Stainless steel is a large group of metals with a couple of properties in common: The main element is iron (> 50 % Fe = “steel”), and apart from that the steel contains at least 10-12 % chromium (Cr). In its simplest form, no other elements are required in order to make “stainless steel”, proved by the fact that the simplest possible stainless steel (EN 1.4003) contains only 10.5 % Cr, and the rest is iron.

Historically, the simple chromium alloyed steel types were invented back in 1912. In 1913, the German Krupp Company added nickel (Ni) in order to improve the mechanical properties (the birth of the austenitic stainless steel), and in 1920, the beneficial effect of adding even small amounts of molybdenum was observed. Thereby, the “acid resistant” stainless steel was invented.

Apart from chromium and nickel, the steel may contain a large array of other elements, all of which affect the mechanical or chemical properties in one way or the other. The description of the effect and importance of the different elements is enclosed in Chapter 2.

According to their microstructure, the stainless steel types may be classified into five main groups:

**Austenitic Stainless Steel**

Usually recognized by a high content of chromium (Cr), high nickel (Ni), low carbon (C) and frequently molybdenum (Mo, up to 6 %), the austenitic group is by far the largest and most important type of stainless steel, and both the common EN 1.4301 (18/8, AISI 304) and the acid resistant steel types (4401/04, AISI 316(L) etc.) belong to this group.

Mechanically, the austenites are recognized by being non-magnetic; however, cold deformation may lead to the steel being slightly magnetic. In general, the austenitic steel types possess a long elongation (A5). This implies great ductility, and the austenites are generally soft and particularly adapted to plastic deformation such as deep drawing of kitchen sinks.

Compared to the other types, the ductile austenites behave a bit like “chewing gum”, and the excellent combination in between the mechanical ductility and the corrosion resistance has ensured that the austenites are still the most widely used group of stainless steel. Anything from door handles to king-size brewery tanks are made of austenitic stainless steel.

In contrast to the ferritic, martensitic and duplex types, the austenitic steel types do not suffer from brittleness at very low temperatures, and their tendency to suffer from “creep” at higher temperatures is lower as well. In addition, the corrosion resistance of the austenitic steel types is generally high; however, in particular the lower ones (4301 and 4401 classes) are vulnerable to stress corrosion cracking (SCC, see Chapter 4). For that reason, the austenites are not always useful in warm conditions.
Chapter 1: What is Stainless Steel?

**Martensitic Stainless Steel**

Normally contains 12-16 % Cr, low Ni, rarely Mo and a relatively high content of carbon (C, 0.12-1.2 %). Due to the carbon content, the martensitic steels can be hardened to more than 1000 HV by rapid cooling, and they are extremely adapt for manufacturing cutting tools, surgical instruments and high-quality kitchen knives.

After the hardening, the martensitic steel types can be neither welded nor cold deformed. Along with any other heat treatment, welding will cause the steel to lose its hardness. The martensitic steel types are strongly magnetic and due to the low chromium content, the corrosion resistance is generally poor. This is the reason why expensive kitchen knives frequently suffer from superficial pitting corrosion after a turn in the dish washing machine.

**Ferritic Stainless Steel**

Typically, this type contains 12-18 % Cr, low Ni, low carbon (C ≤ 0.12) and sometimes molybdenum (Mo). The ferritic stainless steel types possess the same metallurgical structure as mild steel; however, due to the low carbon content, the ferrites are not hardenable. Consequently, the ferrites are relatively soft, but due to a shorter elongation, they are less adapted to cold deformation than the soft austenites. All ferritic stainless steel types are strongly magnetic, and the stabilized types (such as 4512, 4509 and 4521) are weldable.

The lowest alloyed types (i.e. 4003) possess a relatively poor corrosion resistance, in particular in strong acids, whereas the higher alloyed types, such as 4509 and 4521, equal the well-known 4301 and 4401 with respect to pitting corrosion and, to a certain extent, crevice corrosion. Further more, the resistance towards stress corrosion cracking is much better than the parallel austenites (Chapter 4 + 5).

Due to the low nickel content, the ferritic stainless steel types are relatively cheap compared to their austenitic parallel alloys. For that reason, the global consumption of ferritic stainless steel types is steeply increasing, in particular for purposes where one needs a bright, magnetic surface, such as fridge doors or door handles, but does not need the huge elongation of the austenites.

In addition, the ferritic stainless steel types possess great advantages when dealing with "hot equipment". Under such conditions, the risk of SCC may be substantial. Furthermore, it may be advantageous that the thermal conductivity of the ferritic types is better than for the austenites, and the thermal elongation corresponds to that of mild steel – approximately 2/3 of that of the austenites.
Duplex Stainless Steel

Two-phase mixed structure containing approximately 55% ferrite and 45% austenite. Cr is generally high (22–26%), Ni 1–7%, frequently Mo and low C. With regard to pitting corrosion, crevice corrosion, general corrosion and, in particular, SCC, the corrosion resistance is normally high.

Mechanically, the duplex steel types are magnetic and possess a significantly higher yield stress than both the austenitics and the ferrites. From a mechanical point of view, the duplex steel types are particularly useful for large constructions. If so, one can reduce the thickness of the steel and thereby the cost of the material and the result is more corrosion resistant steel at a lower price.

The drawback of the duplex steel types is the increased costs of the manufacturing along with increased difficulties during welding. The risk of formation of intermetallic phases during heat treatment (such as welding) is substantial, and the risk increases with increasing content of Cr and Mo.

For duplex steel, the thermal extension coefficient and heat transfer coefficient are somewhat in between the values of the ferritic and austenitic steel types. This means better heat transfer and less thermal elongation as compared to the austenitic stainless steel types.

Precipitation hardening Stainless Steel (PH)

Two-phase martensitic-austenitic stainless steel alloy typically contains 15–17% Cr, 4–8% Ni, low Mo and up to 5% copper (Cu). At elevated temperatures, precipitation hardening takes place due to the segregation of mainly copper containing phases.

The most common (= least uncommon!) PH alloys are the 15-5 PH and the 17-4 PH. Being strong and hard, they are sometimes used for chains and golf clubs, however, they are still not that common in Scandinavia.

A rare example of the use of the precipitation hardening 17-4-PH alloy (EN 1.4542). Both the face and the body of this high-quality golf club have been made of the alloy.
Chapter 2: The Alloyning Elements of Stainless Steel

Chromium, Cr
The main alloying element in all types of stainless steel, and normally present in between 10 and 25 % (by weight). The invisible passive film of the steel mainly consists of chromium oxides, and in general, the corrosion resistance in most types of media (in particular towards pitting and crevice corrosion) increases with increasing Cr content. The formation of the passive layer is at its best during aerobic (oxygenated) conditions. Ferrite stabilizing element, and mechanically, the yield strength increases with increasing Cr, and so does the heat resistance and the resistance towards high-temperature scaling.

Molybdenum, Mo
Added to the steel from 0.8 to 6.2 %. Even better than Cr in order to form a protective passive layer and even small amounts of Mo improve the corrosion resistance significantly, in particular in acid, anaerobic environments. Works positively against all types of corrosion. Like Cr, Mo is a ferrite stabilizing element which increases the mechanical strength of the steel.

Nickel, Ni
In austenitic steel types present from 8 to 25 %, in duplex 4-7 %, and less than 2 % in ferritic and martensitic types. Ni stabilizes the ductile austenitic phase and thereby works as “softener”, greatly enhancing the elongation of the steel, in particular at low temperatures. In austenites, increased amounts of Cr and Mo are normally compensated by a similar increase in Ni – just to keep the steel austenitic. Ni increases the resistance towards general corrosion and stress corrosion cracking (SCC), and slows down the corrosion velocity once the pitting or crevice corrosion has been initiated. Expensive metal with the nasty habit of creating fluctuating alloy surcharge.

Carbon, C
Harmful element which, apart from the martensites, should be kept as low as possible. Normal limits are < 0.08 % or 0.07 for most types; < 0.03 % for low carbon types. For martensites, C is usually kept in the range of 0.12–1.2 %; the higher C, the harder the steel after hardening. During heat treatment at temperatures in between 500 and 850 °C (i.e. welding), C binds Cr (= sensitization) which may lead to intergranular corrosion. This is the main reason why most steel types are made as low-carbon (such as EN 1.4306, 4307, 4404 and 4435). C is a very strong austenite stabilizer, and low content of carbon must be compensated by an increase in Ni in order to keep the austenite structure. This is particularly evident in the case of 4435.

Nitrogen, N
Present up to 0.5 %. Useful element which enhances the passivity reaction, even in very small amounts. In practice, however, it is very hard to add N to the molten metal. Frequently used in high-end austenites and duplex steel types. N is the only austenite stabilizer which increases the Pitting Resistance Equivalent (PREN) of the steel (factor 16).

Silicon, Si
Normally added as an unwanted pollution from the ceramic melting pots at the steel works. Austenite stabilizer and normally present in a concentration less than 1.0 %. In the normal range, Si has no big effect on the corrosion resistance of the steel, but is useful in high-temperature austenites, such as 4828 and 4841.
Chapter 2: The Alloying Elements of Stainless Steel

Manganese, Mn
Like Si, Mn is normally present as a pollution element in the steel. Concentration level normally < 2 %. In the “AISI 200” series (i.e. 4372), however, Mn is used as a cheap nickel substitute Mn and may reach 7.5 %. Improves the hot rolling properties of the steel and increases the mechanical strength slightly. Mn is an austenite stabilizer with no big effect on the corrosion resistance of the steel apart from binding sulphur as highly harmful manganese sulfides (MnS).

Sulphur, S
Unwanted pollution and extremely harmful to the corrosion resistance. Normally, S is kept lower than 0.015 % (0.030 for rods). However, fine machining steel qualities may contain 0.15–0.35 % (i.e. 4305 = AISI 303). S forms manganese sulfides which tend to make the steel short-chipped and thus reduce tool wear during milling. Consequently, fine machining types are much better than normal austenitic steel types as regards most types of machining. The downside is that i.e. 4305 is significantly less corrosion resistant than the normal 4301, and sulphur alloyed steel types are unsuitable for welding as well as pickling.

Phosphorous, P
Like S, an unwanted pollution. However, slightly less damaging to the corrosion resistance. The limit of most standards is < 0.045 %. In most cases, however, the content is much lower.

Copper, Cu
0–2 %. Increases the corrosion resistance in acid, anaerobic environments (i.e. sulfuric acid) by increasing the effect of the cathodic hydrogen evolution, thereby making the acid more oxidizing (= anodic protection). i.e. 904L (4539) contains 1.2–2.0 % Cu and is particularly adapt for handling sulfuric acid. Cu increases the mechanical strength moderately.

Titanium / Niobium, Ti / Nb
Important elements and usually present up to 0.80 %. Both Ti and Nb bind the potentially harmful C and thereby prevent sensitization and intergranular corrosion. The effect of adding Ti and Nb corresponds to the use of low-carbon steel, and 4541 and 4571 can usually be substituted by 4306/07 and 4404 – and vice versa. It is usually a question of tradition with the Germans preferring the Ti stabilized steel types while most others prefer low-carbon. Mechanically, Ti and Nb alloyed steel types are marginally stronger than the corresponding low-carbon steel while the Ti steels are harder to polish and may give yellowish welds in combination with nitrogen containing gasses. In ferritic steel types (i.e. 4509, 4521, 4526), Ti and/or Nb stabilize the steel and prevent grain growth, thus making the steel weldable without damaging the ability to be polished / electro polished.
Chapter 3: Applications of Common Stainless Steel Alloys

Below, a number of common Damstahl stainless steels are listed together with their most common use. All types are listed according to the new EN standards, which almost (but not 100 %) correspond with the old W.Nr. system. The requirements of the AISI numbers are rarely identical with those of the parallel EN numbers, so instead, they should be regarded as the closest standard. Consequently, the translation should therefore be regarded as approximate, not absolute.

Ferritic Stainless Steel:

EN 1.4003 / AISI 410
The simplest stainless steel, containing approx. 11 % Cr and the rest iron (Fe). Due to the absence of Mo and Ni, 4003 is a cheap alloy possessing a relatively poor corrosion resistance. Possesses a fine mechanical strength and may be forged as well as welded and can be used for a number of applications where mild carbon steel is inadequate, i.e. cars and buses, or where galvanized steel is used indoors. For improved weldability, the Ti stabilized parallel is EN 1.4512.

EN 1.4016 / AISI 430
16 % Cr steel possessing good mechanical strength and a superior corrosion resistance compared to the 4003. With regard to pitting corrosion above/below water, 4016 is close to but still slightly inferior to the austenitic 4301. 4016 possesses a good heat resistance and may be used up to 800 ºC. However, welding is tricky, and a post-treatment is recommended in order to avoid brittle intermetallic phases along the welds. Widely used as sheets and coils for catering purposes. 4016 may, however, also replace galvanized steel for indoor purposes.

EN 1.4113 / AISI 434
Molybdenum containing (1 %), ferritic steel possessing a good corrosion resistance to chloride containing media; roughly in between the 4301 and 4401 classes. Due to the absence of stabilizing elements (Ti, Nb), the 4113 cannot be welded and should be used as coils or sheets.

EN 1.4509 / AISI 441
Ti-Nb stabilized, ferritic, 17½ % Cr steel, corresponding to a slightly upgraded 4016 (AISI 430), with improved properties. Due to its good corrosion resistance, weldability and relatively low and very stable price, 4509 is one of the most interesting and useful steels on the market and may be expected to replace 4301 in many major applications such as catering, building construction and heat exchangers. Theory as well as practice have shown 4509 to equal 4301 with regard to pitting corrosion (Chapter 4 + 5), and for hot parts, the ferrites are generally superior to the austenites due to their improved resistance towards SCC. Furthermore, 4509 has got a great potential as a substitute for galvanized steel. However, like all ferrites, it is only available as thin sheets or pipes. For all ferritic stainless steel types, care must be taken to ensure that the right welding process, filler metal and parameters are chosen.

EN 1.4510 / AISI 439 (430Ti)
With 15.5 % Cr, the 4510 corresponds to a Ti stabilized 4016 (no Nb). As 4509, the 4510 is weldable, but it is slightly less corrosion resistant than 4509 and harder to get. This combination is bound to make the 4510 a rare bird.
Chapter 3: Applications of Common Stainless Steel Alloys

EN 1.4512 / AISI 409
Containing only 11 % Cr, the 4512 is the lowest alloyed Ti-Nb-stabilized (and thereby weldable) ferritic stainless steel. Due to the low Cr, 4512 possesses a comparatively low corrosion resistance; however, it is weldable and inexpensive and may replace galvanized steel for certain indoor applications. Due to their excellent resistance against SCC, the ferrites are particularly useful for warm parts, in particular made of sheets.

EN 1.4521 / AISI 444
Along with the 4509, the “acid resistant ferrite” 4521 is the most interesting and useful ferritic alloy. Stabilized with Ti and Nb, and apart from a high mechanical strength, 4521 possesses an excellent corrosion resistance due to 17.0-20.0 % Cr and 1.80-2.50 % Mo. Theory as well as practice have shown that as regards resistance towards pitting corrosion, 4521 is at least equal to that of “acid resistant” 4404 (AISI 316L) and superior to 4301 in chloride containing environments. Like all the other ferrites, 4521 is superior to its austenitic counterparts with regard to SCC resistance (Chapter 4 + 5) and therefore very useful at higher temperatures (+60 ºC). In short, 4521 is useful for applications where 4401, 4404 or 4571 are normally used. The main drawbacks are potential difficulties in welding and the reduced availability; mostly thin sheets and pipes.

EN 1.4526 / (AISI 436)
Nb stabilized steel containing around 17 % Cr and 1.25 % Mo, performing somewhere in between 4301 and 4404 with regard to pitting corrosion. Excellent corrosion resistance against chloride containing environments and industrial atmosphere and, along with the other ferrites, not prone to SCC. This makes 4526 ideal for warm or hot parts where the conventional austenites (4301 and 4404 classes) will fail. Can be forged and shaped and, using the right parameters, be assembled using resistance welding.

Martensitic Stainless Steel:

EN 1.4057 / AISI 431
Hardenable 15-17 % Cr steel, possessing, relative to the other martensitic steel types, a fairly good corrosion resistance. Widely used for making knives and, due to its high strength, axels. Most easily available as rods.

EN 1.4104 / (AISI 430F)
Martensitic fine machining steel type containing up to 0.35 % S and even a small amount of Mo. Due to its high content of S, this steel type is very useful for machining. Sometimes used if one wants a magnetic fine machine steel grade.

The ideal combination in between hardness and formability. The blade of this Gense knife has been manufactured from the martensitic 4057, while the handle has been made of the softer, but more corrosion resistant 4301.
Chapter 3: Applications of Common Stainless Steel Alloys

Austenitic Stainless Steel:

**EN 1.4301 / AISI 304**
The classical, stainless steel (18/8) quality and still the most important steel for manufacturing anything from kitchen sinks, forks and spoons and dairy and butchery equipment. Ductile, weldable and fairly corrosion resistant in most normal media. However, the resistance in chloride containing environments (in particular at elevated temperatures) is frequently inadequate. Due to chlorides, 4301 should not be used for outdoors purposes. It is better suited for indoors use. At temperatures above 60 °C (and sometimes even below), SCC is a significant risk (Chapter 4). Upgrading to the even more corrosion resistant 4404 ("acid resistant") will solve most corrosion problems; otherwise, even higher alloyed steel types must be considered.

**EN 1.4305 / AISI 303**
Sulphur alloyed 4301 possessing excellent properties for cutting, milling and so due to the formation of MnS (Chapter 2). Only available as rod or wire, and is not good for neither welding nor pickling. Compared to common 4301, the corrosion resistance of 4305 is inferior in almost any type of media. Consequently, 4305 should be used with care.

**EN 1.4306 / AISI 304L**
Low-carbon edition of 4301. C ≤ 0,03 % due to the risk of sensitization and subsequent intergranular corrosion (Chapter 2 + 4). The theoretical disadvantage is a marginally lower mechanical strength. The nickel content of 4306 is quite high (10-12 %), and the steel is therefore slightly "over-austenitic" making it less prone to deformation hardening. This, in turn, makes the 4306 useful for stretch-forming. However, the increased nickel makes 4306 quite expensive and hard to get.

**EN 1.4307 / AISI 304L**
The standard low-carbon 4301. Identical to 4306; however, with less nickel (8-10,5 % Ni). 4307 is identical with 4301 with the sole exception that the upper limit of carbon is only 0.03 % instead of 0.07 %, which is preferable when welding, in particular when welding thick goods (Chapter 2 + 4). Due to the lower Ni, 4307 is cheaper and "less austenitic" than 4306 (10-12 %), and traces of ferrite or deformation martensite may cause some magnetism, in particular after machining.

**EN 1.4310 / AISI 301 / 302**
"18/8 classic". An older edition of the standard 4301 recognizable by comparatively high carbon content. This increases the mechanical strength of the steel. However, the drawback is a significant increase in the risk of sensitization and intergranular corrosion. Sometimes used when high-temperature tensile stress is an issue.

**EN 1.4401 / AISI 316**
The standard "acid resistant" steel type. Mechanically much like the "kid brother" 4301; however, due to its Mo content (2.0-2.5 %), its corrosion resistance is significantly better in almost every single environment, regardless if the risk of corrosion is pitting, crevice corrosion or SCC (Chapter 4). Due to the frequently poor performance of 4301, the 4401 ought to replace 4301 as standard material. However, because of the high and volatile prices of molybdenum and in particular nickel, the 4401 class is often expensive.

**EN 1.4404 / AISI 316L**
The low-carbon edition of 4401, and the standard material for most of the pharmaceutical industry world-wide. 4404 is the most common stainless steel for "critical" parts where the common 4301 or 4306/7 just are not good enough. 4404 is Damstahl's best sold acid resistant steel type and available in almost any shape and condition including a large array of fittings.
Chapter 3: Applications of Common Stainless Steel Alloys

EN 1.4418 / -
Compared to low-alloyed, acid resistant steel, mostly available as rods or bars. The content of only 1% Mo and 4-6% Ni makes the steel two-phased and mechanically strong, and frequently, it is used for hydraulic equipment; sometimes even plated with hard-chromium. Very popular for Norwegian offshore use.

EN 1.4432 / AISI 316L
Developed by the Finnish pulp and paper industry, this 2.5% Mo steel resembles the 4435 a lot. However, the Cr content is marginally lower, and so is Ni. Due to the 2.5% Mo, 4432 is slightly more corrosion resistant than the normal 4404 without adding too much to the price. The downside is lower availability.

EN 1.4435 / AISI 316L
The low-carbon edition of 4436 and thereby a high-alloy 4404. Like 4432 and 4436, the extra 0.5% Mo gives a higher corrosion resistance. However, the main drawback is the high alloy costs due to Mo and Ni. Consequently, 4435 is the most expensive and the most corrosion resistant standard alloy and, for economical reasons, the steel is frequently hard to get.

EN 1.4436 / AISI 316
High-alloyed, acid resistant steel, containing 2.5-3.0% Mo as compared to 2.0-2.5 for normal 4401 or 4404. The extra Mo improves the corrosion resistance, whereas the drawback is the higher price, partly because of the increase in Mo and partly because of the extra Ni required to maintain the austenite phase.

EN 1.4539 / "904L"
Containing 20% Cr, 25 Ni and 4.5 Mo, the 4539 is very corrosion resistant, austenitic steel. Originally developed to handle general corrosion in strong sulfuric acid, which explains the high Ni content and the 1.2% Cu. "Over-austenitic" alloy possessing excellent corrosion resistance in almost any environment, but due to the high Ni content, 4539 is very expensive. Please note that the designation "904L" is not an AISI standard, but rather an antique Swedish factory name.

EN 1.4541 / AISI 321
Titanium stabilized 4301. Ti binds the carbon (Chapter 2+4), and the steel is therefore less prone than 4301 towards sensitization and intergranular corrosion. This makes 4541 better than 4301 for welding, in particular in the case of thick specimens. With regard to corrosion and weldability, 4541 corresponds closely to 4307 and is traditionally used widely, in particular in Germany. Theoretically, 4541 is slightly stronger (mechanically) than 4301, but may produce yellow welds when nitrogen containing purge gas is used (i.e. former gas) and is harder to polish properly. EN 1.4550 (AISI 347) is the niobium alloyed 18/8 possessing almost the same properties as the 4541.

EN 1.4571 / (AISI 316Ti)
Titanium stabilized 4301 and thus the acid resistant equivalent to 4541 and the most widely used stainless steel type in the German industry. As above, the use of titanium alloyed austenites is mostly based on conservatism, and like 4307 vs. 4541, there are rarely any problems by changing from 4404 to 4571 – and vice versa. The marginal differences in between 4571 and 4404 are the same as between 4541 and 4307 (see EN 1.4541 above).
Heat Resistant Austenitic Steel:

**EN 1.4828 / AISI 309**
Lowest alloyed high-temperature stainless steel, resembling the standard 4301 a lot, apart from the fact that the 4828 contains in between 1.5 and 2.5 % silicon (Si) to improve the resistance towards scaling.

**EN 1.4841 / AISI 314**
Very high-alloyed stainless steel containing 24-26 % Cr and 19-22 % Ni. Compared to the 4828 above, the 4841 possesses improved mechanical properties as well as corrosion and scaling properties. The main disadvantage is the high Ni content making the alloy expensive and economically unstable.

Duplex Steel:

**EN 1.4460 / AISI 329**
The original, “classical” duplex steel and the only one classified in the AISI system. At 25-28 % Cr, 1.30-2.0 % Mo and 4.5-6.5 % Ni, the 4460 contains more than 50 % ferrite (the rest being austenite), causing the steel to possess excellent hardness and mechanical strength. Only available as rods and frequently used for high-performance axels.

**EN 1.4462 / “2205”**
At 22 % Cr, 5 % Ni and 3 % Mo, the 4462 is the most widely used duplex stainless steel. A high mechanical strength combined with excellent corrosion resistance makes the 4462 very useful as construction steel. Superior to the “acid resistant” 4401 group with respect to any type of corrosion in almost any environment, in particular SCC. The main drawbacks are the limited availability and the increased manufacturing expenses, including cold deformation and welding.

Precipitation Hardening Steel:

**EN 1.4542 / –**
Rare steel from a rare group. Containing 14-17 % Cr, 4542 normally possesses a corrosion resistance somewhere in between the hardenable martensites and the austenitic 4301. The 3 % Cu makes the steel hardenable through heating, although the possible hardness is lower than that of the martensites. A typical application is high-quality golf irons (I) such as Callaway Big Bertha or Ping G10.
With regard to corrosion, stainless steel is a very smart group of metals. The excellent corrosion resistance combined with an affordable price has made stainless steel the most frequently used group of metals within critical sectors such as the food and pharmaceutical industries as well as the chemical industry.

The excellent corrosion resistance of stainless steel is caused by a very thin layer of oxides in particular chromium and iron oxides, and despite a thickness of only a few nanometres, this oxide layer is so strong that it effectively isolates the steel from the environment. Should the oxide layer suffer from a breakdown, it is quickly regenerated, and the corrosion protection is re-established.

Unfortunately, this ideal scenario does not always take place; the oxide layer may be damaged without repassivating, and the sad result may be serious corrosion. Once the corrosion has started, rapid penetration may occur causing the stainless steel to be a very short-lived construction material. The difference in between the two extremes is sometimes very small: If repassivation takes place, corrosion is prevented and, theoretically, the steel may last forever. If not, severe corrosion may take place, and the life-span of the equipment may be very, very short.

The types of corrosion occurring on stainless steel are as follows:

**General Corrosion**

As mentioned above, general corrosion takes place at extreme pH values, i.e. in very strong acids or, less common, in strong alkalines. Typical media are sulphuric acid, phosphoric acid and so on, and apart from the type of media and the strength, corrosion velocity is highly dependant on the temperature and the presence of impurities, in particular chloride. As a rule, the corrosion increases with increasing temperature and increasing chloride concentration.

The most useful elements in the steel are nickel and molybdenum. In general, low-alloyed ferritic and, in particular, martensitic steels should not be used in strong acids and alkalines.

4301 stainless steel bolt suffering from severe general corrosion after having spent a number of months in a nitric acid-hydrofluoric acid pickle bath. Please note that the loss of metal is quite uniform and quite large while no penetration has occurred yet.
Pitting and Crevice Corrosion

Pitting corrosion (Lochfraß-Korrosion, punktfrätning, grubetæring) is a type of corrosion caused by a local breakdown of the protective oxide layer. Unlike the ideal situation, repassivation does not occur, and severe corrosion will take place. Pitting corrosion is the perfect example of the edge-like nature of stainless steel. Either repassivation occurs, and the steel lasts forever, or corrosion takes place, and penetration may occur rapidly.

Crevice corrosion (CC, Spaltkorrosion, spaltekorrosion) reminds a lot of pitting corrosion; however, CC takes place in crevices, pores and narrow geometries with poor exchange of media – or none at all. Such places, all transport is controlled entirely by diffusion, and compared to the “free surfaces”, the risk of corrosion in crevices is always higher than the risk of pitting corrosion.

An old “rule-of-thumb” says that the risk of CC is substantial at a temperature 20-25 ºC below that of pitting corrosion (i.e. the critical pitting temperature, CPT). If the steel is close to its corrosion limit, the equipment should be designed so that no crevices are present. If this is not possible, more corrosion resistant steel must be chosen.

The risk of pitting corrosion as well as crevice corrosion increases with

- Increasing chloride content
- Increasing temperature
- The presence of oxidants and
- Low pH (acid conditions)

With regard to the alloying elements, an increased content of Cr, Mo and N all benefit the corrosion resistance while the effect of Ni is comparatively small. Non-metallic impurities, such as S and P, tend to lower the corrosion resistance severely.

Based on hundreds of practical experiments, the resistance of a stainless steel against pitting corrosion can be expressed as a Pitting Resistance Equivalent (PREN):

\[ \text{PREN} = \% \text{Cr} + 3.3 \times \% \text{Mo} + 16 \times \% \text{N} \]
Chapter 4: Corrosion of Stainless Steel

By experience, two steel types with the same PREN will perform approximately equally well against pitting corrosion. Please note that in theory, it does not matter if we increase the PREN by adding 1 % Mo or 3.3 % Cr. The important thing is the PREN increase.

Normally, conditions are worst when the steel is immersed completely into the water whereas the problems above the water line usually limit themselves to superficial pitting corrosion. From a cosmetic point of view, such attacks may be very annoying, in particular in the case of very expensive equipment (such as a Danish opera house!). However, it rarely leads to equipment failure.

Stress Corrosion Cracking

Stress corrosion cracking (SCC, Spannungsrißkorrosion, spændingskorrosion) is a type of corrosion giving rise to cracks. SCC is the most severe type of corrosion, and penetration may occur as a matter of days rather than months or years, even in thick steel plates. The name itself indicates that the corrosion takes place in regions of the steel where tensile stress is present. Such tensile stress is common and may occur as a result of any kind of mechanical process including welding and grinding.

The risk of SCC increases with

• Increasing chloride content,
• Increasing temperature,
• Low pH (acid conditions), and
• Evaporation

In particular the temperature is important, and SCC is more dependent on the temperature than any other type of corrosion.

Left: SCC cracks in a milk tank (4301). The longest crack is about 15 mm long, and the corrosion has been caused by high-temperature disinfection.
Right: Micro section of SCC cracks through a distillation unit. Sheet and pipe section are both made of 4301, the temperature has been 60-70 ºC, and the conditions have severely worsened because of the “pocket” in the centre thus being able to trap chloride containing water. After a while, some of the water has evaporated, and the chloride concentration will increase.
SCC is a type of corrosion which almost selectively attacks the lowest grades of austenitic steels, such as the 4301 group, and normally, 4301 will be in danger at temperatures above 60-70 °C. In practice, though, 4301 may suffer from SCC at even lower temperatures, even at room temperature. Due to its content of Mo and Ni, the 4401 group is somewhat more resistant, and the temperature limit is usually around 100-110 °C. However, even this limit cannot be regarded as "safe". SCC in 4401 steel at 30-40 °C has been observed.

Ferritic and duplex steels are significantly less sensitive to SCC than the austenitic steels. Consequently, if SCC is the critical type of corrosion, it is no bad idea to replace the pipes and sheets of 4301 or 4404 by 4509 or 4521, respectively.

Intergranular Corrosion

Intergranular corrosion (IG, interkristalline Korrosion, interkrystallinsk korrosion) is a type of corrosion which is caused by the formation of chromium carbides in the grain boundaries of the steel (Chapter 2). Heating the steel to a temperature in the range of 500-850 °C, carbon is binding the useful chromium causing a weakening of the zones adjacent to the grain boundaries. In popular, this corresponds to dissolving the cement in between the bricks of a house.

The risk of IG increases rapidly with the carbon content of the steel, and this risk is the main reason why one should always chose low-carbon steel (i.e. 1.4306, 4307, 4404 or 4435) or titanium stabilized types (4541, 4571) as compared to normal types (4301, 4401). The thicker the steel (= increased heating time), the more important it is to use low-carbon steel.

Due to the increased effort of the steel works in order to remove the carbon, IG is a rare bird these days.
Chapter 4: Corrosion of Stainless Steel

Time

For all types of corrosion, time is a very important factor, and generally, long-time exposure to a corrosive media is always worse than a short-term dip. Frequently, one can get away with exposing the steel to a much too corrosive environment provided that the contact time is very short, a fact which is utilized in i.e. the dairy business where disinfectants are frequently too corrosive to the common 4301 steel. As long as the cleaning is done in a matter of minutes, it works. On the other hand, remaining pools of disinfectant may cause severe corrosion.

This effect is even more obvious when considering the conditions above water. There, the environment is governed by splashes of water and salts, and provided that the construction is made in such a way that the water is drained off quickly, the stainless steel may last forever. If salt-containing pools or drops are allowed, the risk of corrosion may include cosmetically superficial pitting corrosion to SCC at elevated temperature.

All corrosion data above are based on long-term exposure. If the exposure time can be kept short, the steel may last much better than predicted by the books.
A few years ago, the nickel-free, ferritic, stainless steel was regarded as a bit of a joke. A poor corrosion resistance combined with poor weldability and poor mechanical properties was not enough to compensate for the low price, and ferritic, stainless steels were only considered useful for making very simple, not-critical parts, such as cheap tea spoons.

However, the unpredictable fluctuations of the nickel price during the last few years have changed this pattern markedly. From 2006 to the middle of 2007, the nickel price increased from 15,000 to 55,000 $/ton, and shortly thereafter, it dropped steeply to 30-35,000, and in the time of writing (December 08), the price has plummeted to 10,000 $/ton. Due to its (sometimes) very high price, nickel is the price determining element in normal, austenitic stainless steel, and most of the alloy surcharge for an EN 1.4301 steel (= AISI 304) happens to be nickel. For higher alloyed steel types, this pattern is even more evident. In short, nickel is a pricey and economically unstable element, and a lot could be gained if nickel was by-passed as alloying element. What if one could maintain the corrosion resistance without the nickel?

Fortunately, that scenario is not entirely science-fiction. In most cases, the corrosion resistance depends on molybdenum (Mo) or chromium (Cr), while the main purpose of nickel (Ni) in stainless steel is to stabilize the ductile austenitic phase. Ni owes its presence to mechanical reasons rather than the corrosion resistance (Chapter 2), and by cutting down the Ni content, one gets a stainless steel possessing great corrosion resistance at a much lower cost. In short, that is the “secret” of the ferritic stainless steels: High Cr, perhaps Mo and little or none Ni.

The table below shows the alloy composition of the most common ferritic steel types compared to the common austenitic ones. Please note that the Ni content of the five ferrites is close to zero, while the austenites contain at least 8 % Ni.

<table>
<thead>
<tr>
<th>EN 1.-</th>
<th>Structure</th>
<th>% C</th>
<th>% Cr</th>
<th>% N</th>
<th>% Mo</th>
<th>Others</th>
<th>AISI</th>
<th>SS</th>
</tr>
</thead>
<tbody>
<tr>
<td>4003</td>
<td>Ferrit</td>
<td>≤ 0.08</td>
<td>10.5-12.5</td>
<td>0.30-1.00</td>
<td>-</td>
<td>N ≤ 0.030</td>
<td>4105</td>
<td>-</td>
</tr>
<tr>
<td>4016</td>
<td>Ferrit</td>
<td>≤ 0.03</td>
<td>16.0-18.0</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>430</td>
<td>2320</td>
</tr>
<tr>
<td>4509</td>
<td>Ferrit</td>
<td>≤ 0.030</td>
<td>17.5-18.5</td>
<td>-</td>
<td>-</td>
<td>Ti 0.10-0.60; Nb 3x(C+N) - 1.00</td>
<td>441</td>
<td>-</td>
</tr>
<tr>
<td>4512</td>
<td>Ferrit</td>
<td>≤ 0.03</td>
<td>10.5-12.5</td>
<td>-</td>
<td>-</td>
<td>Ti 6x(C+N) - 0.65</td>
<td>409</td>
<td>-</td>
</tr>
<tr>
<td>4521</td>
<td>Ferrit</td>
<td>≤ 0.025</td>
<td>17.0-20.0</td>
<td>1.80-2.50</td>
<td>-</td>
<td>N ≤ 0.030; Ti 4(C+N)+0.15 - 0.80</td>
<td>444</td>
<td>2326</td>
</tr>
<tr>
<td>4301</td>
<td>Austenit</td>
<td>≤ 0.07</td>
<td>17.5-19.5</td>
<td>8.00-10.5</td>
<td>-</td>
<td>N ≤ 0.11</td>
<td>304</td>
<td>2333</td>
</tr>
<tr>
<td>4306</td>
<td>Austenit</td>
<td>≤ 0.030</td>
<td>18.0-20.0</td>
<td>10.0-12.0</td>
<td>-</td>
<td>N ≤ 0.11</td>
<td>304L</td>
<td>2352</td>
</tr>
<tr>
<td>4307</td>
<td>Austenit</td>
<td>≤ 0.030</td>
<td>17.5-19.5</td>
<td>8.00-10.5</td>
<td>-</td>
<td>N ≤ 0.11</td>
<td>304L</td>
<td>-</td>
</tr>
<tr>
<td>4404</td>
<td>Austenit</td>
<td>≤ 0.07</td>
<td>16.5-18.5</td>
<td>10.0-13.0</td>
<td>2.00-2.50</td>
<td>N ≤ 0.11</td>
<td>316</td>
<td>2347</td>
</tr>
<tr>
<td>4404</td>
<td>Austenit</td>
<td>≤ 0.030</td>
<td>16.5-18.5</td>
<td>10.0-13.0</td>
<td>2.00-2.50</td>
<td>N ≤ 0.11</td>
<td>316L</td>
<td>2348</td>
</tr>
</tbody>
</table>

Because of the attractive ratio in between corrosion resistance and price, the consumption of ferritic, stainless steels has almost exploded. In 2006, 27 % of the world-wide consumption of stainless steel was ferritic alloys, but in 2010, it is estimated that the percentage may reach as high as 47. In particular the car factories are major consumers of ferritic stainless steel, and as Scandinavia possesses a comparatively small car industry, the 2006 and 2010 numbers for Scandinavia are “only” 15 and 25 %, respectively. This increase is due to household appliances, catering and so.
Chapter 5: Ferritic, Stainless Steel

Pitting Corrosion

In most media, local corrosion resistance is dependent on the contents of Cr and Mo, and while the ferrites of the past usually contained around 12 % Cr and no Mo at all, the ferrites of today are much higher alloyed and the corrosion resistance correspondingly higher. As a result, the ferrites of today are fully capable of competing with the traditional austenites (both "normal" stainless and "acid resistant") as regards corrosion resistance.

With respect to pitting corrosion, one of the most destructive types of corrosion for stainless steel, the corrosion resistance, is determined by the Pitting Resistance Equivalent, the PREN (Chapter 4).

Empirically, two stainless steel grades with equal PREN numbers possess the same resistance towards initiation of pitting corrosion, and, using the table above, 4301 (AISI 304) has a PREN of 17.5. The ferritic 4509 has exactly the same PREN which means that the two types 4301 and 4509 can be expected to perform equally well towards pitting corrosion. In October-November 2008, this was confirmed by experiments conducted at the Technical University of Denmark (DTU).

Similarly, the ferritic 4521 (PREN 22.9) can be expected to perform equal to the austenitic 4404 (AISI 316L, PREN 23.1), and, not surprisingly, this was also confirmed by the Technical University of Denmark (DTU). Actually, the pitting potential of the acid resistant ferrite, 4521, proved to be significantly higher than that of the parallel austenite, 4404. Consequently, for both groups of steel (4301 / 4404), it is possible to substitute the traditional austenite with the parallel ferrite and maintain the resistance towards pitting corrosion.

The above considerations apply for the initiation of pitting corrosion. Should the corrosion, against all precautions, start, Ni is a beneficial element, and corrosion tends to propagate faster in a Ni-free, ferritic steel than an austenitic steel type. However, this is just an additional argument for choosing stainless steel with care. Quite simply, one has to choose stainless steel where the corrosion will never initiate. Just choose steel with a sufficiently high PREN.

Stress Corrosion Cracking

Stress Corrosion Cracking (SCC) is a type of corrosion giving rise to cracks due to a combination of mechanical stress and exposure to certain corrosive media, and it is normally regarded as the most destructive type of corrosion. SCC specifically attacks the austenitic steel types, and in particular the 4301 and 4401/04 groups are vulnerable, particularly in chloride containing media.

As a guideline, SCC is a risk for 4301 at temperatures above only 50-60 ºC while the "acid resistant" 4401 class lasts until 100-110 ºC (Chapter 4). This actually makes the austenitic stainless steel inadequate for a number of technical appliances ranging from reactors and distillation columns to heat exchangers, evaporators and drying equipment.

General Corrosion

General corrosion is a type of corrosion which takes place in either very strong acids or very strong alkalines. In these media, the austenites are normally slightly more resistant than the ferritic alternatives so for handling extreme pH media it is safer to stick to the traditional steel types.

It should be mentioned that the different types of passive, stainless steel normally can be connected with no risk of galvanic corrosion provided that both types are sufficiently corrosion resistant. Normally, there is no corrosion problems connected with putting i.e. 4301 and 4509 together in the same media.
Chapter 5: Ferritic, Stainless Steel

Mechanical Properties

Mechanically, the differences in between the austenitic and ferritic types are more evident. Measured by HRC, Rp 0.2 or Rm, most ferrites equal the austenitic steel types. However, ferritics possess slightly higher yield strength (Rp0.2) and slightly lower tensile strength (Rm). As a rule, the mechanical properties of stainless ferrites are comparable to high strength carbon steels.

A major difference in between the ferrites and the austenites is the elongation, i.e. the possible deformation until breakage. For the austenitic 4301 or 4401 groups, the minimum elongation is around 45 % meaning that these steel types may be stretched and deformed very much before they break.

In contrast, the ferritic types posses a minimum elongation of 18-20 % which means that they are much less useful in the case of mechanical deformation such as pure stretch forming. On the contrary, ferritics are more suitable for deep drawing, such as complex exhaust systems. As regards cold forming, the ferrites are comparable with carbon steels, and it is not necessary to use more powerful machines in comparison with cold forming of the austenitic steels.

Notably, alloys like 4016 are widely used in i.e. England and Italy for catering purposes. However, do not expect to be able to make a very complicated double kitchen sink from a ferritic stainless steel. In such a case, the traditional 4301 is better.

Another notable difference is the mechanical properties at extreme temperatures, i.e. notch toughness (AV) and creep strength, respectively, although Nb stabilized ferritics deform less than austenitics in response to long term stresses. Unlike the austenites, the ferrites may become brittle at very low temperatures, and they do not maintain their excellent tensile stress at very high temperatures (typically 700–800 °C and above). In addition, long-term exposure to temperatures in between 400 and 550 °C may give rise to "475°-brittleness", an “illness” which may also attack the duplex stainless steels in the same temperature range.

In short, the ferritic steels are less useful in extreme temperatures than the austenites; however, ferritics are more suited for cyclic high temperature applications while austenitics are preferably used in isothermal applications. In any case, each and every situation should be evaluated separately.

Magnetism, Thermal Elongation and Wear

Magnetically, the ferritic stainless steels resemble mild steel. All ferritic stainless steels are strongly magnetic while the nickel containing austenites are either non-magnetic or, in the case of cold working, slightly magnetic.

Also with respect to thermal properties, the ferritic stainless steels are closer to the carbon steels than the austenites. The thermal elongation of the ferrites is about 30-35 % lower than that of the austenitic types thereby reducing the risk of deformation during welding or subsequent operation. This is particularly important if the equipment is to be made from both stainless steel and mild steel as the thermal tension in between the mild steel and the austenitic steel is larger than in between the mild steel and the ferrites.

With regard to wear, stainless steel against stainless steel has a nasty habit of adhesive wear. This risk may be reduced by choosing two different types of stainless steel (i.e. with two different grain structures). A ferrite against an austenite is a better wear combination than austenite against austenite, although still inferior to well-known combinations as, say, bronze against stainless steel.
Welding of Ferritic Stainless Steel

In contrast to previous teachings, it is perfectly possible to weld ferritic stainless steels, although they are less foolproof than the austenites. The lack of Ni increases the risk of grain growth and the formation of unwanted phases as a result of the heating. Such effects may cause brittleness and reduced corrosion resistance, and therefore, one has to be more careful when welding the ferrites as compared with the austenites, in particular with regard to the heat input. The thicker the steel, the more important it is to keep the heat input low in order to avoid unwanted side effects.

This said, the present-day ferritic steels are much easier to weld than the past generations of steel. This is due to the fact that the higher alloyed ferrites are “stabilized” by adding titanium (Ti) and/or niobium (Nb), both of which stabilize against grain growth during welding. It is essential to employ stabilizers in sufficient quantities, e.g. Ti and/or Nb, both strong carbide formers and blocking grain growth. Thereby, chromium carbides are unable to form during the thermal cycles of welding.

Unstabilized ferritic grades, such as 4016, can therefore be susceptible to intergranular corrosion in the HAZ due to chromium carbide formation. For this reason, the non-stabilized types, such as 4003 and 4016, are not recommended for welding without a subsequent heat treatment.

4509, 4521 and 4526 and the low-alloyed 4512 (10.5-12.5 Cr, 0 Mo) can be welded (TIG or MIG) by using filler metal type 4430 (20 Cr, 2.5-3.0 Mo) or similar types. In the case of 4512 and 4509,

Up to 1-1½ mm thickness, welding can be done with no filler metal at all. No particular problems should occur when welding ferrites (4509, 4521) and austenites (4301, 4401 groups) together. Recommended filler metal for the 4301/4509 is 309L (22-24 Cr, 12-15 Ni, 0 Mo) whereas the molybdenum alloyed 4430 is preferred when welding the 4404/4521.

An important difference in between the ferrites and the austenites is the use of purge gas. For TIG, welding of ferritic stainless steel, argon (Ar) or argon-helium (< 20 % He) is recommended while Formier gas (N2 + H2) should not be used due to the risk of grain growth and brittleness. For MIG welding, Ar + 2 % CO2 is recommended; higher content of CO2 may give rise to carbide formation (sensitization).
Chemical Surface Treatment

In contrast to the information given by the literature in the last millennium (before 2000!), ferritic stainless steels can be subject to a chemical surface treatment. The higher alloyed ones, such as 4509, 4521 and 4526, can be pickled, passivated and even electro polished, although it is recommended to be more careful than with the austenitic types. The reason for this extra care is the fact that ferrites are generally more sensitive towards very strong acids than the parallel austenites.

When performing a pickling process, one should take care that the ferrites are etched rather quickly when exposed to strong acids, and one should make sure that a relatively mild pickle is used. This is just one of a number of reasons why the heat tinting should be kept at a low level during the welding of ferritic steel types.

Electro polishing of ferritic stainless steels is possible as well. However, in these extreme acids (50 to 70 % sulfuric and phosphoric acids at temperatures around 60 °C), the ferrites are more sensitive than the austenites, and it is hard to obtain the same mirror-bright surface. If a mirror-like surface is required, the austenites are better.

Passivation may be carried out with a pure nitric acid (Chapter 7). The lowest alloyed ferrites, such as 4003 and 4512, can neither be pickled nor electro polished, and passivation should only be done with a di-chromate inhibited nitric acid.

Food Appliances and Nickel Problems

Without any problems, ferritic stainless steel may be used in most applications where the austenitic steels are, at present, the state of the art. This includes the food industry, and the ferritic 4016 is widely used for catering purposes in England and Italy, and the higher alloyed 4509, 4521 and 4526 may easily be used for more demanding purposes within the same business.

A particular advantage with the ferritic steel types is the absence of nickel and with a Ni content of zero, the risk of Ni leaking into the media is equally zero. In contrast, the 4301 and 4404 contain 8 and 10 % Ni, respectively which (mostly by corrosion) may be leaked into the media. At present, there are no rules and regulations with regard to the use of nickel free steel types in the food industry. However, should this ever be the case, it does not hurt to be ahead of time.
Supply, Dimensions and Prices

The most important ferritic stainless steels are the 4509, the “acid resistant” 4521 and the very popular 4016. They are all available as sheets (various surfaces) and pipes; however, in all cases, the thickness hardly ever exceeds 3 mm, apart from hot-rolled sheets. In any case, the supply time for any ferritic stainless steel may be longer than for the similar austenites, and despite the increasing production and demand, it will take a few years until the supply of the ferrites exceeds that of the austenites.

The prices depend on the steel type, the dimensions, and, of course, the fluctuations in the alloy surcharge. In particular, this is dependent on the nickel content, for which reason the economical advantage of using the ferrites more or less follows the development in the nickel prices. The higher the nickel price, the larger the economical advantage by switching to ferrites.

In July 2008, this difference was 25 %. However, the subsequent nickel drop has reduced this advantage. Still, the price of the nickel-free ferrites is markedly more stable than for the austenites, and in case of an exploding nickel price (once again!), the price difference is going to be much bigger.

Similar advantages are obtained for the acid resistant ferrite 4521 compared to the austenitic 4404.

Possible Applications

The ferrites are less ductile than the austenites (making cold forming a bit more complicated), and the welding process is somewhat more sensitive than that of the traditional austenites. In addition, the reduced supply is bound to have a negative effect, but the ferrites are nevertheless extremely useful. With regard to manufacturing and corrosion, a list of possible pros and cons are, among others, given below:

<table>
<thead>
<tr>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Comparable local corrosion resistance (PREN4509 = PREN4301)</td>
<td>• Due to risk of crevice corrosion, more attention for design is needed</td>
</tr>
<tr>
<td>• Excellent resistance towards SSC; much better than the austenites</td>
<td>• Welding parameters are more critical</td>
</tr>
<tr>
<td>• Good corrosion resistance towards general and intergranular corrosion</td>
<td>• Low notch toughness for thicknesses above 3 mm</td>
</tr>
<tr>
<td>• Pickling, passivation and electro polishing possible</td>
<td>• Lower elongation = less suitable for pure stretch-forming</td>
</tr>
<tr>
<td>• No risk of Ni leakage to food</td>
<td>• Reduced toughness at very low (cryogenic) temperatures</td>
</tr>
<tr>
<td>• Low thermal expansion</td>
<td>• Brittleness at long-term exposure to temperatures around 475 °C</td>
</tr>
<tr>
<td>• High thermal conductivity</td>
<td>• Magnetic (sometimes a disadvantage)</td>
</tr>
<tr>
<td>• Less prone to spring-back during cold-forming</td>
<td>• Lower availability, in particular thick dimensions; better planning required</td>
</tr>
<tr>
<td>• Magnetic (sometimes an advantage)</td>
<td>• Lower and less volatile price</td>
</tr>
<tr>
<td>• Lower and less volatile price</td>
<td></td>
</tr>
</tbody>
</table>
Consequently, the "prime targets" of ferritic stainless are:

- Simple equipment with easy bending, stretching and welding
- Thin goods, mainly sheets and coils
- Simple manufacturing
- Large steel costs (= great savings)

A major consumer of stainless ferrites is the car industry of Europe and USA and also within building and construction, industry, mailboxes, signboards, household appliances, white goods and catering there is an expanding market for the corrosion resistant and inexpensive stainless ferrites.

In general, in particular the weldable alloys, 4509 and 4521 are expected to posses a great future as they - with respect to pitting corrosion - are quite close to the 4301 and 4401 groups, respectively. In these applications, where pitting corrosion is the limitation, it is frequently possible to switch from austenite to ferrite with no loss of corrosion resistance.

In addition, galvanized carbon steel has become so expensive that it is worth considering substituting plain galvanized steel with ferritic stainless steel. Here, the weldable 4509 and the cheaper 4512 (only 11 % Cr) are particularly relevant indoor while the mechanically stronger and more corrosion resistant 4521 is preferable for outdoor purposes.

Above water (in cold conditions), superficial pitting corrosion is the major problem, and in such cases, 4301 can frequently be replaced by the ferritic 4509 – and the 4401/4 by the 4521. Such replacements are not uncommon in the catering and kitchen industry; however, there is still plenty of room for such substitutions. The 4509 is perfect indoor, and the 4521 is bound to be an inexpensive standard steel for outdoor purposes where the 4404 is too expensive, and where the 4301 is not good enough – despite the fact that lots of contractors use it almost anywhere.

When SCC is the problem, the advantage of using ferrites is magnified. At temperatures above 60 °C (for the 4301; about 100 °C for the 4404 class), extreme care should be taken when using the austenites, and for exhaust pipes, baking ovens or heat exchangers, the ferrites are a much safer choice. By switching from austenites to ferritic stainless steel, one gets a more corrosion resistant material at a lower price.

Not a bad combination!
Chapter 6: The Manufacturing of Stainless Steel and how it affects the Corrosion Resistance

No matter how the stainless steel is used, a certain degree of manufacturing is required. This may include cutting, bending, welding or grinding; however, no matter what we do, the corrosion resistance of the steel is affected.

When the stainless steel leaves the factory, it is "perfect". From this moment, its corrosion resistance is at its best, and the vast majority of manufacturing processes affect the resistance in a negative way. Most processes will tend to weaken the corrosion resistance, and, consequently, all manufacturing should be performed in such a way that the negative effect is as small as possible. If this is not possible, the manufacturing should be followed by a chemical surface treatment (Chapter 7).

Welding
One of the most severe processes is welding. Apart from introducing a second phase (the filler metal), the steel is subject to a very powerful heat treatment, which may affect the corrosion resistance in a number of different ways. All negative, of course.

The risk of corrosion connected to the weld itself is often reduced by choosing a filler metal with a higher content of Cr and Mo than the base metal. Still, any crevice caused by inadequate binding, pores or so, and suddenly, one has to cope with the risk of crevice corrosion (Chapter 4).

A rule of the thumb states that CC occurs at a temperature 20-25 °C below the critical pitting temperature (CPT). To cope with this, crevices should be completely avoided below the water line (= intensified control), or a better steel with a higher PREN should be chosen. Thereby, a larger safety margin is induced allowing a few more "defects".

Heating the steel to a temperature in between 500 and 850 °C, an inevitable phenomenon close to the welding zone, implies a risk of formation of harmful chromium carbides. This does not happen in the weld itself, but rather in the Heat Affected Zone (HAZ), close by. Normally, this problem is greatest when welding thick steel plates, and in practice, one can cope with it by choosing low-carbon steel (4306, 4307 or 4404), or titanium stabilized steel (4541 or 4571, Chapter 4).

A related phenomenon is the formation of harmful intermetallic phases such as the "sigma" (Cr-Fe) or the "ksi" phase (Cr-Mo). This problem is particularly big when welding high-alloyed "super duplex" steels (i.e. 4410, duplex 2507 and Zeron 100) and the high-end ferritic steel types (i.e. 4509, 4526 and 4521).
At least just as harmful is the bluish or yellowish heat tinting which is formed on the steel surface during welding. These discolorations are caused by a warm oxidation of the steel surface and consist of thick oxides of mainly chromium and iron. If left untreated, these layers imply a significant loss of corrosion resistance, and to cope with the problem, either their formation should be entirely prevented (by using extreme amounts of purge gas) or they should be removed afterwards. In most cases, the latter is the more economical, and in practice, it is feasible to accept a certain level of bluish discoloring and later remove the layer by pickling (Chapter 7) or a combination in between grinding and a subsequent pickling or passivation.

Removing the heat tinting by a glass blasting is less desirable as the heat tinting and the de-chromed layers will be mashed into the surface rather then being removed. Prior to the glass blasting, a pickling will do the job.

Finally, any welding process implies the formation of tensile stress which will increase the risk of stress corrosion cracking. As removal of the stress is not feasible, this problem should be taken care of in the design phase by choosing a steel type possessing a sufficient resistance towards SCC. Fighting SCC by hoping to reduce the level of tensile stress is not recommended.

Cutting, Sawing and Others

Due to the risk of heat tinting, the most dangerous methods are the hot ones. A "hot classic" is the angular cutter, which, apart from producing a rough and uneven surface, gives rise to a spray of hot particles. These have a nasty tendency to stick to stainless steel surfaces, and the result is heat tinted crevices, a very sad combination implying a severe loss of corrosion resistance. The easy way to cope with the problem is to remove the spray particles carefully with i.e. a screw driver and perform a subsequent pickling.

Even the cold cutting processes may affect the corrosion resistance in a negative way. The center of the steel normally contains a larger concentration of harmful inclusions and segregations than the surface, and thus the centre of even thin sheets is less corrosion resistant than the surface.

This inevitable effect originates from the making of the steel at the steel works. When the steel solidifies, it takes place from the outside and inwards pushing the insoluble impurities towards the centre of the slab. Hot and cold rolling the slab from a thickness of 200 mms to, say, less than 1 still maintains the impurities in the center, and cutting the steel exposes these impurities and creates a less corrosion resistant surface. A subsequent chemical treatment (such as a pickling) will minimize the problem (Chapter 7).
Brushing, Blasting, Grinding etc.

Any mechanical treatment of stainless steel affects the surface roughness and thereby the corrosion resistance of the steel. As a general rule, the corrosion resistance decreases with increasing surface roughness, and a very rough surface (say, sandblasted) performs markedly worse in a corrosion testing than the normal, smooth 2b.

The reason for this is double: At first, a rough surface is much better than a smooth one at "collecting" dirt and corrosive salts, thus forming "local elements". Secondly, a rough grinding will tend to expose a larger concentration of impurities from the steel itself. Such impurities, in particular sulfides, may act as points of attack for pitting corrosion, and thereby lower the corrosion resistance.

In addition, a rough grinding will tend to increase the level of tensile stress in the surface of the steel, increasing the risk of stress corrosion cracking. In contrast, a fine blasting (shot peening or glass blasting – not sand blasting) may increase the level of compressive stress and thus increase the resistance against SCC.

From a corrosion point of view, it is normally an advantage not to perform any kind of mechanical surface treatment at all! The smooth and pickled 2B surface of the cold-rolled sheets possesses its maximum corrosion resistance and no matter how much we grind, it just gets worse. As above, a proper chemical surface treatment (Chapter 7) will reduce the damage of the steel.
Handling and Transport

A particular risk when dealing with stainless steel is iron contamination originating from using the same tools and equipment for handling mild steel along with stainless steel. Using the same trucks, the same fork lifts or the same machinery may transfer minor amounts of mild steel or rust onto the stainless steel. Apart from looking ugly, the contaminations may cause corrosion of the stainless steel itself.

As discussed later in Chapter 7, the iron contaminations may be removed chemically; however, preventing the whole thing from happening is at least as effective. In particular, all tools, trucks and lifts used for stainless steel should only be used for stainless steel – not mild steel.

Even if the tools are separated, another risk is the transfer of metal dust from the grinding of mild steel onto the stainless steel further down the alley. This can only be prevented by keeping the production of mild steel and stainless steel separated completely, preferably in two separate buildings. If this cannot be arranged, a chemical post-treatment is mandatory.

A nasty example of carbon steel particle having been mashed into the stainless steel surface during cold forming. The iron particle must have been very hard as it has been pressed into the stainless steel, and even though a pickling will remove the iron contamination, the holes remain.
Any manufacturing or handling of stainless steel implies the potential risk of weakening the corrosion resistance. Should this weakening be larger than the built-in safety margin for the steel as compared to the corrosivity of the environment, one has to reestablish the original corrosion resistance of the steel. In most cases, the cheapest and safest way to do this is by performing a chemical surface treatment.

**Pickling**

By far the most important chemical treatment, the pickling consists of an aqueous solution containing in between 10 and 20% nitric acid (HNO₃) and between 1 and 8% hydrofluoric acid (HF). High-alloy stainless steel types require an aggressive pickle containing a high concentration of HF, while the "normal" 4301 and 4401 grade steels should be pickled in a milder acid with a lower content of HF. Instead of HF, some pickles contain hydrochloric acid (HCl) as "activator"; however, using such aqua regia pickles implies a serious risk of pitting corrosion during the pickling process. HCl-based pickles are not recommended!

At room temperature, the pickling time may be anything from 30 minutes to several hours depending on the pickle itself as well as the darkness of the heat tinting to be removed (the darker, the longer time required) and the concentration of metal contaminations in the bath.

After pickling, all contaminations and inclusions in the steel surface have been dissolved along with the heat tinting and the critical de-chromed layer underneath. After the pickling, all the weak spots have been removed efficiently, and (after repassivation) the steel has reestablished its excellent passive layer and thereby its original corrosion resistance.

The main drawback with the pickling process is the fact that it is a powerful etching of the steel. Apart from losing a few microns of thickness (affecting fine tolerances), the surface roughness will usually increase, in particular for very smooth specimens; an effect which may be unwanted in the dairy and medical industry. Here, the surface roughness should be kept low in order to make life difficult for microorganisms, and frequently, a limit of 0.6 μm for Ra is used as the upper limit.

In addition, even small variations in the surface roughness may affect the visual appearance of the specimen; however, this is mainly a cosmetic problem.

Applying the pickle can be done in two ways. The easiest one is to simply immerse the specimen into the pickling bath. However, if this is not possible, the pickle can be applied as a paste. In this case, one has to use a pickle in which a "thickener" has been added, so that the product resembles a paste. Thereby, one can "paint" the pickle onto selected parts of the specimens.

Note that the lowest alloyed ferritic types (such as 4003 or 4512) are suitable for pickling, and neither are the sulphur alloyed fine machining steel types (such as 4305) or any of the martensitic ones. Higher alloyed ferritics (4509, 4521) may be pickled, but require a milder pickle than the austenites. In Denmark, using hydrofluoric acid pickles require a special permit which can be obtained at a police station.
Passivation

The purpose of a passivation is to strengthen the natural protective oxide film of the steel, and in addition, non-metallic inclusions are largely dissolved. Normally, the bath consists of pure 18-25 % nitric acid (HNO₃), and typically, the process time is about one hour. As above, sulphur alloyed steels and low-alloyed ferritics need special treatment, i.e. di-dichromate inhibited nitric acid.

![Image of Steel-Tech “Pickle Gel 122”](image1)

*Left: Steel-Tech “Pickle Gel 122”, a nitric acid + hydrofluoric acid based paste, useful for normal stainless steel. Applied by using a special brush.*

*Right: Using pickling paste on a weld on the inside of a 4436 steel pipe.*

A significant advantage of the passivation is the fact that the surface roughness is not affected (measurably) by the process. A passivation is therefore an excellent treatment after a grinding or glass blasting. A major disadvantage is the lack of effect on the heat tinting. To remove these and the de-chromed layer underneath, a pickling is required – or a gentle grinding followed by a passivation.

Decontamination

Literally, decontamination means de-poisoning, and that is exactly what is happening. It is a semi-advanced dishwashing where all impurities are removed while the stainless steel is hardly affected at all; neither heat tinting nor the natural passive layer, and therefore decontamination does not affect the surface roughness. In addition, decontamination does not affect most rubber and plastic types, all of which make the process very useful in i.e. the medical industry and other super-critical equipment where etching of the steel itself or damage of the gaskets are unacceptable. Many polymers do not like nitric acid or other strongly acidic oxidants.

Decontamination is typically performed in a solution of 2-10 % of a weak acid such as phosphoric acid, nitric acid, citric acid, formic acid, oxalic acid or so. The temperature can be anything from 20 to 90 ºC, and the process time may exceed many hours if the impurities are very sticky.

Iron contamination (Chapter 6) is a particular problem, but frequently, one can get away with de-contamination as compared to a pickling. Rust (iron oxides and hydroxides) is generally slowly soluble in nitric acid, but much easier to cope with in a hot mixture of citric acid and phosphoric acid. Metallic iron, on the other hand, is easier soluble in nitric acid.
Electro Polishing

Electro polishing is the only surface treatment process using an external current source. Typically, the bath is a strong mixture of sulphuric acid and phosphoric acid, the temperature is above 50 °C, and using a rectifier, the specimen is connected to the anodic pole. As cathodes, stainless steel is normally used.

During the process, the steel is slowly dissolved and, as the etching primarily takes place from the tops of the micro-roughness, the process minimizes the difference in between the top and the bottom of the surface profile. This "leveling" process reduces the surface roughness, and the surface becomes gradually brighter (SEM photo in Chapter 6).

Apart from producing a very bright surface, the corrosion resistance of an electro polished stainless steel is better than any other surface (of the same type of steel, of course!). This is linked to the low surface roughness making it increasingly difficult to form harmful local environments. Above the waterline, the main benefit is the inability of salts and water to stick to the bright surface causing an electro polished 4301 to perform almost as well as a 4401, 2b.

In theory, electro polishing is able to remove heat tinting. However, this may not always be the case. If heat tinting is the problem, a pickling should be performed prior to the electro polishing.

The drawback of electro polishing is mainly the price. It is a complicated and expensive process partly due to the equipment and partly due to the trouble mounting the cathodes and performing the process. Consequently, electro polishing is a process which is most widely used within critical appliances such as the medical business where the ultra-low surface roughness is essential for hygienic reasons.

Chemical Surface Treatment, Overview:

<table>
<thead>
<tr>
<th>Process</th>
<th>Bath</th>
<th>Process Time</th>
<th>Anløbninger</th>
<th>Cr-oxidder</th>
<th>Ruhed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pickling</td>
<td>10-20 % HNO3 + 1-6 % HF</td>
<td>1-12 hrs.</td>
<td>Removed</td>
<td>Removed</td>
<td>Increase</td>
</tr>
<tr>
<td>Passivation</td>
<td>18-25 % HNO3</td>
<td>30-60 min.</td>
<td>No effect</td>
<td>Strengthened</td>
<td>No effect</td>
</tr>
<tr>
<td>Decontamination</td>
<td>2-10 % &quot;semi-weak acids&quot;</td>
<td>1-48 hrs.</td>
<td>No effect</td>
<td>No effect</td>
<td>No effect</td>
</tr>
<tr>
<td>Electro Polishing</td>
<td>60-70 % H2SO4 + H3PO4</td>
<td>10-15 min.</td>
<td>Some effect</td>
<td>(Removed)</td>
<td>Decrease</td>
</tr>
</tbody>
</table>
Chapter 8: Welding methods

TIG and Laser

At our plant, in-line welding is carried out with a completely automatic LASER and TIG (Tungsten Inert Gas) method, depending on tube wall thickness according to the commonly used production norms.

Welding is carried out after cold forming by fusing the two strip edges thus limiting the thermally altered area and protecting the inner area with an appropriate shielding gas. LASER and TIG welding methods give high reliability of the weld area making the product suitable for any kind of application.

See picture n° 1: Laser welding – heat affected area of around 1mm (x50)
See picture n° 2: TIG welding – heat affected area of around 4.5 mm (x50)
H.F. High Frequency

Welding method is carried out for the production of tubes having structural purposes as well as for the production of car exhaust-systems. For these applications, the HF method is preferred because of its advantages in terms cost effective productivity. On the contrary, the small weld seam obtained with High Frequency (see picture n° 3 – x50), cannot always grant the optimum in terms of workability, withstanding of pressure and corrosion resistance due to the lack of fusion of strip edge and the oxide formation on the weld edges.
Chapter 8: Welding methods

Bright Annealing

Bright annealing is carried out in a furnace full of Hydrogen (H2) at temperatures ranging between 1040° C and 1100° C and is followed by a rapid cooling. The Hydrogen is NOT an oxidising agent and therefore no surface oxidation is created and pickling is no longer required after the bright annealing.

The main advantage of this system, besides a bright and even surface that eases further processing of the tubes, is the improved corrosion resistance of the material. Such treatment, carried out at the final stage of the production process, ensures the complete solution of the possible carbides precipitated at the grain border, thus obtaining an austenitic matrix free of defects. This makes it possible to avoid the dangerous phenomena of intergranular corrosion. The austenitic structure obtained through off-line bright annealing, is homogeneous with regular grain size (dimension varies from 6 to 8 ASTM); the consequence is an improvement of stainless steel tensile properties, in particular traction and elongation, with an increase of plasticity and a decrease of residual stress. This is a material characteristic very well appreciated by all end users who are making further manipulations on tubes such as bending and forming.

See picture n° 4- x50 where the dentritic zone material has been totally replaced by the austenitic material.
Tubes not annealed - Pickled

Welded tubes can be supplied in not annealed condition. This product undergoes the same production process with the exception of the heat treatment. The tubes are instead submitted to a pickling chemical treatment. The pickling bath is composed of Sulphuric and Fluoridric acids.

This process can eliminate, both on the outside and inside surface, and on the ends, any trace of ferrous contamination and also any possible oxides which may be on the metal surface as a result of mechanical working (welding rolls, abrasive belts, cutting equipment) and welding.

See picture n°5 – x50 not annealed tube
Chapter 8: Welding methods

Brushed tubes

On the marketplace brushed tubes are available. The brushing is made on the external surface only, to avoid the chemical treatment of pickling.

These products, however, have a lower corrosion resistance than pickled tubes if submitted to the same environmental attack. This is due both to the deposits on the metal surface contaminated during the production process and to the greater surface roughness which can easily retain oxides and traces of ferrous contamination. The abrasive belts in itself can leave material that could originate corrosion.

Brushed tubes, because of their finishing, need a more frequent periodical maintenance compared to pickled tubes.

It must be underlined that brushing is exclusively external and therefore cannot remove any contamination existing on the inside surface and at the ends cut by shears made of steel based materials.

Eddy Current Test

Welded tubes produced by Ilta Inox, after being calibrated, are submitted to an Eddy Current test with circumferential coils with differential windings.

Such non-destructive control is carried out by creating a Magnetic Field around the tube and detecting any interruption caused by leaks or holes.
<table>
<thead>
<tr>
<th>EN</th>
<th>Structure</th>
<th>C  %</th>
<th>Cr  %</th>
<th>Ni  %</th>
<th>Mo  %</th>
<th>Si  %</th>
<th>Mn  %</th>
<th>S</th>
<th>P</th>
<th>Other remarks</th>
<th>AISI (UN)</th>
<th>SS</th>
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<td>1.4003</td>
<td>Ferrite</td>
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<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>≤ 0.03</td>
<td>10.5-12.5</td>
<td>0.30-1.00</td>
<td>-</td>
<td>1.00</td>
<td>1.50</td>
<td>0.015</td>
<td>0.040</td>
<td>N ≤ 0.030</td>
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<td>-</td>
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<td></td>
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<td>-</td>
<td>-</td>
<td>1.00</td>
<td>1.00</td>
<td>0.015</td>
<td>0.040</td>
<td></td>
<td>430</td>
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<td>-</td>
<td>-</td>
<td>1.00</td>
<td>1.00</td>
<td>0.015</td>
<td>0.040</td>
<td>Ti 0.10-0.60; (3xC+0.30) ≤ Nb ≤ 1.00</td>
<td>441</td>
<td>UNS 43932</td>
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<tr>
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<td>≤ 0.05</td>
<td>16.0-18.0</td>
<td>-</td>
<td>-</td>
<td>1.00</td>
<td>1.00</td>
<td>0.015</td>
<td>0.040</td>
<td>[4(C+N)+0.15] ≤ Ti ≤ 0.80</td>
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<td>-</td>
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<td>1.00</td>
<td>0.015</td>
<td>0.040</td>
<td>Ti; 0.15≤ N ≤ 0.80</td>
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<td>-</td>
<td>1.80-2.50</td>
<td>1.00</td>
<td>1.00</td>
<td>0.015</td>
<td>0.040</td>
<td>N ≤ 0.030, [4(C+N)+0.15] ≤ Ti ≤ 0.80</td>
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<td>-</td>
<td>1.00</td>
<td>1.50</td>
<td>0.030</td>
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<td>8.00-10.5</td>
<td>-</td>
<td>1.00</td>
<td>2.00</td>
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<td>0.045</td>
<td>N ≤ 0.11</td>
<td>304</td>
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<td></td>
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<td>8.00-10.0</td>
<td>-</td>
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<td>2.00</td>
<td>0.15-0.35</td>
<td>0.045</td>
<td>Cu ≤ 1.00; N ≤ 0.11</td>
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<td>10.0-12.0</td>
<td>-</td>
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<td>2.00</td>
<td>0.015</td>
<td>0.045</td>
<td>N ≤ 0.11</td>
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<td>-</td>
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<td>2.00</td>
<td>0.015</td>
<td>0.045</td>
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<td></td>
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<td>≤ 0.80</td>
<td>2.00</td>
<td>2.00</td>
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<td>0.045</td>
<td>N ≤ 0.11</td>
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<td>9.00-12.0</td>
<td>-</td>
<td>1.00</td>
<td>2.00</td>
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<td>0.045</td>
<td>Ti ≤ 0.70</td>
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<td>2.00</td>
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<td>0.045</td>
<td>N ≤ 0.11</td>
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<td>2.00-2.50</td>
<td>1.00</td>
<td>2.00</td>
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<td>0.045</td>
<td>N ≤ 0.11</td>
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<td>2348</td>
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<td></td>
<td>≤ 0.06</td>
<td>15.0-17.0</td>
<td>4.00-6.00</td>
<td>0.80-1.50</td>
<td>0.70</td>
<td>1.50</td>
<td>0.015</td>
<td>0.040</td>
<td>N ≤ 0.00</td>
<td>-</td>
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<td>2.50-3.00</td>
<td>1.00</td>
<td>2.00</td>
<td>0.015</td>
<td>0.045</td>
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<td>2.50-3.00</td>
<td>1.00</td>
<td>2.00</td>
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<td>2.50-3.00</td>
<td>1.00</td>
<td>2.00</td>
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<td>0.045</td>
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<td>≤ 0.020</td>
<td>19.0-21.0</td>
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<td>4.00-5.00</td>
<td>0.70</td>
<td>2.00</td>
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<td>0.030</td>
<td>N ≤ 0.15, Cu 1.20-2.00, &quot;904L&quot;</td>
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<td>1.00</td>
<td>2.00</td>
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<td>≤ 2.00</td>
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<td>≤ 0.20</td>
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<td>19.0-22.0</td>
<td>1.50-2.50</td>
<td>≤ 2.00</td>
<td>0.015</td>
<td>0.045</td>
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<td>314</td>
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<td>1.4845</td>
<td></td>
<td>≤ 0.10</td>
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<td>19.0-22.0</td>
<td>≤ 1.50</td>
<td>≤ 2.00</td>
<td>0.015</td>
<td>0.045</td>
<td>N ≤ 0.11</td>
<td>-</td>
<td></td>
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<tr>
<td>1.4460</td>
<td>Duplex</td>
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<td>25.0-28.0</td>
<td>4.50-6.50</td>
<td>1.30-2.00</td>
<td>1.00</td>
<td>2.00</td>
<td>0.015</td>
<td>0.035</td>
<td>N ≤ 0.05-0.20</td>
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<td>2324</td>
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<td>4.50-6.50</td>
<td>2.50-3.50</td>
<td>1.00</td>
<td>2.00</td>
<td>0.015</td>
<td>0.035</td>
<td>N ≤ 0.10-0.22</td>
<td>2377</td>
<td></td>
</tr>
</tbody>
</table>

Please note that the present EN standards do not correspond exactly to the old material number names. The columns with "AISI", "UNS" and "SS" indicate the immediate parallel standard. In particular the AISI system does not correspond exactly to EN. Consequently, the AISI and SS specifications are to be considered as approximate.
<table>
<thead>
<tr>
<th>EN</th>
<th>HB 30</th>
<th>Hardness (HRC)</th>
<th>Rp 0.2 (≥N/mm²)</th>
<th>Rp 1.0 (≥N/mm²)</th>
<th>Rm</th>
<th>Ultimate strength (≥N/mm²)</th>
<th>A5</th>
<th>Impact value (≥%)</th>
<th>Z</th>
<th>Area reduction (≥%)</th>
<th>Av</th>
<th>Density (≥kg/dm³)</th>
<th>Electric resistance (≥Ω.mm²/m)</th>
<th>Elasticity modulus (≥kN/mm²)</th>
<th>Heat capacity (≥J/g.K)</th>
<th>Heat conduction (≥W/K.m)</th>
<th>Terminal expansion coefficient 20-100º C (≥10⁻⁶/ºC)</th>
<th>Electric resistance (≥Ω.mm²/m)</th>
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2) At 600 ºC. All other data for Rp 1.0 are measured at room temperature.
3) Neither “316Ti” nor “904L” exists in the AISI system. However, both designations are often used in practice.