High Temperature Ferritic Stainless Steel

Steel grades

Outokumpu	EN number	EN designation
4713	1.4713	X10CrA17
4724	1.4724	X10CrAl13
4742	1.4742	X10CrAl18
4762	1.4762	X10CrAl24

Characteristic properties

- Excellent resistance to oxidising and reducing sulphur containing atmospheres
- Good resistance to oxidation
- High thermal conductivity – low thermal expansion

Applications

Outokumpu Stainless ferritic high temperature steels are mostly used in high temperature applications with sulphurous atmospheres and/or low tensile loads such as for installations within:

- Chemical industry (drums)
- Power industry (coal burners)
- Metalworking industry (heat treatment boxes)
- Furnace technology (walls, doors)

General characteristics

The high temperature (HT) ferritic stainless steels complement Outokumpu Stainless austenitic heat and creep portfolio. The main alloying element in the ferritic grades is chromium. Its positive effect on the scaling resistance is enhanced by silicon and aluminium.

The two lower alloyed grades are best suited for temperatures between 550°C and 850°C, at which most HT austenitic stainless steels are prone to form brittle phases.

The higher alloyed ones are applied at temperatures up to 1150°C and show excellent resistance against reducing sulphur attacks and molten metals.

Due to their ferritic structure, the ferritic steels show lower strength at temperatures exceeding 600°C, but are more resistant to thermal shocks than HT austenitic stainless steels. With the thermal conductivity higher and the thermal expansion lower than the respective values for austenitic steels, equal thermal shocks will result in lower thermal stresses in the ferritic material. In these terms, ferrites allow greater tolerances for design and operation.

All grades are included in the European Standard EN 10095 “Heat-resisting steels and nickel alloys”.

4713 does not form brittle phases but should only be exposed to moderately corrosive atmospheres owing to its low chromium content.

4724 is a truly stainless high temperature grade with 13% chromium. It is not critical in terms of embrittlement.

4742 shows better scaling resistance than 4724 and can be subjected to reducing sulphur environments without risk. It is subject to 475°C embrittlement and grain coarsening at temperatures above 950°C. σ-phase may form after long time exposures to temperatures around 650°C.

4762 - with the highest chromium content- is the most resistant to reducing sulphurous gases. It is susceptible to the same embrittlement phenomena as 4742 whilst σ-phase forms during long exposures in the range 600°C to 800°C.

Chemical composition

The chemical composition fulfills the European standard.

Chemical composition Table 1

Outokumpu steel name	International steel No EN	Typical analysis, %				
		C	Mn	Cr	Si	Al
4713	1.4713	0.08	0.7	6.5	0.8	0.8
4724	1.4724	0.08	0.7	13.5	1.0	1.0
4742	1.4742	0.08	0.7	18.0	1.3	1.0
4762	1.4762	0.08	0.7	24.0	1.4	1.5

Characteristic temperatures Table 2

Steel grade	Maximum service temperature in dry air, °C	Hot forming[1], °C	annealing[2], °C
4713	800	1100-750	750-800
4724	850	1100-750	800-850
4742	1000	1100-750	800-850
4762	1150	1100-750	800-850

[1] cooling still air. [2] cooling forced air or water.

Microstructure

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.

In all, only 4742 and 4762 are critical in terms of embrittlement at intermediate temperatures. Thus, service durability should be taken into consideration and shock loads avoided at room temperature, when their cold brittleness shows full effect.

Mechanical properties

At room temperature, the HT ferritic stainless steels have mechanical properties equal to their austenitic counterparts. When subjected to high temperatures (> 600°C), the creep strength drops possibly to only a quarter of the value austenitic heat resistant steels show at the same conditions. Therefore, loads applied to the component should be taken into consideration for dimensioning and construction.

Mechanical properties at room temperature Table 3

Steel grade	Proof strength $R_{p0,2}$ [N/mm²] min.	Tensil strength R_m (N/mm²)	Elongation ($L_0 = 5\ D_0$) (%) lonh.	trans.	Hardness (HB) max.
4713	220	420-620	20	15	192
4724	250	450-650	15	11	192
4742	270	500-700	12	9	212
4762	280	520-720	10	7	223

Creep properties of 47XX, $R_{p0,1}$ N/mm² (mean values) Table 4

Time, h	Temperature, °C 500	600	700	800	900
1 000	80	27.5	8.5	3.7	1.8
10 000	50	17.5	4.7	2.1	1.0

Creep properties of 47XX, $R_{p0,1}$ N/mm² (mean values) Table 5

Time, h	Temperature, °C 500	600	700	800	900
1 000	160	55	17	7.5	3.6
10 000	100	35	9.5	4.3	1.9
100 000	55	20	5.0	2.3	1.0

Physical properties

The values given below have been extracted from STAHL-EISEN-Werkstoffblatt 310, as the documentation in the European Standard EN 10095 is often imprecise.

Physical properties Table 6

Steel grade	Density [kg/dm³]	Thermal expansion coefficient [10^6/°C] between 20°C and			Thermal conductivity [W/m°C]		Heat capacity [J/kg°C]	Electric resistivity [μ_m]
	20°C	600°C	800°C	1000°C	20°C	500°C	20°C	
4713	7.65	13.2	-	-	20.5	25.4	425	0.707
4724	7.58	12.2	-	-	15.7	22.3	439	0.919
4742	7.56	12.1	12.9	-	16.0	22.3	450	0.906
4762	7.47	12.0	12.9	14.0	14.2	20.9	457	1.019

Corrosion resistance

Aquerous corrosion

As their main purpose is to withstand corrosion at high temperatures, ferritic heat resistant grades – like other heat resistant steels – are not expected to perform well in low-temperature environments. Consequently, they are not resistant to acid condensates etc.

High-temperature corrosion

To which extent a material is resistant to hot gases is closely related to the composition of the material. Alloy contents determine whether or not a protective oxide layer can be maintained or formed to begin with, or if other detrimental reactions could occur.

Below, a number of high-temperature corrosion types are discussed. Insensitivity to reducing sulphurous gases is the most exceptional feature of the HT ferritic stainless steels. Since industrial environments usually consist of a mixture of several aggressive gases, it is understood, that the chosen grade has to be a compromise.

Oxidation

In oxidising environments, a protective oxide layer is likely to be formed on the metallic surface. If the layer is tight and adherent, it can prevent other aggressive elements in the environment from attacking and reacting with the steel. However, the layer can grow in thickness due to constant oxidation. The resulting porous layer will allow the gas to penetrate through to the base material through pores or cracks. Silicon and aluminum are both beneficial for oxidation resistance. Low thermal expansion and high thermal conductivity of the ferritic base material reduce changes in volume and thus spalling of the protective layer.

Sulphur attaccks

As a rule, ferrites perform better than austenites in oxidising and reducing sulphurous atmospheres.
SO_2 or H_2S are possible compounds in sulphur containing process gases or fuels.

In oxidising atmospheres, attack can be delayed as long as the existing oxide scale is continuous and dense. However, scaling temperatures are up to 200°C lower than in air. Thus, the oxide layer can grow faster and less compact - forming undesirable pores and cracks - and spall. With ferritic material in use, there is no risk of formation of low-melting-point nickel sulphides. That liquid phase can destroy the remaining oxide layer and inhibit further passivation of an austenite. Additionally, eutectic phases precipitated at 650°C - preferably on grain boundaries - weaken the structure and lead to rapid destruction of austenitic material.

In “reducing” sulphurous atmospheres, the oxygen activity may be sufficient to form a protective oxide layer, provided the Cr-content is higher than 25 %. This usually not being the case in austenitic heat resistant steels, the catastrophic corrosion attacks described above will be the consequence. Thus, ferritic material is best utilized in reducing sulphur environments.

Carbon and nitrogen pick-up

In terms of resistance to carburisation, austenitic grades show more favorable results than ferritic ones due to their high Ni-content. Formation of chromium carbides or chromium nitrides, respectively, embrittles the material. Additionally, the surrounding matrix becomes chromium depleted and thus less able to form an oxide layer, which consequently reduces the scaling resistance of the material.

Silicon has a beneficial effect on both carbon and nitrogen pick-up. Aluminum is only favorable in terms of carburisation. The high nitrogen affinity of aluminum results in aluminum nitrides retarding formation of a protective alumina and leading to premature failure of the material.

Molten metals

In molten metals, Nickel is the most susceptible element to dissolution. Austenitic material is bound to fail when e.g. molten copper penetrates the grain boundaries. HT ferrites - on the other hand - are expected to show good compatibility with molten copper. Final resistance will, of course, depend on the composition of the molten metal.

Fabrication

Hot forming

Hot working should be carried out within the temperature ranges given in Table 2.

Formability/Machining

Generally, ferrites are difficult to form in the cold condition. They are formable at room temperature when sheets are no thicker than 3 mm; 4713 even 6 mm. Thicker 4713 and 4724 plates must be preheated and formed within the temperature range 250 - 300°C. 4742 and 4762 should even be heated up to 800 - 900°C to avoid formation of any brittle phases. Generally, the minimum radius for bending deformation can be taken as “double thickness”.
Machining is considered to be less problematic due to their low strain hardening rates.

Welding

The same precautions as for carbon steels are normally required. Preheating of the joints to 200-300°C is necessary for plates thicker than 3 mm. Due to grain growth in the heat affected zone, the heat input should be minimised. Gas shielded welding methods such as GTA (TIG), plasma arc and GMA (MIG) are preferred. Pure argon should be used as the shielding gas.

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

Heat treatment

Heat treatment will only be necessary after severe cold working. Otherwise it can be set aside, as the material will be exposed to high temperatures during service. Nevertheless, the temperatures for a proper annealing are indicated in Table 2.

Products

Surface finishing is carried out according to customer specification. Usual choice is the “annealed and quenched” condition since the material is destined to exposure to high temperatures where the scale layer will grow anew.

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Quarto plates Table 7

Min. thickness	Max. thickness*	Max. width	Max. length	Max. weigth
2 mm	12 mm	2.5 m	9 m	2.3 t

* Plates thicker than 12 mm in thickness are also available but mechanical properties according to EN 10095 cannot be guaranteed.

Outokumpu is an international stainless steel and technology company. Our vision is to be the undisputed number one in stainless, with success based on operational excellence. Customers in a wide range of industries use our metal products, technologies and services worldwide. We are dedicated to helping our costumers gain competitive advantage.

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