

## Austenitic and Duplex Stainless Steels used as Construction Materials



### Dear Reader

We have during recent years, as you probably are aware of due to the accelerated costs for stainless steel, experienced an increased demand for this material in a variety of applications. You and quite a few more people around the world have realised that quality pays off in the long run. It is far better to pay a little extra when installing different types of equipment instead of getting the costs as maintenance at a later occasion.

Maintenance means not only extra costs for replacement material, but also production losses, erection of expensive scaffolding and maybe emissions of hazardous compounds, e.g. residues from sand blasting operations and solvents from epoxy coatings.

The article describes how you could make better use of this beautiful material for the building and construction industries, emphasising welding.

Enjoy the reading!

Yours sincerely

*Jan Olsson*

Technical editor of Acom

# Austenitic and Duplex Stainless Steels used as Construction Materials

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## Abstract

Stainless steel is today more and more used as an engineering material in architecture- and building constructions. It is a material with high aesthetic attraction, good weldability and formability and also high strength when needed. A further aspect is durability of the material and no need for protective coatings against corrosion or fire. Austenitic stainless steels are the most used stainless steels in building applications. The trend today however is an increased use of high strength duplex stainless steels.

Typical stainless properties are discussed in the paper such as formability, increased strength by cold deformation, corrosion resistance and especially weldability. Different applications today and future possibilities are shown as well as different design criteria.

For stainless steels the most used joining technique is arc welding. The paper will highlight specific questions such as how should a weld look like to fulfil mechanical properties, fatigue, removal of weld oxides, corrosion, and aesthetic appearance, prestigious material. To reach sufficient corrosion resistance and mechanical properties correct filler material must be used as well as a qualified welding procedure and welding operator.

## Stainless steel in architecture, building and construction

Stainless steel is among the most prestigious architectural and building materials. It is a beautiful material with high aesthetical attraction. Stainless steel is easy to form due to its good ductility and it is suitable for a wide range of applications. Shortly after the material had been discovered, it found its way to buildings in large scale.

Stainless steel can still be seen in old prestige buildings, like Chrysler building with its ornamented top in New York. Since then the popularity of stainless steel has increased within architects and building engineers. Today you can choose between a large range of surface finishes, colours and product forms and it is easy to find an optimum stainless steel grade for your purpose, Fig. 1. Chrysler building has been

**Fig. 1** From the left: Chrysler Building (New York), One Canada Square in Canary Wharf (London) and Petronas Towers (Kuala Lumpur).



renovated because of water leakage in some parts of the upper floors. During the renovation the quality of the stainless steel plates was controlled and they were considered still to be in perfect condition after more than 80 years of service in harsh weather conditions, exposed to a combination of urban/industrial and marine environments.

There are good reasons for starting to look at stainless steel as a construction material. Stainless steels are amongst the most corrosion resistant materials that exist. Stainless steel has self-healing properties in case of small damages on the surface. The covering oxide layer is replaced quite fast after the damage. With the right choice of grade for the purpose and appropriate manufacturing methods, stainless will be unaffected by the environment even in the most aggressive industrial sites including marine atmospheres.

More than 90 percent of all building applications today can be constructed using a small number of stainless steels. The most common ones are ferritic and austenitic steels. The common steel grades in building applications today are: EN 1.4301 (304), EN 1.4307 (304L), EN 1.4401 (316), EN 1.4404 (316 L), EN 1.4571 (316Ti), EN 1.4510 (439) and EN 1.4016 (430). Fast development of duplex stainless grades has influenced that these steels are considered as the future construction materials in the building and construction industry. Examples of such duplex steels are: EN 1.4362 (SAF 2304), EN 1.4462 (2205) and a new low nickel alternative EN 1.4162 (LDX 2101). [1]. Two ferritic grades are used in load carrying constructions EN 1.4113 (434) and EN 1.4003 (410S). Common for both these grades is the high proof strength of a mean value of 370 MPa. EN 1.4113 is also used for architectural exteriors trims and profiles. Also decorative profiles and metallic finishing for building are typical applications. EN 1.4113 has a higher Cr content of than EN 1.4003 and about 1% Mo content. This leads to a significant improvement in pitting corrosion resistance.

Normally the austenitic grades EN 1.4301, EN 1.4306, EN 1.4541, EN 1.4571, EN 1.4318 are available in different product forms including hollow sections. For these grades the mechanical strength and fire resistance properties vary to some degree. The information about the behaviour of the different materials has become available through continuous research. The duplex grades are also used in building and construction applications when high mechanical strength is needed in aggressive environments, like bridge structures.

Today stainless steel is used in many other areas than in facades and roof covers, which were the first applications back in the twenties. Other important aspects are life cycle costs and the ideal of sustainable development. Even if the initial material costs for stainless steel can be higher than for carbon steel, stainless steel requires no painting and surface treatment. This, together with the savings in maintenance, compensates more than well the higher material costs. Stainless steel is 100% recyclable after the product life cycle and there is no limitation for the recyclable scrap that can be used for new production of stainless steel. [2]

### **Stainless steel as a construction material**

In principal all the common design and construction rules are also suitable for stainless steel. This small discussion of the design with stainless steel is based on some chosen literature references. One of the most important at the moment is the handbook from Euro Inox [3]. It is based on the results of an international research and co-operation project, where many EU countries participated, including Sweden. It presents all the design aspects for stainless steel and especially those differing from carbon steel ones. Another important reference is the new Eurocode – Eurocode 3 for steel construction. [4].

Stainless steel is often compared with carbon steel. The obvious reason is that they have very similar mechanical properties. Carbon steel is by far the most used material

for construction. The largest differences in physical and mechanical properties between stainless steel and carbon steel are that the stainless steel has:

- Higher thermal expansion (austenitic steels)
- Lower thermal conductivity
- Strong deformation hardening
- Larger deflection under beam bending load
- Higher strength over a large temperature range
- Good energy absorbing ability (toughness)
- Better fire resistance properties

Thermal expansion is a measure of the expansion of the material at higher temperatures. Ferritic and duplex steels have an expansion similar to carbon steel. Austenitic steels expand most of these materials. Thermal expansion is an important aspect in constructions designed for high temperatures or in long tubular constructions.

Thermal conductivity is low for stainless steel compared to carbon steel. For example a heat exchanger has a lower utilization factor than one manufactured using carbon steel. However, in many cases the use of stainless steel is necessary because of the need for high corrosion resistance. At high temperatures the thermal conductivity increases in austenitic stainless steels.

A typical behaviour of stainless steel is the deformation hardening in normal temperatures. The degree of deformation hardening is depending of the steel grade, chemical properties, microstructure and manufacturing history. A rule of thumb is that austenitic steel deformation hardens heavily, duplex stainless hardens somewhat, ferritic less and martensitic steels only slightly.

Deformation hardening has an influence on mechanical properties, mainly strength and elongation. On the other hand, this has an effect on fabrication methods like forming, bending and machining. As the material hardens successively after the grade of deformation in the forming process, the manufacturing process has to be designed taking this into account. In case of plate bending the deformation hardening causes the spring back effect which has to be taken care of by over bending in order to get the wanted angle. Deformation hardening can even be advantageous because of the increased strength in final component even if this cannot be utilized during calculations. Typically the increase in strength is in the range of 20 – 100% in bended plate corner. It is important to have this discussion with the manufacturer in order to find out the possible restrictions in cold forming because forming of stainless steel may need more force to form than carbon steel. Length of pressed plate details may be reduced because of the size of the machinery or the available force when forming thicker or higher strength material. Duplex stainless steels require approximately the double force compared with the austenitic steels. Because of the lower ductility of duplex steels, larger radii in corners have to be used.

Toughness of the austenitic stainless steels is very good. Typical fracture elongation up to 50% can be achieved without the cold-formed material being brittle. Austenitic stainless steels are tougher than construction steels at all temperatures and they are used, for example, as reinforcement in concrete structures for cryogenic installations such as storage tanks for liquefied gases.

The deflection of a bended beam is deduced at Serviceability Limit State according to Eurocode 3. Usually the deflection can be calculated according to common steel design theory with one exception: The secant modulus has to be used instead of elasticity modulus. Secant modulus varies according to stress level in the beam. The values can be calculated according to a simplified method in Eurocode 3 [4].

The strength of stainless steel varies, see Table 1. This is mainly due to the material's

microstructure, chemical composition and manufacturing method. But as mentioned earlier, cold forming during the fabrication process can influence the component strength. For many austenitic steels, chosen for a specific environment, there is often a duplex alternative with similar corrosion properties but with higher proof strength. This gives a possibility to optimize a construction for both material cost and capacity.

As mentioned earlier, the strength of the final product depends at the end of the manufacturing process. The deformation hardening of stainless steel can be utilized by cold stretching/ hard rolling the material to higher strength. Increased material strength can then be taken advantage of by reducing the material thickness to make the product lighter and/or getting better deformation or dent resistance e.g. in cover plates. This method is used for austenitic stainless steels, which have a high deformation hardening capacity, especially the grades 1.4310, 1.4301 and to a certain extent also 1.4401, see Table 2.

**A sample of typical strength values for some common stainless steels. The guaranteed values according to European standard are also shown in the table.**

Table 1

Outokumpu steel name		Outokumpu typical values				No.	EN, mm. values				
		R <sub>p0.2</sub> MPa	R <sub>p1.0</sub> MPa	R <sub>m</sub> MPa	A <sub>5</sub> %		R <sub>p0.2</sub> MPa	R <sub>p1.0</sub> MPa	R <sub>m</sub> MPa	A <sub>5</sub> %	KV J
4016	C	380		520	25	1.4016	260		450	20	
248 SV	P	730		930	20	1.4418	660		840	14	55
LDX2101®	P	480		700	38	1.4162					
SAF 23040®	P	450		670	40	1.4362	400		630	25	60
2205	P	510		750	35	1.4462	460		640	25	60
SAF 25070®	P	590		830	35	1.4410	530		730	20	60
4310	C	300	330	800	50	1.4310	250	280	600	40	
4301	P	290	330	600	55	1.4301	210	250	520	45	60
4311	P	320	360	640	55	1.4311	270	310	550	40	60
4401	P	280	320	570	55	1.4401	220	260	520	45	60
4404	P	280	320	570	55	1.4404	220	260	520	45	60
4436	P	300	340	590	50	1.4436	220	260	530	40	60
4432	P	280	320	570	50	1.4432	220	260	520	45	60
904L	P	260	300	600	50	1.4539	220	260	520	35	60
254SM0®	P	340	380	680	50	1.4547	300	340	650	40	60

**Strength classes for hard rolled EN 1.43**

Table 2

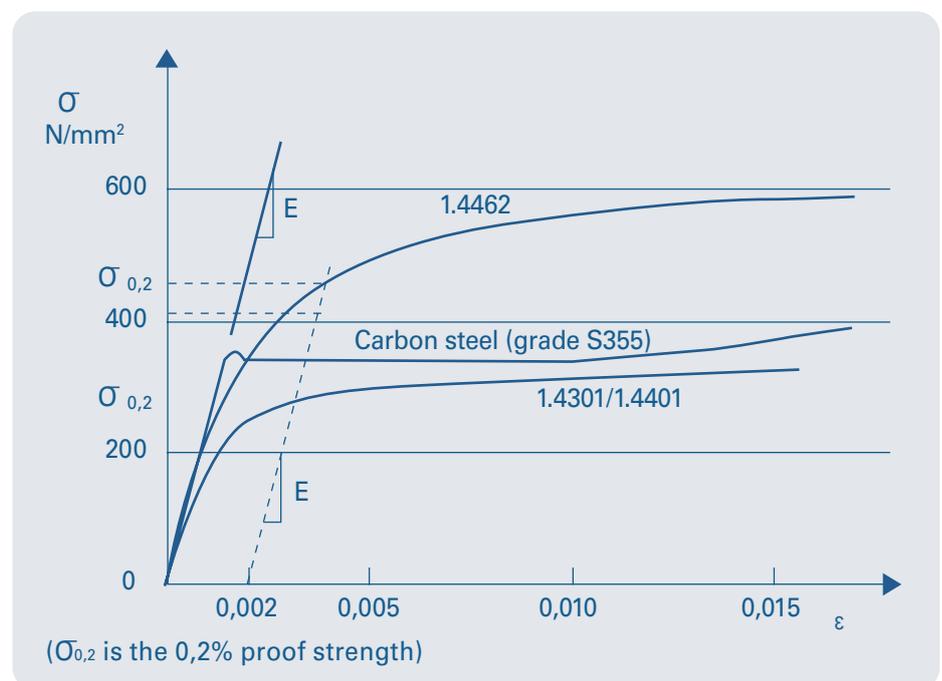
Steel Grade (EN)	Strength Class (EN)	R <sub>m</sub> [MPa]	R <sub>p0.2</sub> [MPa]	A <sub>5</sub> Typical
1.4310	C700	700–800	~400	45
	C850	850–1000	~600	35
	C1000	1000–1150	~750	30
	C1150	1150–1300	~900	20
	C1300	1300–1500	~1100	12

## Stress- strain properties of stainless steel

Stress – strain properties of stainless steel are different than carbon steel in many ways. The form of the stress-strain curve is the most important difference. Carbon steel usually shows linear elastic behaviour up to yield point and thereafter a plateau before nonlinear stress-strain (deformation hardening) curve. Stainless steel behaves nonlinearly all the way without such clear change from linear to non-linear. This is the reason why the ‘yield point’ in stainless steels is defined as a certain percentage of permanent strain (conventionally the 0,2% strain), a proof strength, defined as indicated in the Figure 2.

Fig. 2 shows typical experimental stress-strain curves. They are representative for just that type of material and they are not to be used for the design. Because of its exceptional ductility (especially the austenitic ones) and its deformation hardening capability stainless steels can tolerate noticeable local deformations on the surface.

**Fig. 2** Typical stress-strain curves for stainless steel and carbon steel (for longitudinal tension) [1]



The strength of austenitic and duplex materials is increased through cold working. The 50% increase of proof strength (0.2%) can be considered as typical for cold-formed corner in a profiled plate. This effect on strength is very local and the increase in the components load bearing capacity is depending on where the higher strength corner is situated in the component or its cross section. The increase in the material strength compensates well the effect of local thinning of the material because of the forming process.

## Corrosion resistance

When using stainless steel as a construction material it is important to remember that stainless steel can corrode in some circumstances. It is therefore important that the designer make the correct choice of steel, filler material, welding procedure and post weld cleaning for a certain exposure environment to avoid later corrosion problems. The most frequent stainless steel corrosion types occurring in constructions are pitting and crevice corrosion although the discussion will also cover galvanic corrosion of carbon steel.

Pitting is often localized to the weld area due to weld tint, spatter, unintentional arcing and coarse grinding, Figure 3a. Crevice corrosion might occur in overlap joints, flanges, root weld defects and under deposits.

Galvanic corrosion of carbon steel can take place if it is welded to stainless steel and if both materials are immersed in a corrosive environment, e.g. water. To avoid this the carbon steel surface should be coated, e.g. painted, and so also the stainless steel surface to a distance of about 10–20 cm from the joint.

Another common phenomenon is extraneous corrosion, i.e. corrosion of carbon steel, which has contaminated the stainless steel surface. Reasons can be that tools or lifting devices have been used for the handling of both carbon steel and stainless steel or just carbon steel dust in a workshop without separation of the two materials, Figure 3b.

**Fig. 3** Different corrosion types in stainless constructions: a) Pitting in non-sufficiently cleaned welds, b) Extraneous corrosion due to contamination with mild steel.



Stress corrosion cracking (SCC) is normally not a problem within the building and construction industry, but one such problem should still be emphasised, SCC in load bearing structures in swimming pool buildings. Volatile compounds, mainly chloramines, can precipitate on cold metal surfaces and cause a special type of SCC, occurring at ambient temperatures.

### **Welded structures – different design criteria, applications**

Welded constructions of stainless steel differ somewhat from corresponding carbon steel constructions. The main differences are found in weld methods, choice of filler material, limitation of weld energy, tack weld technique, cleaning afterwards and sometimes post weld heat treatment. Welding processes are discussed in a separate chapter. When constructing stainless steel details it is very important that weld types and weld procedures are being used, which prevent weld defects at the weld root. Noticeable defects will strongly decrease the corrosion resistance of the weld if exposed to a corrosive environment. Such defects are also detrimental for the mechanical strength of the joint, especially the fatigue strength.

A welded joint is always a potential impairment for the construction. It is therefore highly recommended to place joints in mildly loaded parts of a component. A typical case is not to place a weld at a corner. If there is a risk for sediment on bottom of a tank, it may be possible to design the welded detail so that welded joint is not exposed to unnecessary difficult corrosive environment. Stainless steel deforms easier during the welding process than carbon steel. This is due to the difference in thermal expansion and thermal conductivity. This effect appears most often when welding thin materials. It is therefore important to weld with methods that introduce less heat into the weld. Automatic welding with laser or TIG is recommended. Semi-automatic welding shows also interesting results as the new MIG/MAG facilities on the market can already be used for welding down to 1 mm material thickness. Welding is performed at such a low heat input that deformation and buckling of the material can be avoided or reduced.

There are good applications where stainless steel is used as a replacement for traditional carbon steel. The use of stainless steel is expected to increase in the future in areas like:

- Where the difficulty or cost of maintenance makes other alternatives uneconomical in the life cycle cost analysis

- When structural integrity in critical components is important and the inspection routines are either costly or impossible to follow
- Where the good mechanical properties of stainless steel, like e.g. high strength, can be combined with inherent excellent corrosion properties
- When aesthetic appearance is of high importance

Good examples where all of these aspects can be combined are bridges where carbon steel is still the traditional first choice material, but where the most advanced new constructions using duplex stainless steel as a construction material are beginning to appear, see Fig. 4.

**Fig. 4** Stainless steel bridge in Menorca, Spain. The material is EN 1.4462 (2205) duplex stainless steel.

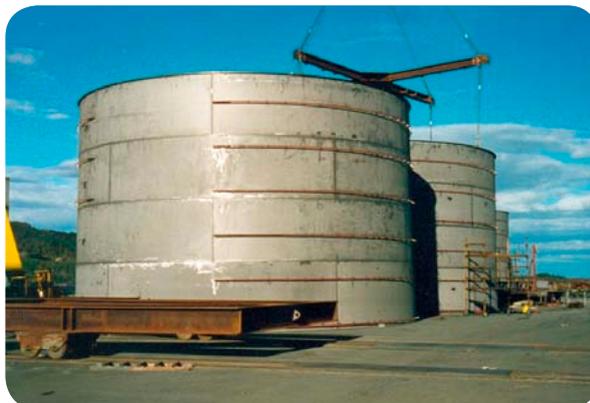


When designing tanks containing liquids the high strength of duplex stainless steels can be utilized, Figure 5. Proof strengths of 400–500 MPa for duplex stainless steels make it possible to reduce the plate thickness of the walls and in thus spare money by using duplex steel EN 1.4462 (2205) instead of the ‘standard’ stainless EN 1.4401 (316). The same goes for many other load bearing structures, e.g. bridge components, see Fig. 6 where the high strength, good weldability and good ductility of duplex stainless steels can be utilized.

Several accidents due to failures in load bearing structures in swimming pools buildings show that the risk of SCC makes the normal austenitic grades such as 1.4306 and 1.4404 unsuitable for several such applications in certain environments. Test results show that grades EN 1.4547, EN 1.4529 and EN 1.4565 are suitable for critical load-bearing components in pool hall atmospheres that are not washed or cleaned frequently. This is in agreement with the requirements of the German building code. As a result of their microstructure, duplex grades are more resistant to SCC than the standard austenitic grades. There are some recent examples in the UK of flumes being suspended with super duplex grade EN1.4507 stranded wire. There are also examples of duplex grade 1.4462 (2205) giving satisfactory performance in safety critical, load-bearing swimming pool applications. [5].

Stainless steels are on their way to be used in car components as well. Automotive vehicle structural crashworthiness is defined as the capability of an automotive structure to provide adequate protection for the vehicle and its passengers in the event of a crash. The vehicle structure and the occupant restraint system interact to protect vehicle occupants. The structure needs to maintain enough space inside the vehicle so that the occupant restraints can operate effectively. One very potential component for stainless steel is front bumper

**Fig. 5** Storage tanks of duplex stainless steel.



**Fig. 6** A bridge detail of duplex stainless steel EN 1.4462 (2205)



support, which requires very good energy absorbing capability. In a Swedish project one has succeeded in creating a stainless steel bumper support construction that is 26% lighter than the existing structure keeping the costs the same and having the same energy absorbing capacity. The material is HyTens from Outokumpu.

Mixed joints with carbon steel are possible in most cases. However, use of over alloyed filler material is then often required. In case of heavy gauges in austenitic grades a small risk for hot cracking does exist. This is quite typical welding defect for austenitic stainless steels. It can be avoided by using a filler material, which gives 2–10% ferrite in the weld metal. In EN 1011-3 some other overall recommendations are given for handling and welding of stainless steel.

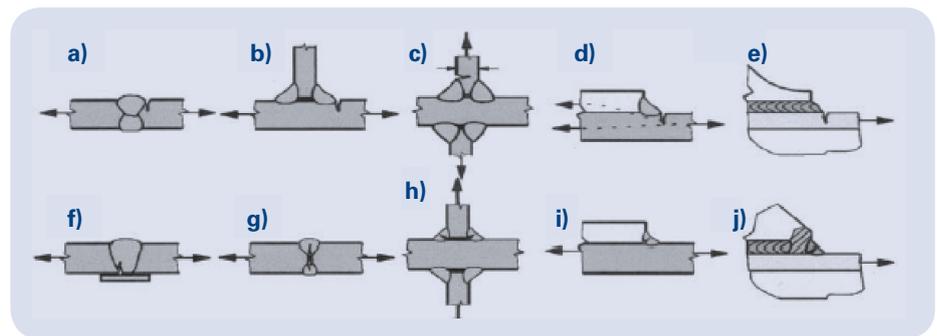
Stainless reinforcing steels, rebars, are inherently resistant to corrosion. The use of stainless rebars significantly decrease the demand for inspection and maintenance, and consequently also the cost, of structures facing a risk of rebar corrosion. Stainless steel rebars are also resistant to high chloride ion contents in concrete and they do not need an extra coating for corrosion protection. By using stainless steel rebars the maintenance, traffic problems and reparations can be reduced. All this can lead to cost reductions [6].

### Design against fatigue

Fatigue phenomenon is especially important for components or details in structures that are subjected to load/stress variations. Typical constructions or structures which face the risk for fatigue are lifting arrangements, bridges, cars, vibrating machines or components that are exposed to wind loads like high towers and masts. This list can be quite long. It is often said that fatigue is the most common cause of failure in structures and machine components. Like in carbon steel constructions the combination of stress concentrations and defects at welded joints makes them the most risky details in construction, see Fig. 7. The factors, which have stress increasing effect, can be classified to following three categories:

- Macro-geometric effects
- Structural discontinuities
- Local notches (at weld toe)

Macro-geometric effects occur usually in large structures and they cause concentration of membrane stresses and formation of secondary shell bending stresses. They are never readily included in the S-N data gained from usual fatigue test pieces. Structural discontinuities are features included in many test specimens. The effects are similar to those caused by macro-geometric features but they occur within a smaller region.

**Fig. 7** Typical initiation points for fatigue cracks.

Typical fatigue crack initiation points are the contact areas between weld material and base material, weld toe, Fig. 7. You can almost always find there a small initial crack or crack like fault which starts to grow under fatigue loading. These structural details can be classified according to standardized fatigue classes. From fatigue point of view the best would be detail a), butt weld, and the worst one either h), load carrying fillet weld, depending on the weld type and quality, or d), welded reinforcement.

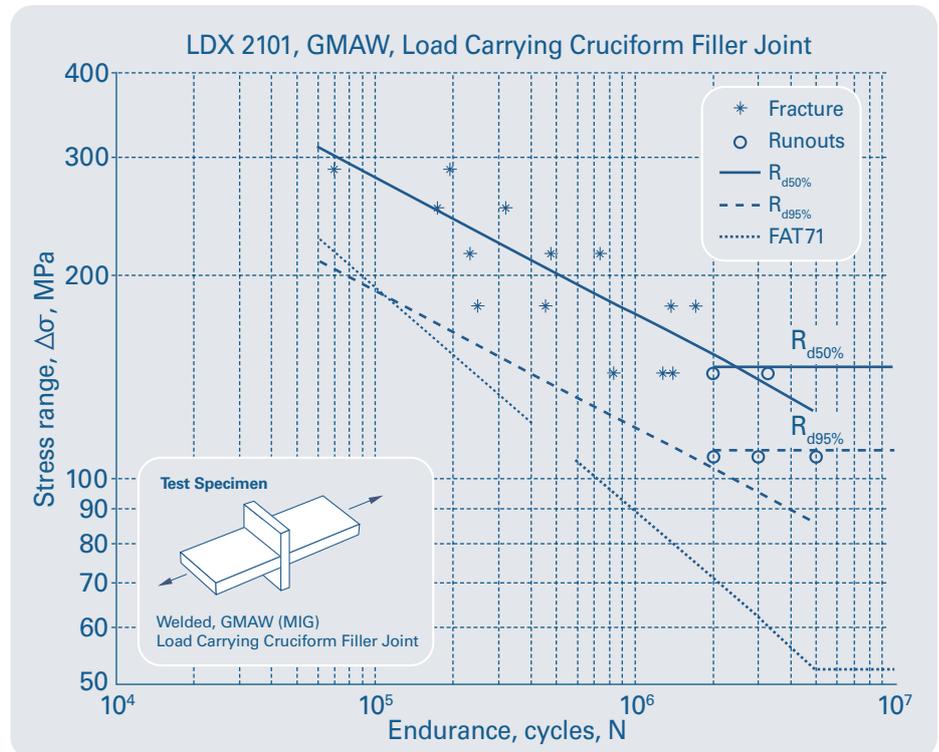
The most used fatigue life estimation method is more or less similar in all modern fatigue standards. The standards include tables for choosing the most correct welded joint type, like those in Fig. 7. The welded joints are grouped to several fatigue classes (FAT) and each class is represented by S-N-curve, like the one in Fig. 8, FAT 71, detail c in Fig. 7. Examples of joint classification can be found e.g. in ENV 1993-1-1, Ch. 9. After the classification of the joint S-N-curve parameters are given and the fatigue life can be calculated. Instructions how to calculate fatigue strength of a component or a detail in carbon steel constructions are valid also to stainless steel, see Chapter 9 in ENV 1993-1-1, which is going to be replaced by EN 1993-1-9.

By following good design practice a lot can be done to reduce the sensitivity for fatigue. This is in the first hand a question of appropriate detail design, having a consecutive design strategy of choosing a structural detail that has as good fatigue strength as possible. The key to good fatigue design is to take fatigue into account early in the design process. It still happens that fatigue is checked only after the other design criteria are fulfilled. This can lead to inadequate design from fatigue point of view or costly re-design of the structure.

It is also important to take the manufacturing and installation process into account. A miss in e.g. welding the detail can lead to a defect that causes a potential fatigue crack initiation/growth leading in the best case to unplanned and hence costly repair work. These potential risky details must be pointed out for the manufacturer in order to get the best possible result. This is especially important for details like lifting brackets or holes.

Fatigue properties of duplex stainless steel are at least as good as for carbon steels. Fig. 8 shows test results for a relatively new duplex stainless steel LDX 2101.

**Fig. 8** Example of fatigue test results for the new duplex stainless steel LDX 2101.



It is possible to avoid fatigue problems and in worst case structural failure by concentrating on construction details, their design and manufacturing, and by avoiding:

- Abrupt changes in cross sections leading to stress concentrations
- Angular misalignment and eccentricity in welded details
- Small discontinuities like scratches and grinding marks, especially perpendicular to principal stresses
- Unnecessary welding of lifting brackets
- Imperfect welding, fillet welds, tack welds, etc.
- Unintentional arcing
- Crater cracks at electrode ends
- Placing the welds at high stress areas like corners
- Too sharp weld toe angles
- Oversized welds.

## Welding of stainless steels

### General

The most common austenitic stainless steels used for construction purposes have all very good weldability. In Table 3 some of the weldability factors for the different steels are given. The most discussed weldability factor when welding carbon steel or martensitic stainless steel is the problem with hydrogen cracking. This phenomenon sometimes appears in the heat-affected zone, HAZ, of heavy wall constructions (>20mm). High strength carbon steels with carbon equivalents (CEV, IIW) above 0.4 are consequently welded mostly with preheat (>75–150°C). It is also important to use filler materials with low hydrogen content (< 5ml/100g weld metal). These phenomena do not exist when welding austenitic and most duplex materials.

It is recommended that a fabricator uses a quality system for the welding operation. The new international QA system, ISO 3824 gives a good guideline for the fabricator. In this standard procedures for qualifying welders, qualification of welding procedures as well as quality requirements for different constructions are given. For fabrication of steel constructions, a new standard is now almost ready for publication, prEN 1090-2. This new standard can also be used for stainless steel structures. The standard contains technical requirements for execution, fabrication, welding, erection and cleaning for different execution classes.

It is important that welds in stainless steels as well as welds in other materials are free of defects to secure mechanical strength. Stainless steel welds must also fulfil the requirements for corrosion resistance.

This means that the surface of the steel or the weld area must be free from contamination or surface defects, which otherwise might cause localised corrosion. Requirements are given in for example EN 25817. Examples of surface defects are iron contamination, coarse grinding, spatter and unintentional arcing as well as heat tint. It is often advantageous that the design engineer specifies the as-welded profile and surface condition required. This may influence the choice of welding process or post weld treatment.

### Weldability

Weldability of some steel grades.

Table 3

Micro-Structure	Steel Type	Filler	Working/ Welding Temperature	Hydrogen Cracking	Grain Growth	475°C - Embrittlem.	Hot Cracking
Martensitic	1.4021/420	Austenitic (martensite.)	200 – 400°C (200 – 400°C)	Very sensitive	No	No	No
Ferritic	1.4016/430	Ferritic Austenitic	200–300°C RT	Sensitive	Yes	Yes	No
Austenitic	1.4401/316	Austenitic	RT	No	No	No	Some
	1.4539/904L	"	RT	No	No	No	Some
	1.4845/310S	"	RT	No	No	No	Yes
Duplex	1.4462/2205	Duplex	RT	No	Some	Yes	Small
Carbon Steel		Ferritic	RT to 150°C Dependent of thickn. and C-ekv.	Sensitive	Yes	No	Some
Mixed joint	C-Steel to Stainl. steel	Over alloyed		Some			Small

### Welding processes

The common used fusion methods can be used for welding of stainless steels. When welding thin gauge materials GTAW, PAW and Laser are the most used methods. The development of the GMAW equipments has now given the operators the possibility to use this method down to 1.0 mm. This increases productivity when welding in the field compared to GTAW. When welding heavier gauges on site the trend today is to use flux-cored wires. They give the welder good weld pool control and a high productivity. Thin walled constructions may be designed with an overlap joint. In such cases resistance spot/seam welding are often used due to high productivity. The design engineer must however be aware of the risk of crevice corrosion.

## Consumables

### 1. Duplex steels

Duplex steels should be welded with designed fillers. This optimizes microstructure, mechanical properties and corrosion resistance. The following fillers are recommended.

Parent material	Filler: Avesta Welding
LDX 2101	LDX 2101
SAF 2304	2304 / LDX 2101 / 2205
2205	2205
SAF 2507	2507 / P100

### 2. Austenitic steels

The steels presented in this article have all very good weldability. They can be welded autogenously or with the use of filler. Recommended fillers are shown below.

Parent material	Filler: Avesta Welding
1.4310	308L/MVR
1.4301 (304)	308L/MVR
1.4404 (316L)	316L/SKR
1.4571 (316Ti)	316L/SKR

### 3. Ferritic steels

These steels do not have the same good weldability as the other presented.

The sensitivity to grain growth implicates the need to weld with very low heat input. They are mostly welded with austenitic fillers to give a weldment as high ductility as possible. They are also limited in thickness.

## Welding distortion

In common with other metals, stainless steel suffers from distortion due to welding. However, the distortion of stainless steel, particularly austenitic grades, is greater than that of carbon steels due to a higher coefficient of thermal expansion and lower thermal conductivity. Welding distortion can only be controlled, not eliminated. The designer and fabricator can take some actions to reduce distortion. Few beads, small joints, symmetric joint configuration, pre-setting of the plates, clamping jigs, back stepping and by using a welding process that gives a narrow weld (e.g. Laser) are examples that can be used to reduce weld distortion.

## Post weld cleaning

Post weld cleaning is an important and very often forgotten item. Adequate cleaning is essential if optimum corrosion resistance is required or if an architect has chosen stainless steel for aesthetic reasons. It is therefore important for the designer to define the required post weld cleaning for avoiding cost overruns and possible poor service performance. Commonly used cleaning processes are, brushing, grinding + polishing and cleaning with pickling products. Pickling gives the highest corrosion resistance. It is often good practice to combine mechanical and chemical processes. Coarse grinding can on the other hand reduce the corrosion resistance of the welded joint. Even the fatigue properties might be reduced if coarse grinding is used as the final operation.

If the architect has chosen the stainless welded construction for aesthetic reasons, the cleaning of the weld area might be a very important matter in practice. The first and easiest way is to try to make the weld invisible. If this is not possible, the surface appearance after treatment should be as similar as the original delivered condition. For example, if polishing is the final treatment the steel could be delivered as polished.

A deco or pattern rolled surface should not have exposed welds because they will normally not be accepted from an aesthetic aspect after a cleaning operation. And the same philosophy should be applied if the surface of the steel is cold rolled skin passed. Such a bright shiny surface will after welding and cleaning mostly give a dull appearance of the weld area.

### Post weld heat treatment (PWHT) of welded joints

From the material point of view, it is very unusual to heat treat stainless steel after welding. It is very often the case that more problems appear after PWHT than what was to be solved with the operation. Duplex steels are more difficult to PWHT than standard austenitic steels. By this reason PWHT is not recommended..

If the construction must be heat treated to reduce weld stresses, quench annealing at 1050–1100°C is recommended. If this procedure is used it is important that the construction has a suitable form and that the cooling can be performed uniform and rapidly. A certain grade of reduction of weld stresses can be obtained by PWHT at 450–480°C during 2–10 hours depending on the material thickness. This low temperature range is not suitable for duplex steels.

Welded constructions in EN 1.4462 loose strength at temperatures above 900°C. This may cause deformation due to the own weight effect. Quench annealing requires consequently that the construction is supported during the heat treatment. The cooling after PWHT of duplex constructions must be rapid to avoid embrittlement due to sigma phase precipitates. Water quenching is recommended. Stress relieving at 600–650°C can be carried out if the steel has low carbon content (< 0.030) or if it is stabilized. The holding time can be 0.5 – 4 hours depending of the material thickness.

### Summary

The important properties in stainless steel compared to carbon steel for constructional use are:

- No specific yield point like carbon steels,  $R_{p0.2}$  (or sometimes  $R_{p1.0}$ ) are used instead
- Stainless steel has generally better toughness than carbon steels
- Stainless steel deform hardens much more than carbon steel – especially the austenitic ones
- Some specific design methods like using secant modulus instead of Young's modulus when calculating beam bending
- Detail design and fabrication is important for the fatigue properties like it is for carbon steels
- Post weld cleaning is important for corrosion and aesthetical reasons
- Stainless steels are more sensitive to high heat inputs during welding
- To design and construct using stainless steel is not difficult, it is just a bit different.

In conclusion it is appropriate to refer to Mr. Payet-Gaspard's words [7]:

*“Stainless steel is one of the construction industry's trump cards. With stainless steel, the imagination is liberated, boldness and safety are reconciled and creative passion and responsibility become allied... Architects should not hesitate to use stainless steel in building construction. Those who dare will win, every time.”*

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