outokumpu
high performance stainless steel

Therma
High service temperatures

Stainless steels for high service temperatures

Outokumpu Therma range datasheet

General characteristics

The Therma range covers heat-resisting stainless steels for use in applications with high service temperatures.

A common feature of these Outokumpu high temperature steels is that they are designed primarily for use at temperatures exceeding approximately 550 °C/1020 °F.

The range covers both austenitic and ferritic steels. Ferritic stainless steels have resistance to sulfur containing hot gases and lower thermal expansion. Austenitic stainless steels have resistance to carburizing and nitriding/low oxygen hot gas and higher creep strength.

The following properties can be found among the grades in the Therma range:

- Good resistance to oxidation
- Good resistance to high-temperature corrosion
- Good mechanical strength at elevated temperatures
- High thermal conductivity
- Low thermal expansion (ferritic grades)
- Excellent resistance to sulfur containing atmospheres (ferritic grades)

Chemical composition

Table 1

Therma — Stainless steels for high service temperatures (550 °C/1020 °F). — Outokumpu Pro family

Steel and alloy designations				Performance		Typical chemical composition, % by mass					
Outokumpu name	EN	ASTM		Maximum application temperature (°C) [1]	Grade family						
		Type	UNS			C	Cr	Ni	Si	N	Others
Resistance to carburizing and nitriding/low oxygen hot gas, higher creep strength											
Therma 253 MA	1.4835	–	S30815	1150	A	0.09	21	11	1.6	0.17	Si Ce
Therma 310S/4845	1.4845	310S	S31008	1050	A	0.05	25.5	19.1	0.5	–	–
Therma 304H/4948	1.4948	304H	S30409	800 [2]	A	0.05	18.1	8.3	0.4	–	–
Therma 321H/4878	1.4878	321H	–	850	A	0.05	17.3	9.1	0.4	–	Ti
Therma 347H	–	347H	S34709	850 [2]	A	0.05	17.5	9.5	0.4	–	Nb
Therma 4828	1.4828	–	–	1000	A	0.05	19.3	11.2	1.9	–	Si
Therma 309S/4833	1.4833	309S	S30908	1000	A	0.06	22.3	12.3	0.3	–	–
Therma 314/4841	1.4841	314	S31400	1150	A	0.06	24.3	19.2	1.6	–	Si
Resistance to sulfur containing hot gases, lower thermal expansion grades											
Therma 4713	1.4713	–	–	800	F	0.06	6.5	–	0.7	–	Al Si
Therma 4724	1.4724	–	–	850	F	0.07	12.5	–	0.9	–	Al Si

Grade family: A = austenitic, D = duplex. [1] EN 10095; for air; (for guidance only). [2] Estimated (for guidance only).

Please see values for other product forms at **steelfinder.outokumpu.com**

Applications and products

Resistance to carburizing and nitriding/low oxygen hot gas, higher creep strength

Table 2

Outokumpu name	Typical applications	Product forms
Therma 253 MA (EN 1.4835/UNS S30415) An austenitic stainless steel with excellent oxidation and creep resistance in cyclic conditions that is best employed in temperatures up to 1150 °C/2102 °F. There is a slight susceptibility to embrittlement during continuous operation between 600–850 °C/1110–1560 °F.	• Conveyor belts • Refractory anchors • Expansion bellows • Radiant tubes • Rotary kilns • Automotive exhaust manifolds • Power generation applications • Cyclone dip tubes • Impact separators • Bell furnaces • Muffle furnaces • Tube shields • Heat treatment trays • Dampers • Recuperator tubes • Large-scale bakery ovens	• Cold rolled coil and sheet • Hot rolled coil and sheet • Quarto plate • Precision strip
Therma 310S/4845 (EN 1.4845/UNS S31008) An austenitic stainless steel with very good oxidation resistance in general and good oxidation resistance in mildly cyclic conditions that is best employed in temperatures up to 1050 °C/1922 °F. There is a slight susceptibility to embrittlement during continuous operation between 600–900 °C/1110–1652 °F.	• Furnace equipment • Oil industry equipment • Heat treatment baskets • Heat exchangers • Steam boilers • Thermowells • Automotive components • Valves and flanges	• Cold rolled coil and sheet • Hot rolled coil and sheet • Quarto plate • Precision strip
Therma 304H/4948 (EN 1.4948/UNS S30409) An austenitic Core 304/4301 variant with improved high-temperature creep strength that is best employed in temperatures up to 800 °C/1472 °F. Offers good formability and weldability.	• Tubes • Pressure vessels • Valves and flanges	• Quarto plate
Therma 321H/4878 (EN 1.4878/UNS –) A Ti-stabilized austenitic heat resisting stainless steel with comparable wet corrosion resistance to Core 321/4541 that is best employed in temperatures up to 850 °C/1560 °F.	• Furnace equipment • Case hardening boxes • Valves and flanges	• Quarto plate
Therma 347H (EN –/UNS S34709) A Nb-stabilized austenitic heat resisting stainless steel with excellent long-term creep resistance at 550–600 °C/1020–1110 °F and comparable wet corrosion resistance to Core 347/4550.	• Oil refineries • Fired heater tubes • Boiler casings • Pressure vessels • Reactor vessels • Welded tubes • Fittings • Stack liners • Tanks for storing organic chemicals • Furnace heating elements • Tanks for thermal storage • Valves and flanges	• Quarto plate

Table continues on the next page.

Table 2, continued

Outokumpu name	Typical applications	Product forms
Therma 4828 (EN 1.4828/UNS –) An austenitic heat resisting stainless steel with improved oxidation resistance in temperatures up to 1000 °C/1830 °F. There is a slight susceptibility to embrittlement during continuous operation at temperatures between 600–850 °C/1110–1560 °F.	• Furnace equipment (especially supporting parts) • Annealing and hardening boxes • Air heaters • Exhaust systems • Automotive components such as turbochargers • Valves and flanges	• Cold rolled coil and sheet • Hot rolled coil and sheet • Quarto plate • Precision strip
Therma 309S/4833 (EN 1.4833/S30908) An austenitic stainless steel with improved oxidation resistance in temperatures up to 1000 °C/1830 °F. There is a slight susceptibility to embrittlement during continuous operation at 600–900 °C/1110–1652 °F.	• Furnace equipment • Annealing boxes • Thermowells • Baffle plates • Pots for quenching salt • Valves and flanges	• Cold rolled coil and sheet • Hot rolled coil and sheet • Quarto plate • Precision strip
Therma 314/4841 (EN 1.4841/S31400) An austenitic heat resisting stainless steel with excellent oxidation resistance in temperatures up to 1150 °C/2100 °F. There is a high susceptibility to embrittlement during continuous operation at 600–900 °C/1110–1652 °F.	• Furnace equipment • Superheater suspensions • Enameling grates and hardening boxes • Valves and flanges	• Cold rolled coil and sheet • Hot rolled coil and sheet • Quarto plate • Precision strip

Resistance to sulfur containing gases and with lower thermal expansion

Table 3

Outokumpu name	Typical applications	Product forms
Therma 4713 (EN 1.4713/ UNS –) A ferritic low-alloyed stainless steel best employed at 550–800 °C/1020–1470 °F when you need higher mechanical loading compared to other ferritic grades. Offers good resistance against sulfur attack compared to austenitic stainless grades.	• Furnace equipment • Air heaters • Annealing boxes • Conveyor belts • Thermowells	• Cold Rolled Sheet & Coil • Hot Rolled sheet & coil • Quarto Plate
Therma 4724 (EN 1.4724/ UNS –) A ferritic low-alloyed product with improved oxidation resistance in temperatures up to 850 °C/1560 °F. Offers good resistance against sulfur attack compared to austenitic stainless grades.	• Furnace equipment • Thermal boiler components • Grids • Burner nozzles • Conveyor belts • Thermowells	• Cold Rolled Sheet & Coil • Hot Rolled sheet & coil • Quarto Plate

Comparison of product performance — Table 4

Outokumpu name	EN	ASTM		Maximum application temperature (°C) [1]	Creep rupture strength	Structural stability	Resistance to hot gases			
							Sulfur containing		Carburizing	Nitriding/ low oxygen
		Type	UNS				Reducing	Oxidizing		
Resistance to carburizing and nitriding/low oxygen hot gas and with higher creep strength										
Therma 253 MA	1.4835	–	S30815	1150°C/2100°F	★★★★★	★★★	★★	★★★★	★★★	★★★
Therma 310S/4845	1.4845	310S	S31008	1050°C/1920°F	★★★	★★	★	★★★	★★★	★★★★
Therma 304H/4948	1.4948	304H	S30409	800°C/1470°F	★★★	★★★	★★	★★★	★	★
Therma 321H/4878	1.4878	321H	–	850°C/1560°F	★★★	★★★★	★★	★★★	★	★
Therma 347H	–	347H	S34709	850°C/1560°F [2]	★★★	★★★★	★★	★★★	★	★
Therma 4828	1.4828	–	–	1000°C/1830°F	★★★	★★	★	★★★	★★	★★★
Therma 309S/4833	1.4833	309S	S30908	1000°C/1830°F	★★★	★★★	★	★★★	★★	★★★
Therma 314/4841	1.4841	314	S31400	1150°C/2100°F	★★★	★	★	★★★	★★★★	★★★★
Resistance to sulfur containing hot gases and with lower thermal expansion										
Therma 4713	1.4713	–	–	800°C/1470°F	★	★★★★	★★★★	★★★★	★	★
Therma 4724	1.4724	–	–	850°C/1560°F	★	★★★	★★★★	★★★★	★	★

[1] EN 10095; for air; (for guidance only). [2] Estimated (for guidance only).

Product performance at high temperatures

The performance of a product in high temperature service depends on the demands of the environment and the design and how the balanced property profile of the alloy selected reaches up to these demands.

The most important properties for high temperature applications are

- Resistance to the environment, e.g., oxidation and corrosion resistance.
- Mechanical strength, i.e., the creep resistance at the temperature and prospected duration of the product.
- Structure stability, i.e., will the properties change during the life time of the product.
- Physical properties, i.e., will properties as thermal conductivity and expansion have implications on design or durability.

Table 4 gives a high level overview of the performance of the different grades in the Outokumpu Therma range from different aspects. More specific information is given in the following chapters. In most cases the balanced property profile need to be considered – what properties are most important and how can the design be optimized to achieve the best performance.

Corrosion resistance

Aqueous corrosion

Since most high-temperature materials are optimized with regard to strength and corrosion resistance at elevated temperatures, their resistance to low-temperature wet corrosion may be less satisfactory. Components made of high-temperature material should therefore be designed and used so that acid condensates are not formed (or at least so that any such condensates are drained away). As Therma 321H/4878 and Therma 347H are stabilized stainless steels, they will probably show the best resistance to aqueous intergranular corrosion.

High-temperature corrosion

The resistance of a material to high-temperature corrosion is in many cases dependent on its ability to form a protective oxide layer. In a reducing environment, when such a layer cannot be created or maintained, the corrosion resistance of the material will be determined by its alloy content. A number of high-temperature corrosion types are discussed below. Since industrial environments usually consist of a mixture of several aggressive gases, a compromise has to be made when choosing the product.

Oxidation

When a material is exposed to an oxidizing environment at elevated temperatures, a more or less protective oxide layer will be formed on its surface. Even if oxidation is seldom the primary cause of high-temperature corrosion failures, oxidation behaviour is important as the properties of the oxide layer will determine the resistance to attack by other aggressive elements in the environment. The oxide growth rate increases with increasing temperature until the rate of oxidation becomes unacceptably high, or until the oxide layer begins to crack and fall off (i.e. until the maximum service temperature is reached).

The alloying elements that are most beneficial for oxidation resistance are chromium, silicon and aluminium. A positive effect has also been achieved with small additions (also referred to as Micro Alloying, MA) of so-called reactive elements such as yttrium, hafnium, and rare earth metals like cerium. These affect the oxide growth so that the formed layer is thinner, tougher, and more adherent and therefore offers better protection. The reactive element effect is especially favourable under conditions of varying temperatures. Here the differences between the thermal expansion/contraction of the metal and the oxide induce stresses in the boundary layer and increase the risk of scaling. This explains the relatively high oxidation resistance of Therma 253 MA.

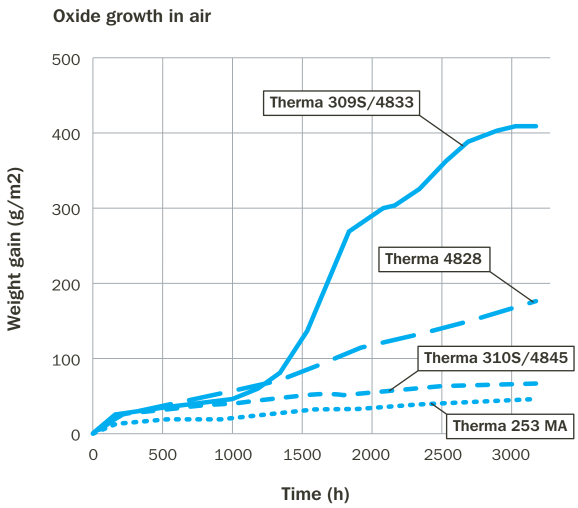

Fig. 1. Oxide growth in air at 1000 °C/1830 °F, 165 hour cycles for austenitic high temperature steels.

For ferritic grades, low thermal expansion and high thermal conductivity of the base material reduces changes in volume. This reduces the risk that the protective layer cracks and falls off.

The existence of water vapour in the environment reduces the resistance to oxidation and therefore the maximum service temperature by up to 100 °C/210 °F. Other, more aggressive components in the environment will lead to even greater reductions in the maximum service temperature.

Molybdenum has a positive effect on corrosion properties at room temperature and moderately elevated temperatures, but can lead to so-called catastrophic oxidation at temperatures exceeding approximately 750 °C/1380 °F.

Sulfur attacks

Various sulfur compounds are often present in flue gases and other process gases. As a rule, they have a highly detrimental effect on the useful life of the exposed components. Sulfides can nucleate and grow due to kinetic effects, even under conditions where only oxides would form from a thermodynamic point of view. In existing oxide layers, attacks can occur in pores and cracks. It is therefore essential that the material is able to form a thin, tough, and adherent oxide layer. This requires a high chromium content and preferably also additions of silicon, aluminium, and/or reactive elements. Ferritic steels typically perform better than austenitic steels in oxidizing and reducing sulfurous environments.

Under so-called reducing conditions, the oxygen activity of the gas can still be sufficiently high to enable the formation of a protective oxide layer, provided that the chromium content of the material is sufficiently high (> 25%). If this is not the case, low-melting-point nickel sulfides can be formed instead. Under such circumstances, a ferritic grade should be selected.

Carbon and nitrogen pick-up

In small amounts, the pick-up of carbon and/or nitrogen can improve certain properties of a material. This can therefore be used to enhance properties such as surface hardness and resistance to wear and/or fatigue.

However, excessive pick-up of either element has an adverse effect on the material. In addition to the fact that the carbides or nitrides formed have an embrittling effect, they generally have a higher chromium content than the steel itself. The corresponding chromium depletion in the adjoining metal will reduce the oxidation resistance.

The best protection against this type of corrosion is a dense oxide layer. Consequently, strong oxide formers such as chromium and silicon are beneficial alloying elements. Aluminium is favourable with regard to carbon pick up. However, its high nitrogen affinity causes a significant reduction in the protective effect of the aluminium oxide under strong nitriding conditions. In certain applications a high carbon and/or nitrogen activity is combined with a low oxygen content. This means protective layers cannot be formed. Under such conditions the bulk composition of the material will determine the pick-up resistance.

The most advantageous alloying element in this case is nickel, but silicon also has a positive effect. The higher nickel content in austenitic grades means that they are generally favoured over ferritic grades in terms of carburization resistance. In certain applications with high carbon activity, low oxygen activity and moderately high temperatures, a type of catastrophic carburization referred to as metal dusting can occur, manifesting itself as a disintegration of the material into particles of graphite, metal, and oxide.

The risk of carbon pick-up increases when the material is subjected to alternating carburizing and oxidizing environments. This can occur in carburizing furnaces or heat-treatment furnaces if there are oil residues on the material being heat treated, or during decoking in petrochemical industry processes. The risk of nitrogen pick-up is particularly high in furnaces working at high temperatures with oxygen-free gases consisting of cracked ammonia or other nitrogen/hydrogen mixtures.

Halogens

Gases containing halogens or hydrogen halides (such as Cl_2 and HCl) are very aggressive to most metallic materials at higher temperatures. Aluminium and, in particular, nickel appear to increase the resistance to corrosion in most gases containing halogens. Chromium and molybdenum, on the other hand, can have either a positive or a negative effect, depending on the composition of the gas.

Molten salts

In certain industrial processes, molten salts are used deliberately. These salts easily dissolve existing protective oxide layers and can therefore be very aggressive. However, since the conditions are well known and relatively constant, it is possible to keep the effects of corrosion at an acceptable level by accurate process control and optimum material selection (a high nickel content is often favourable).

The corrosive effect of molten salts is highly dependent on salt type. Therma grades such as Therma 347H and Therma 321H have been shown to resist molten nitrate salts at temperatures up to 570 °C in energy storage applications for concentrated solar power. Other salt types, such as hydroxide and chloride salts are significantly more aggressive, especially at higher temperatures.

However, the detrimental effects of undesirable molten salts can be much worse. The most important example of these effects is caused by deposits on the fire side of various heat-transfer surfaces. This type of problem is difficult to reduce or solve by material selection. Instead, modifications should be made in operational conditions and maintenance procedures.

Erosion

Erosion is a very complex phenomenon in which not only the properties of the construction material are significant, but also those of the eroding particles – for example, hardness, temperature, velocity, and angle of impact.

Generally, an adherent, tough, and ductile oxide layer is required for good erosion resistance. Experience has shown that rare earth metal additions improve these properties and thus improve erosion resistance at high temperatures.

Structure stability

For most high-temperature alloys, the composition is optimized with regard to strength and/or resistance to corrosion at elevated temperatures.

Diffusion controlled transformations will occur in the material at sufficiently high operating temperatures. The most common type of reaction is the precipitation of non-desirable phases, which, besides lowering the corrosion resistance by consuming beneficial alloying elements (above all chromium), leads to a reduced toughness/ductility of the material – especially at room temperature. The precipitates are often intermetallic phases such as sigma, chi, and so-called Laves phases.

In Therma 253 MA® the formation of sigma phase is counteracted by the relatively high contents of nitrogen and carbon in the steel. Instead, precipitation of carbides and nitrides can occur in the same temperature range, which can result in an equally low impact toughness at room temperature as for intermetallic-embrittled high temperature alloys. Experience and certain laboratory tests have, however, shown that carbide/nitride embrittled steels have a greater ductility when deformation rates are lower, e.g. in tensile and bending tests.

High diffusion rates in the ferritic matrix accelerate the short-range order reaction at 475 °C and chromium contents exceeding 13%. Fine particles of Fe-Cr precipitate coherently in the matrix forming the ⟨α'-phase, which results in an increased hardness and decreased toughness. Silicon and aluminum further promote this phenomenon and are therefore added only in tolerable concentrations.

Alloys with chromium contents of approximately 20% and higher, are also subject to σ-formation. Services at temperatures between 600 °C and 800 °C result in low room temperature impact toughness. This phenomenon is usually accompanied by carbide embrittlement whilst the ferritic structure is chromium depleted and suffers losses of heat resistance and ductility.

Mechanical properties

Creep strength

While Therma range austenitic steels are mainly optimized for oxidation and high temperature corrosion resistance, they also have good mechanical properties. This is partly due to their austenitic structure and partly due to certain alloying elements. Therma 253 MA is especially alloyed with nitrogen to increase the creep resistance, this is illustrated in relation to other grades in the Therma range in Figure 2, and from a exposure test in Figure 3. Design values are usually based on minimum yield strength values for constructions used at temperatures of up to approximately 550 °C/1020 °F. Outokumpu values are shown in tables 5–7, as values may differ between standards, see the relevant specifcation for correct values. For higher temperatures, average creep strength values are used, see tables 8–13.

At room temperature, Therma range ferritic stainless steels have mechanical properties equal to their austenitic counterparts. When subjected to high temperatures (greater than 600 °C/1110 °F), the creep strength drops, possibly to only a quarter of the value shown by Therma range austenitic steels in the same conditions. Therefore, the loads applied to the component and the creep properties of the steel must be taken into consideration during dimensioning and construction.

Figure 4 illustrates how the required wall thickness differs between some select Therma grades depending on design temperature.

Fatigue

Service conditions at elevated temperatures are rarely constant. In most cases, a component will be subjected to both varying loads and temperatures. This can eventually lead to fatigue failure. Isothermal fatigue can be subdivided into two groups: high cycle fatigue (HCF), which is stress controlled with low amplitudes, and low cycle fatigue (LCF), which is strain controlled with large amplitudes. HCF mainly occurs in rotating and/or vibrating components. LCF is primarily a result of transients during start-ups, shut-downs, and major changes in service conditions. LCF gives a shorter life than HCF.

Pure thermal fatigue in a component is caused by thermal gradients and the corresponding differences in (internally constrained) thermal expansion. The most complex situation is when temperature and load vary simultaneously. This is known as thermo-mechanical fatigue (TMF). A simplified test for these conditions consists of letting the temperature and stress/strain vary in or out of phase. In the results from the in phase TMF test series, ageing has a beneficial effect on the fatigue life of (nitride forming) Therma 253 MA, while the effect is detrimental for Therma 310S/4845 due to sigma phase precipitation.

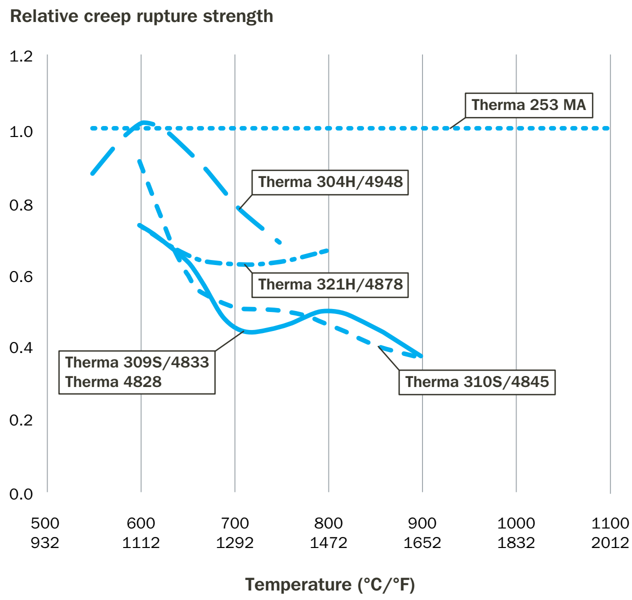

Fig. 2. 100,000 hours creep rupture strength, relative to Therma 253 MA.

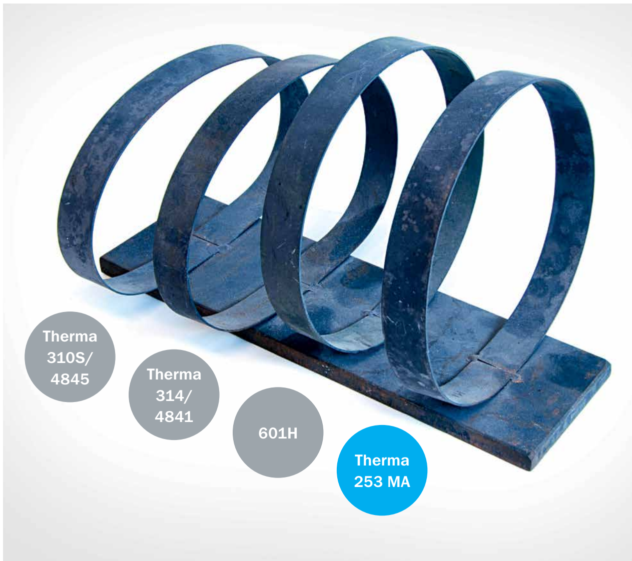

Fig. 3. Therma 310S/4845 and Therma 314/4841 rings collapsed due to their own weight during exposure to 1000 °C/1830 °F for 35 hours. Sample thickness: 1 mm/0.04 in.

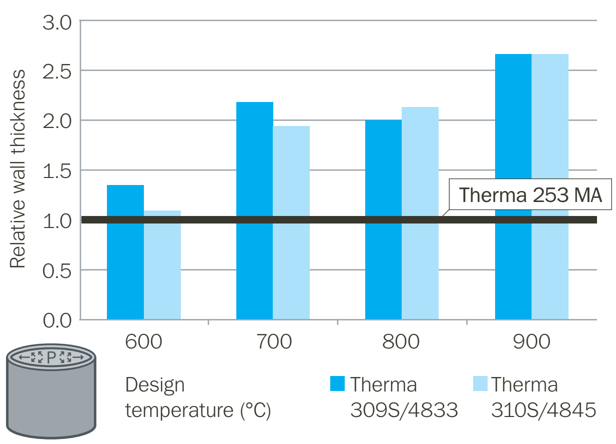

Fig. 4. Required relative wall thickness in a pressurized vessel.

Elevated temperature yield strength $R_{p0.2}$ (MPa), minimum values [1)]

Table 5

Outokumpu name	Temperature °C								
	50	100	150	200	250	300	350	400	450
Resistance to carburizing and nitriding/low oxygen gas and with higher creep strength									
Therma 253 MA	280	230	198	185	176	170	165	160	155
Therma 310S/4845	–	140	128	116	108	100	94	91	86
Therma 304H/4948	178	157	142	127	117	108	103	98	93
Therma 321H/4878	–	162	152	142	137	132	127	123	118
Therma 347H	191	177	167	157	147	136	130	125	121
Therma 4828	–	140	128	116	108	100	94	91	86
Therma 309S/4833	–	140	128	116	108	100	94	91	86
Therma 314/4841	–	140	128	116	108	100	94	91	86

[1)] Outokumpu values based on EN 10028-7.

Elevated temperature yield strength $R_{p1.0}$ (MPa), minimum values [1)]

Table 6

Outokumpu name	Temperature °C								
	50	100	150	200	250	300	350	400	450
Resistance to carburizing and nitriding/low oxygen gas and with higher creep strength									
Therma 253 MA	315	265	230	215	206	200	195	190	185
Therma 310S/4845	–	185	167	154	146	139	132	126	123
Therma 304H/4948	215	191	172	157	147	137	132	127	122
Therma 321H/4878	–	201	191	181	176	172	167	162	157
Therma 347H	229	211	196	186	177	167	161	156	152
Therma 4828	–	185	167	154	146	139	132	126	123
Therma 309S/4833	–	185	167	154	146	139	132	126	123
Therma 314/4841	–	185	167	154	146	139	132	126	123

[1)] Outokumpu values based on EN 10028-7.

Elevated temperature tensile strength R_m (MPa), minimum values [1)]

Table 7

Outokumpu name	Temperature °C								
	50	100	150	200	250	300	350	400	450
Resistance to carburizing and nitriding/low oxygen gas and with higher creep strength									
Therma 253 MA	630	585	560	545	538	535	533	530	515
Therma 310S/4845	–	470	450	430	420	410	405	400	385
Therma 304H/4948	484	440	410	390	385	375	375	375	370
Therma 321H/4878	–	410	390	370	360	350	345	340	335
Therma 347H	476	435	400	370	350	340	335	330	320
Therma 4828	–	470	450	430	420	410	405	400	385
Therma 309S/4833	–	470	450	430	420	410	405	400	385
Therma 314/4841	–	470	450	430	420	410	405	400	385

[1)] Outokumpu values based on EN 10028-7.

Creep rupture strength $R_{km\ 1,000}$ (MPa mean values)

Table 8

Outokumpu name	EN	ASTM		Temperature °C					
		Type	UNS	500	600	700	800	900	1000
Resistance to carburizing and nitriding/low oxygen gas and with higher creep strength									
Therma 253 MA	1.4835	–	S30815	–	238	105	50	24	12
Therma 310S/4845	1.4845	310S	S31008	–	170	80	35	15	–
Therma 304H/4948	1.4948	304H	S30409	–	–	–	–	–	–
Therma 321H/4878	1.4878	321H	–	–	200	88	30	–	–
Therma 347H	–	347H	S34709	–	–	–	–	–	–
Therma 4828	1.4828	–	–	–	190	75	35	15	–
Therma 309S/4833	1.4833	–	S30415	–	190	75	35	15	–
Therma 314/4841	1.4841	314	S31400	–	170	90	40	20	5
Resistance to sulfur containing hot gases and with lower thermal expansion									
Therma 4713	1.4713	–	–	160	55	17	7.5	3.6	–
Therma 4724	1.4724	–	–	160	55	17	7.5	3.6	–

Creep rupture strength $R_{km\ 10,000}$ (MPa mean values)

Table 9

Outokumpu name	Temperature °C												
	500	550 [1]	600	650 [1]	700	750 [1]	800	850 [1]	900	950 [1]	1000	1050 [1]	1100 [1]
Resistance to carburizing and nitriding/low oxygen gas and with higher creep strength													
Therma 253 MA	–	250	157	98	63	41	27	18	13	9.5	7	5.5	4
Therma 310S/4845	–	–	130	65	40	26	18	13	8.5	–	–	–	–
Therma 304H/4948 [2]	250	191	132	87	55	34	–	–	–	–	–	–	–
Therma 321H/4878	–	–	142	82	48	27	15	–	–	–	–	–	–
Therma 347H [3]	–	236	162	113	71	–	–	–	–	–	–	–	–
Therma 4828	–	–	120	70	36	24	18	13	8.5	6.5	4	–	–
Therma 309S/4833	–	–	120	70	36	24	18	13	8.5	6.5	–	–	–
Therma 314/4841	–	–	130	65	40	28	20	14	10	–	–	–	–
Resistance to sulfur containing hot gases and with lower thermal expansion													
Therma 4713	100	–	35	–	9.5	–	4.3	–	1.9	–	–	–	–
Therma 4724	100	–	35	–	9.5	–	4.3	–	1.9	–	–	–	–

[1] Outokumpu data.
[2] Values according to EN 10028-7.
[3] Data for 1.4550 according to EN 10222-5.

Creep rupture strength $R_{km\ 100,000}$ (MPa mean values)

Table 10

Outokumpu name	Temperature °C												
	500	550 [1]	600	650 [1]	700	750 [1]	800	850 [1]	900	950 [1]	1000	1050 [1]	1100 [1]
Resistance to carburizing and nitriding/low oxygen gas and with higher creep strength													
Therma 253 MA	–	160	88	55	35	22	15	11	8	5.5	4	3	2.3
Therma 310S/4845	–	–	80	33	18	11	7	4.5	3	–	–	–	–
Therma 304H/4948 [2]	192	140	89	52	28	15	–	–	–	–	–	–	–
Therma 321H/4878	–	–	65	36	22	14	10	–	–	–	–	–	–
Therma 347H [3]	–	161	107	58	–	–	–	–	–	–	–	–	–
Therma 4828	–	–	65	35	16	10	7.5	5	3	–	–	–	–
Therma 309S/4833	–	–	65	35	16	10	7.5	5	3	–	–	–	–
Therma 314/4841	–	–	80	33	18	11	7	4.5	3	–	–	–	–
Resistance to sulfur containing hot gases and with lower thermal expansion													
Therma 4713	55	–	20	–	5	–	2.3	–	1	–	–	–	–
Therma 4724	55	–	20	–	5	–	2.3	–	1	–	–	–	–

[1] Outokumpu data.
[2] Values according to EN 10028-7.
[3] Data for 1.4550 according to EN 10222-5.

Creep deformation strength $R_{A1\ 1,000}$ (MPa mean values)

Table 11

Outokumpu name	EN	ASTM		Temperature °C					
		Type	UNS	500	600	700	800	900	1000
Resistance to carburizing and nitriding/low oxygen gas and with higher creep strength									
Therma 253 MA	1.4835	–	S30815	–	170	66	31	15.5	8
Therma 310S/4845	1.4845	310S	S31008	–	100	45	18	10	–
Therma 304H/4948	1.4948	304H	S30409	–	–	–	–	–	–
Therma 321H/4878	1.4878	321H	–	–	110	45	15	–	–
Therma 347H	–	347H	S34709	–	–	–	–	–	–
Therma 4828	1.4828	–	–	–	120	50	20	8	–
Therma 309S/4833	1.4833	–	S30415	–	100	40	18	8	–
Therma 314/4841	1.4841	314	S31400	–	105	50	23	10	3
Resistance to sulfur containing hot gases and with lower thermal expansion									
Therma 4713	1.4713	–	–	80	27.5	8.5	3.7	1.8	–
Therma 4724	1.4724	–	–	80	27.5	8.5	3.7	1.8	–

Creep deformation strength $R_{A1\ 10,000}$ (MPa mean values)

Table 12

Outokumpu name	Temperature °C												
	500	550 [1]	600	650 [1]	700	750 [1]	800	850 [1]	900	950 [1]	1000	1050 [1]	1100 [1]
Resistance to carburizing and nitriding/low oxygen gas and with higher creep strength													
Therma 253 MA	–	230	126	74	45	28	19	14	10	7	5	3.5	2.5
Therma 310S/4845	–	–	90	52	30	17.5	10	6	4	–	–	–	–
Therma 304H/4948 [2]	147	121	94	61	35	24	–	–	–	–	–	–	–
Therma 321H/4878	–	–	85	50	30	17.5	10	–	–	–	–	–	–
Therma 347H	–	–	–	–	–	–	–	–	–	–	–	–	–
Therma 4828	–	–	80	50	25	15.5	10	6	4	–	–	–	–
Therma 309S/4833	–	–	70	47	25	15.5	10	6.5	5	–	–	–	–
Therma 314/4841	–	–	95	60	35	20	10	6	4	–	–	–	–
Resistance to sulfur containing hot gases and with lower thermal expansion													
Therma 4713	50	–	17.5	–	4.7	–	2.1	–	1	–	–	–	–
Therma 4724	50	–	17.5	–	4.7	–	2.1	–	1	–	–	–	–

[1] Outokumpu data.
[2] Values according to EN 10028-7.

Creep deformation strength $R_{A1\ 100,000}$ (MPa mean values)

Table 13

Outokumpu name	Temperature °C												
	500	550 [1]	600	650 [1]	700	750 [1]	800	850 [1]	900	950 [1]	1000	1050 [1]	1100 [1]
Resistance to carburizing and nitriding/low oxygen gas and with higher creep strength													
Therma 253 MA	–	150	80	45	26	16	11	8	6	4.5	3	2	1.2
Therma 304H/4948 [2]	114	96	74	43	22	11	–	–	–	–	–	–	–
Therma 321H/4878	–	135	80	45	26	15	9	5	3	1.8	1	–	–

[1] Outokumpu data.
[2] Values according to EN 10028-7.

Physical properties

The physical properties of the Therma grades as presented in Tables 14–15 are based on a combination of data presented in European standard, and Outokumpu's own experience.

Table 14

Metric												
Outokumpu name	Density [kg/dm^3]	Modulus of elasticity [GPa]			Coefficient of thermal expansion between 20 °C and T [10^{-6}/K]			Thermal conductivity [W/(m x K)]			Thermal capacity [J/(kg x K)]	Electrical resistivity [Ω x mm^2/m]
	20 °C	20 °C	600 °C	1000 °C	600 °C	800 °C	1000 °C	20 °C	500 °C	800 °C	20 °C	20 °C
Resistance to carburizing and nitriding/low oxygen gas and with higher creep strength												
Therma 253 MA	7.8	200	155	120	18.5	19.0	19.5	15	21	26	500	0.84
Therma 310S/4845	7.8	196	150	120	18.8	19.4	20.0	15	19	24	472	0.96
Therma 304H/4948	7.9	200	155	125	18.5	–	–	17	21	–	450	0.71
Therma 321H/4878	7.9	196	150	–	18.8	19.4	–	15	21	26	472	0.74
Therma 347H	7.9	200	155	–	18.8	19.4	–	15	21	–	500	0.73
Therma 4828	7.8	196	150	120	18.8	19.4	20.0	15	21	25	472	0.87
Therma 309S/4833	7.8	196	150	120	18.8	19.4	20.0	15	19	25	472	0.87
Therma 314/4841	7.8	196	150	120	18.8	19.4	20.0	15	19	25	472	0.96
Resistance to sulfur containing hot gases and with lower thermal expansion												
Therma 4713	7.7	220	–	–	12.5	13.0	–	23	25	–	450	0.70
Therma 4724	7.7	220	–	–	12.0	12.5	–	21	23	–	500	0.75

Table 15

Imperial												
Outokumpu name	Density [lbm/in^3]	Modulus of elasticity [psi]			Coefficient of thermal expansion between 68 °F and T [µin / (in x °F)]			Thermal conductivity [Btu/(hr x ft x °F)]			Thermal capacity [Btu/(lbm x°F)]	Electrical resistivity [µΩ x in]
	68 °F	68 °F	1112 °F	1832 °F	1112 °F	1472 °F	1832 °F	68 °F	932 °F	1472 °F	68 °F	68 °F
Resistance to carburizing and nitriding/low oxygen gas and with higher creep strength												
Therma 253 MA	0.282	29×10^6	22×10^6	17×10^6	10.3	10.6	10.8	8.7	–	14.8	0.120	33.1
Therma 310S/4845	0.280	28×10^6	22×10^6	17×10^6	10.5	10.8	11.1	6.9	–	14.0	0.113	37.8
Therma 304H/4948	0.285	29×10^6	22×10^6	18×10^6	10.3	–	–	9.8	–	–	0.107	28.0
Therma 321H/4878	0.285	28×10^6	22×10^6	–	10.4	10.8	–	8.7	–	14.9	0.113	29.1
Therma 347H	0.285	29×10^6	–	–	10.5	10.8	–	8.0	–	–	0.119	28.7
Therma 4828	0.282	28×10^6	22×10^6	17×10^6	10.4	10.8	11.1	8.7	–	14.3	0.113	34.3
Therma 309S/4833	0.282	28×10^6	22×10^6	17×10^6	10.4	10.8	11.1	8.7	–	14.3	0.113	34.3
Therma 314/4841	0.282	28×10^6	22×10^6	17×10^6	10.4	10.8	11.1	8.7	–	14.3	0.113	37.8
Resistance to sulfur containing hot gases and with lower thermal expansion												
Therma 4713	0.278	32×10^6	–	–	7.0	7.2	–	13.3	14.5	–	0.108	27.6
Therma 4724	0.278	32×10^6	–	–	6.7	7.0	–	12.1	13.3	–	0.120	29.5

Fabrication

Hot and cold forming

Therma range stainless steels can be readily cold formed by all standard methods. Like other austenitic stainless steels, Therma range austenitics can be formed in the hot or cold condition. However, as a result of their relatively high nitrogen content, the mechanical strength of certain grades is higher, and consequently greater deformation forces will be required. Further data on forming is available from Outokumpu.

The forming properties of Therma range ferritics are similar to those of low-alloyed carbon steels. Generally, the minimum inner radius for bending operations should be the double thickness.

Machining

The relatively high hardness of austenitic stainless steels and their ability to strain harden must be taken into consideration in connection with machining. Machining of ferritic grades is considered to be relatively easy due to the low strain hardening of these products.

For more detailed data on machining, please see the Outokumpu machining guidelines available for Therma 310S/4845, and Therma 253 MA, or contact us at **outokumpu.com/contacts**

Welding

Outokumpu Therma range austenitic steels have good or very good weldability and can be welded using the following methods:

- Shielded metal arc (SMAW) welding with covered electrodes. When welding Therma 253 MA, voestalpine Böhler Welding 253 MA-NF electrodes are recommended for applications at 650 °C–950 °C/1200–1740 °F. The absence of ferrite provides a stable, ductile microstructure in the weld metal. The 253 MA electrode can be used for applications at temperatures over 950 °C/1740 °F.

- Gas shielded welding, e.g., GTAW (TIG), plasma arc, and GMAW (MIG/MAG). Pure argon is normally used as the shielding gas for TIG, while Ar + 0.03% NO or Ar + 30% He +2–2.5% CO_2 is recommended for MIG welding. TIG/MIG weld joints have been found to give the best creep resistance compared with other weld processes.

- Submerged arc welding (SAW). Compared with Therma 310S/4845, the risk of hot cracking is lower when welding Therma 253 MA. Basic fluxes are preferred.

Some general recommendations for the welding of Therma range austenitic steels:

1. The oxide layer on a component already exposed to high temperature must be removed by brushing or grinding before welding.

2. Penetration into the base material is lower for high-temperature steels compared with standard stainless steels such as Core 304/4301 or Supra 316L/4404. The molten filler materials are also less fluid. This necessitates somewhat greater bevel angles (60–70 °) and a slightly increased root gap (2–3 mm/ 0.07–0.11 in) compared with standard austenitic stainless steels.

For Therma range ferritics, the same precautions as for carbon steels should normally be taken. Preheating of the joints to 200–300 °C/480–570 °F is necessary for plates thicker than 3 mm/0.11 in. Due to grain growth in the heat affected zone (HAZ), heat input should be minimized. Gas-shielded welding methods such as GTAW (TIG), plasma arc, and GMAW (MIG/MAG) are preferred. Pure argon should be used as the shielding gas.

Matching filler material has a detrimental effect on the ductility, which is why austenitic welding consumables, e.g. 307, 309 or 310 are recommended. If the weld will be exposed to a sulfurous environment, overlay welding with a matching ferritic filler will be necessary.

For more information, see the Outokumpu Welding Handbook, available from our sales offices.

Heat treatment

Heat treatment after hot or cold forming, or welding, will often not be necessary as the material will be exposed to high temperatures during service. However, if that is not sufficient, the best option is proper solution annealing, with the second best being stress-relief annealing. Components in which the material has become embrittled during service will benefit from a rejuvenating solution anneal before any maintenance work – for example, straightening or repair welding is to be carried out.

Characteristic temperatures

Table 16

Steel grade	Solidification range, °C	Maximum application temperature (°C) [1]	Hot forming, °C	Solution annealing, °C	Stress relief annealing (min. 0.5 h), °C
Resistance to carburizing and nitriding/low oxygen hot gas and with higher creep strength					
Therma 253 MA	1430–1350	1150	1150–900	1020–1120	900
Therma 310S/4845	1410–1340	1050	1150–980	1050–1150	1040–1070
Therma 304H/4948	1450–1385	800 [2]	1150–850	1050–1110	840–900
Therma 321H/4878	1440–1370	800	1150–850	1020–1120	840–900
Therma 347H	1445–1400	850 [2]	1150–850	950–1090	450–800
Therma 4828	1420–1350	1000	1150–950	1050–1150	1010–1040
Therma 309S/4833	1420–1350	1000	1150–950	1050–1150	1010–1040
Therma 314/4841	1400–1330	1150	1150–980	1050–1150	1040–1070
Resistance to sulfur containing hot gases and with lower thermal expansion					
Therma 4713	–	800	1100–750	750–880	–
Therma 4724	–	850	1100–750	800–850	–

[1] EN 10095; for air; (for guidance only).
[2] Estimated (for guidance only).

Heat treatment

Heat treatment after hot or cold forming, or welding, will often not be necessary as the material will be exposed to high temperatures during service. However, if that is not sufficient, the best option is proper solution annealing, with the second best being stress-relief annealing. Components in which the material has become embrittled during service will benefit from a rejuvenating solution anneal before any maintenance work – for example, straightening or repair welding is to be carried out.

outokumpu.com/contacts

Welding consumables

Table 17

Outokumpu name		Covered electrode	Solid wire	Flux cored wire
Resistance to carburizing and nitriding/low oxygen hot gas and with higher creep strength				
Therma 253 MA	ISO designation	253 MA *) 253 MA-NF *)	253 MA *)	–
Therma 310S/4845	ISO designation	25 20	25 20	–
Therma 304H/4948	ISO designation	19 9 or 308/308H *)	19 9	19 9
Therma 321H/4878	ISO designation	19 9Nb	19 9Nb	19 9Nb
Therma 4828	ISO designation	23 12 253 MA *) 253 MA-NF *)	23 12	23 12
Therma 309S/4833	ISO designation	23 12 253 MA *)	23 12	23 12
Therma 314/4841	ISO designation	25 20	25 20	–

[1] voestalpine Böhler Welding designation.

Products and dimensions

To find the minimum and maximum thickness and width by surface finish for a specific product in the Therma range, please contact Outokumpu.

Standards, specifications and approvals

For a list of international standards by product, see **steelfinder.outokumpu.com**

For a list of certificates and approvals by mill, see **outokumpu.com/certificates**

Contacts and enquiries

Contact us

Our experts are ready to help you choose the best stainless steel product for your next project.

outokumpu.com/contacts

1565EN:5. November, 2022.

Working towards a world that lasts forever

We work with our customers and partners to create long lasting solutions for the tools of modern life and the world's most critical problems: clean energy, clean water, and efficient infrastructure. Because we believe in a world that lasts forever.

outokumpu classic

outokumpu pro

Moda	Core	Supra	Forta	Ultra	Dura	Therma	Prodec	Deco
Mildly corrosive environments	Corrosive environments	Highly corrosive environments	Duplex & other high strength	Extremely corrosive environments	High hardness	High service temperatures	Improved machinability	Special surfaces

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