has no significant effect on the corrosion resistance of VDM® Crofer 22 H after 1110 h at 800 °C in air. There is a significant effect on the oxidation resistance of VDM® Crofer 22 APU.

Figure 7 shows long term results of VDM® Crofer 22 H and Crofer 22 APU (first commercial melt and a heat from current production, which is restricted in residual elements), which clearly shows the excellent corrosion resistance of VDM® Crofer 22 H.

Figure 8 shows long term results of VDM® Crofer 22 H for different thicknesses. For 0.3 mm thickness after about 3000 h at 800 °C in air, corrosion increases in comparison to 0.5 mm and 1 mm thickness.

As shown in Figure 9 the thickness of sheet material has also no significant effect on the corrosion resistance of VDM® Crofer 22 H at 900 °C in air up to 1,000 hours. There is a significant effect on the oxidation resistance of VDM® Crofer 22 APU.

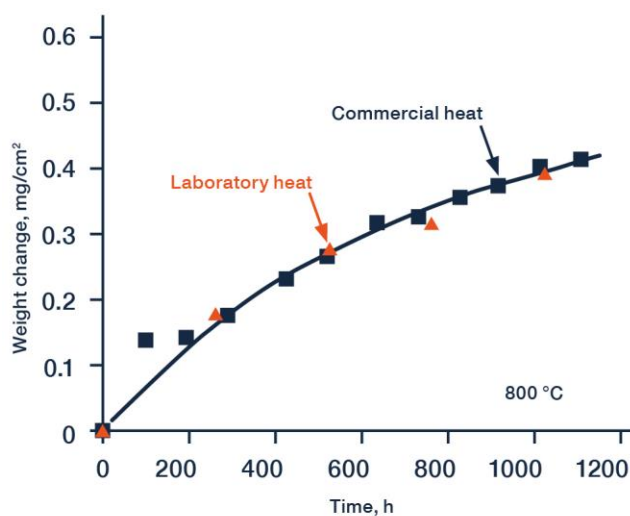


Figure 5 – Mass change during discontinuous oxidation tests (100 h cycles) of a commercially produced Crofer 22 H heat in air at 800 °C as a function of time. For comparison a laboratory melt (250 h cycles) is included (typical values)
(After Quadackers, Niewolak et al., Forschungszentrum Jülich)

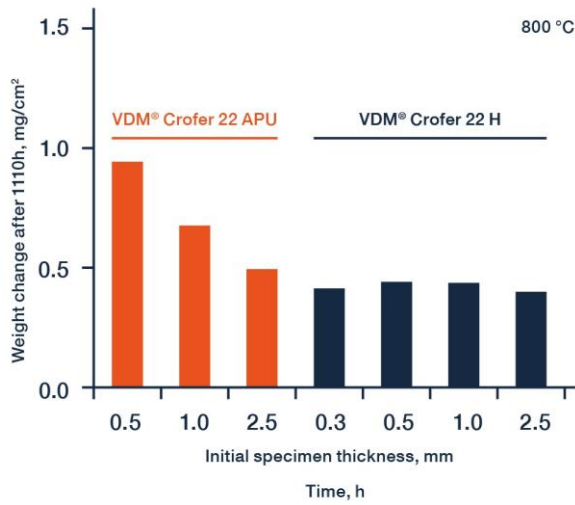


Fig. 6 - Mass change after 1,110 hours of discontinuous oxidation tests (100 h cycles) in air at 800 °C of samples with varying thickness from Crofer 22 H and Crofer 22 APU (typical values) (After Quadackers, Niewolak et al., Forschungszentrum Jülich)

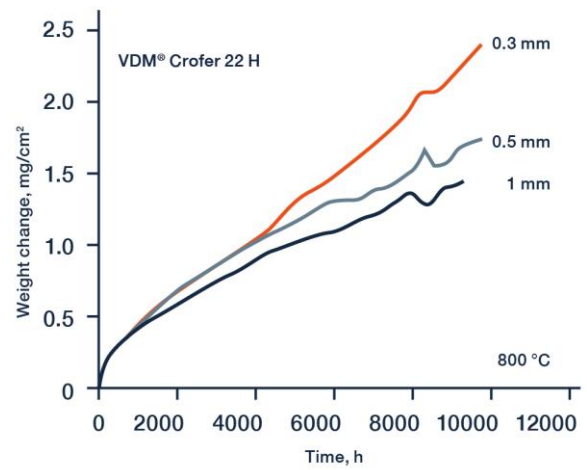


Figure 8 – Mass change during discontinuous oxidation tests (250 h cycles) of commercially produced Crofer 22 H in air at 800 °C as a function of time (typical values) (After Quadackers, Niewolak et al., Forschungszentrum Jülich)

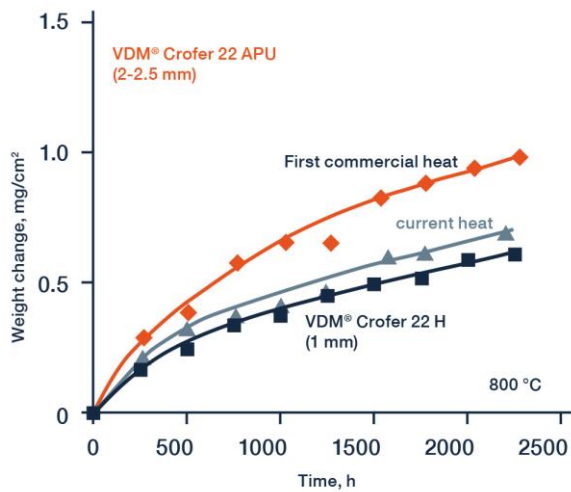


Fig. 7 - Mass change during discontinuous oxidation tests (250 h cycles) of commercially produced Crofer 22 H and Crofer 22 APU in air at 800 °C as a function of time (typical values) (After Quadackers, Niewolak et al., Forschungszentrum Jülich)

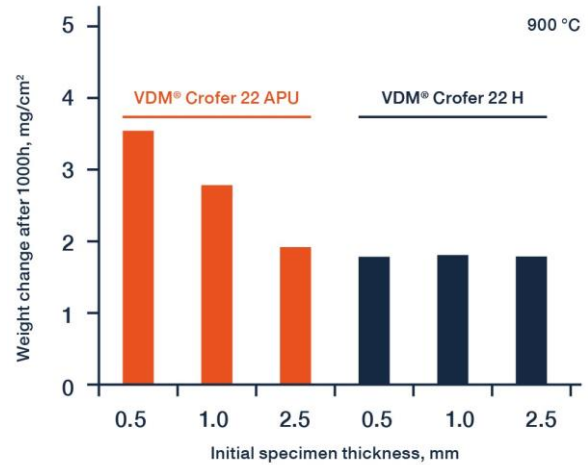


Figure 9 – Mass change after 1,000 hours of cyclic oxidation tests in air at 900 °C (cycles of 2 h and 15 min. cooling) of samples with varying thickness from commercially produced Crofer 22 H and Crofer 22 APU (typical values) (After Quadackers, Niewolak et al., Forschungszentrum Jülich)

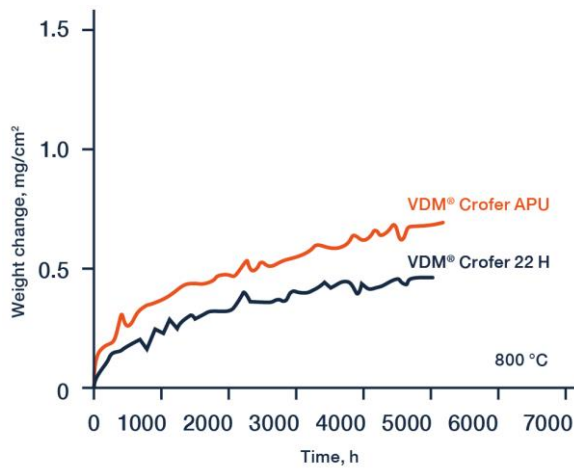


Figure 10 – Mass change during discontinuous oxidation tests (100 h cycles) of commercially produced Crofer 22 H and Crofer 22 APU in Argon 4% H₂ 20% H₂O at 800 °C for a sheet thickness of 2,5 mm as a function of time (typical values)
(After Quadackers, Niewolak et al., Forschungszentrum Jülich)

Figure 10 shows long term results of VDM® Crofer 22 H and VDM® Crofer 22 APU (current production) in Argon 4% H₂ 20% H₂O at 800 °C, which clearly shows the excellent corrosion resistance of Crofer® 22 H.

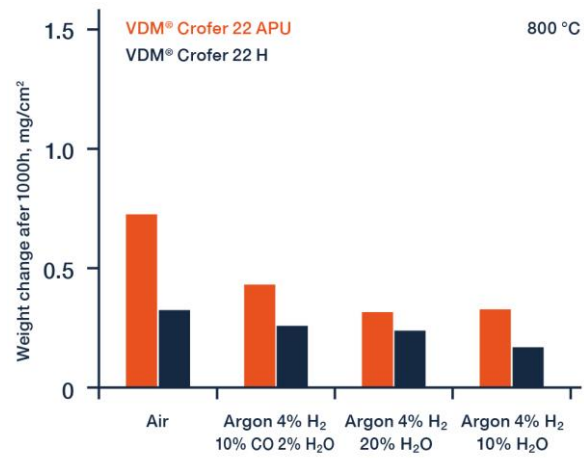


Fig. 11 - Mass change after 1,000 hours of discontinuous oxidation tests (100 h cycles) in various gases at 800 °C of commercially produced Crofer 22 H and Crofer 22 APU for a sheet thickness of 1 mm (typical values)
(After Quadackers, Niewolak et al., Forschungszentrum Jülich)

Figure 11 shows the corrosion resistance of VDM® Crofer 22 H and VDM® Crofer 22 APU at 800 °C in various gases, which again demonstrates the excellent corrosion resistance of VDM® Crofer 22 H

Applications

VDM® Crofer 22 H is used for interconnector plates to separate individual plates in solid oxide fuel cells (SOFC).

Fabrication and heat treatment

VDM® Crofer 22 H can be easily formed both hot and cold and can also be machined.

Heating

Production pieces must be clean and free from all kinds of contaminants before and during any heating operation.

VDM® Crofer 22 H may become embrittled if heated in the presence of contaminants such as sulfur, phosphorus, lead and other low-melting-point metals. Sources of such contaminants include marking and temperature-indicating paints and crayons, lubricating grease, fluids and fuels.

Fuels must be as low in sulfur as possible. Natural gas should contain less than 0.1 wt.-% sulfur. Liquid fuels with a sulfur content not exceeding 0.5 wt.-% are suitable.

Due to their close control of temperature and lack of contamination, thermal treatments in electric furnaces under vacuum or in an inert gas atmosphere are to be preferred. Treatments in an air atmosphere and, alternatively, in gas-fired furnaces are acceptable though, if contaminants are kept at low levels so that a neutral or slightly oxidizing furnace atmosphere is attained.

A furnace atmosphere fluctuating between oxidizing and reducing conditions must be avoided as well as direct flame impingement on the metal.

Cold forming

For cold working the solution annealed condition is recommended.

Heat treatment

A solution annealing can be performed at temperatures typically above 1,050 °C (1,922 F), followed by fast cooling with air or a protective atmosphere.

After cold forming a recrystallization heat treatment, typically above 1,050 °C, is required

Descaling and pickling

Oxides of VDM® Crofer 22 H and discoloration adjacent to welds are more adherent than on standard stainless steels. Grinding with very fine abrasive belts or discs is recommended. Care should be taken to prevent tarnishing. Before pickling which may be performed in a nitric/hydrofluoric acid mixture the surface oxide layer must be broken up by abrasive blasting, by carefully performed grinding or by pretreatment in a fused salt bath. Particular attention should be paid to the pickling time and temperature.

Welding information

When welding nickel alloys and special stainless steels, the following information should be taken into account:

Workplace

A separately located workplace, which is specifically separated from areas in which C-steel is being processed, must be provided. Maximum cleanliness is required, and drafts should be avoided during gas-shielded welding.

Auxiliary equipment and clothing

Clean fine leather gloves and clean working clothes must be used.

Tools and machines

Tools that have been used for other materials may not be used for nickel alloys and stainless steels. Only stainless steel brushes may be used. Processing and treatment machines such as shears, punches or rollers must be fitted (felt, cardboard, films) so that the workpiece surfaces cannot be damaged by the pressing in of iron particles through such equipment, as this can lead to corrosion.

Edge preparation

Welding seam preparation should preferably be carried out using mechanical methods through lathing, milling or planing. Abrasive waterjet cutting or plasma cutting is also possible. In the latter case, however, the cut edge (seam flank) must be cleanly reworked. Careful grinding without overheating is also permissible.

Striking the arc

The arc should only be struck in the seam area, such as on the weld edges or on an outlet piece, and not on the component surface. Scaling areas are areas in which corrosion more easily occurs.

Cleaning

Cleaning of the base material in the seam area (both sides) and the welding filler (e.g. welding rod) should be carried out using acetone.

Welding process

VDM® Crofer 22 H in thin thicknesses (= 1.5 mm/0.06 in.) can be joined to itself by GTAW (TIG) without the use of filler metal. It can also be joined by spot welding or roll-seam welding.

For welding, VDM® Crofer 22 H should be in the solution annealed condition and should be free from scale, grease and markings. Argon 4.8 is recommended for shielding gas as well as for root backing. A hydrogen and/or nitrogen containing gas should be avoided. Any heat tint should be removed preferably by brushing with a stainless steel wire brush while the weld metal is still hot.

Welding parameters and influences (heat input)

Care should be taken that the work is performed with a deliberately chosen, low heat input. The heat input per unit length should not exceed 8 kJ/cm.

Post-treatment

Brushing with a stainless steel wire brush immediately after welding, i.e., while the metal is still hot, generally results in removal of heat tint and produces the desired surface condition without additional pickling.

For pickling refer to the information under "Descaling and pickling". Neither pre- nor postweld thermal treatments are normally required.

Availability

VDM® Crofer 22 H is available as sheet, plate and strip.

Sheet & Plate

(for cut-to-length availability, refer to strip)

Delivery condition: hot or cold rolled, soft-annealed and pickled

Condition	Thickness mm (in)	Width mm (in)	Length mm (in)
Cold rolled	1.10 – < 1.50 (0.043 – < 0.060)	2000 (80)	8000 (320)
	1.50 – < 3.00 (0.060 – < 0.120)	2500 (100)	8000 (320)
Cold/Hot rolled	3.00 – < 7.50 (0.120 – < 0.300)	2500 (100)	8000 (320)
Hot rolled	7.50 – ≤ 25.00 (0.300 – ≤ 1.000)	2500 (100)	8000 (320)

Strip

Delivery condition: cold rolled, heat treated, pickled or brushed

Thickness mm (in)	Width mm (in)	Coil internal diameter mm (in)			
0.025 – 0.15 (0.000984 – 0.00591)	4 – 230 (0.157 – 9.06)	300 (11.8)	400 (15.7)	500 (19.7)	–
0.15 – 0.25 (0.00591 – 0.00954)	4 – 720 (0.157 – 28.3)	300 (11.8)	400 (15.7)	500 (19.7)	–
0.25 – 0.6 (0.00954 – 0.0236)	6 – 750 (0.236 – 29.5)	–	400 (15.7)	500 (19.7)	600 (23.6)
0.6 – 1 (0.0236 – 0.0787)	8 – 750 (0.315 – 29.5)	–	400 (15.7)	500 (19.7)	600 (23.6)
1 – 2 (0.0787 – 0.118)	15 – 750 (0.591 – 29.5)	–	400 (15.7)	500 (19.7)	600 (23.6)
2 – 3 (0.0787 – 0.118)	25 – 750 (0.984 – 29.5)	–	400 (15.7)	500 (19.7)	600 (23.6)

Rolled sheet – separated from the coil – are available in lengths from 250 to 4,000 mm (9.84 to 157,4 in).

Legal notice

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