Stainless Steel Hollow Sections Handbook

Stala Tube

Outokumpu

FCSA
Finnish Constructional Steelwork Association

Stainless Steel Hollow Sections Handbook

Editor:
M.Sc. (eng.) Pekka Yrjölä,
Finnish Constructional Steelwork Association Ltd
Design:
Teemu Seppänen

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Foreword

This **Stainless Steel Hollow Sections Handbook** is based on the European Eurocode standards and particularly on the stainless steel part, standard EN 1993-1-4:2006 which is intended to be used mainly in the design of building and civil engineering works. Instructions presented for stainless steel hollow sections in this handbook can also be used for the design of other stainless steel load-bearing members and selection of materials where applicable. The handbook is the first extensive reference book on the design of stainless steel hollow section components.

The objective of the handbook is to facilitate the selection of stainless steel as a structural material for hollow sections. The handbook contains useful information on stainless steels, structural hollow sections made of stainless steels and their properties such as corrosion resistance, strength, weldability and formability. Separate sections have been dedicated to the design of structures and costs. The handbook can be used for everyday work routines and also as learning material.

The content of the handbook has been compiled by M.Sc. (eng.) Pekka Yrjölä, who works as Senior Technical Advisor on the structural design of stainless steel structures in the Finnish Constructional Steelwork Association. The members of the workgroup responsible for producing the handbook are M.Sc. (eng.) Jukka Säynäjäkangas, Outokumpu Tornio Works, Engineer Bengt Slotte, Oy Outokumpu Stainless Tubular Products Ab and M.Sc. (eng.) Kenneth Söderberg, Stalatube Oy. The following people participated in the formulation of, and commenting on, the handbook: M.Sc. (eng.) Tero Taulavuori, M.Sc. (eng.) Minna Sellman and M.Sc. (eng.) Pekka Vainio, Outokumpu Tornio Works,

MA CEng MICE Nancy Baddoo, The Steel Construction Institute (SCI), M.Sc. (eng.) Jouko Kouhi and D.Sc. (tech.) Olli Kaitila, Finnish Constructional Steelwork Association, M.Sc. (eng.) Asko Talja VTT Technical Research Centre of Finland, M.Sc. (eng.) Antero Kyröläinen, Steelpolis Oy, Lic.Sc. (tech.) Asko Kähönen, Engineer Hans Storbacka, Oy Outokumpu Stainless Tubular Products Ab and M.Sc. (eng.) Petteri Maaranen, Engineer Jari Maukonen and Production development specialist Jukka Nyyssönen, Stalatube Oy.

This handbook contains sections from the publication ”Ruostumattomat Teräkset”, which is a special edition of the raw materials handbook series created by the Finnish Federation of Technology Industries and published by Teknologiainfo Teknova Oy. The sections quoted are from the first part of the metals handbook (in finnish) (Raaka-ainekäsikirja, osa 1, Muokatut teräkset, ruostumattomat teräkset). The translation was carried out by CoCom Corporate Communications Oy. B.Sc. (arch.) Teemu Seppänen was responsible for the page layout and cover design of the handbook. The handbook has been printed and bound by Libris Oy. We wish to thank everyone for participating in the development of this handbook.

The steering group looks forward to receiving feedback on the contents of this handbook which they will take into account in the development of the next edition.

Helsinki, Finland 1 March 2008
Finnish Constructional Steelwork Association FCSA

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1. Introduction

Stainless steel has established its position as a structural material by having excellent corrosion resistance properties, good long-term durability, hygiene and mechanical strength. Stainless steel grades are regularly used in heavy machinery and in the processing and transport vehicle industries as a material for the frames and bodies of machines and equipment, tanks and railings. The use of stainless steel in building industry applications such as façades and other visible structures has also increased.

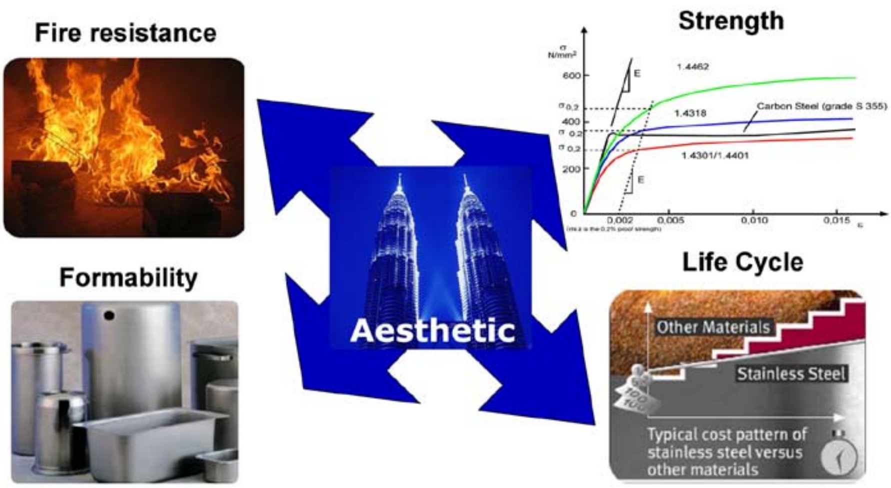
Stainless steel is a suitable choice as a construction material when durability, long lifespan, easy maintenance and aesthetic appearance are required characteristics for a structure. Stainless steel is also a safe choice for concealed structures where inspection is difficult, which can be damaged by moisture if materials with lower corrosion resistance are used.

The chromium (Cr) content of stainless steel is at least 10,5 % / EN 10088-2:2005/. The most commonly used stainless steel grades, however, have a chromium content of 17–18 %, which ensures good corrosion resistance and condition of the surface in a number of different applications. The durability of stainless steel in corrosive environments is based on the passive layer of the steel surface. The passive layer is created when chromium in the metal oxidises, and it protects the surface so that no other protection against corrosion is required. If the surface is damaged, the passive layer quickly reforms due to the reaction of the chromium with the oxygen in the air.

The basic alloying elements of stainless steel grades are chromium (Cr) and nickel (Ni). In addition, stainless steel includes other alloying elements such as molybdenum (Mo), titanium (Ti) and manganese (Mn). The alloying elements define the stainless steel grade and affect the mechanical and anti-corrosive properties. The basic stainless steel types classified on the basis of their metallurgical structure are austenitic, ferritic, austenitic-ferritic (duplex), martensitic and precipitation-hardening stainless steels. Austenitic, duplex and ferritic steel types are used in structural applications. The mechanical properties and corrosion resistance of different steel types are specified in standards, instructions and regulations.

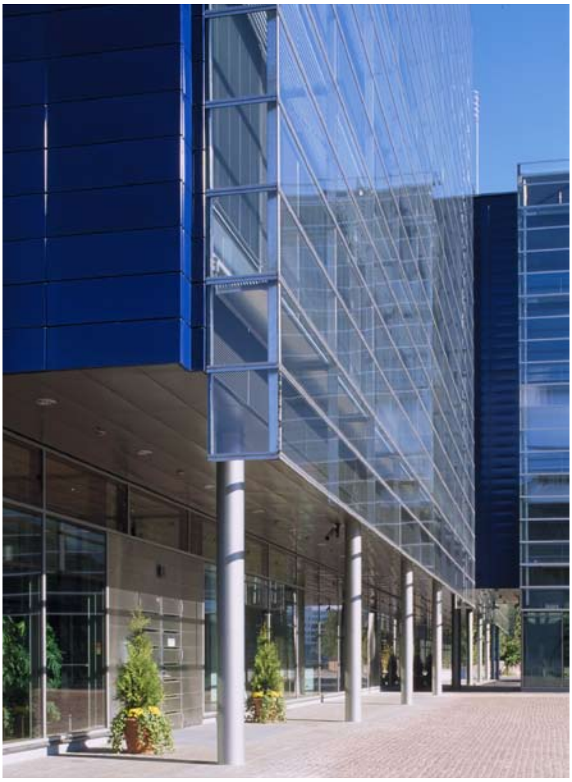
Austenitic steel grades in particular have a strong tendency to work-harden during cold working. As a result of work-hardening, the design strength of austenitic stainless steel hollow sections can be increased to correspond to the enhanced strength. In addition, the mechanical strength values of austenitic steels remain high across a wide range of temperatures, which can be useful in the design of certain structures.

It must be noted that the selection of the stainless steel grade requires simultaneous consideration of the mechanical strength, formability, functionality, corrosion resistance and surface finish. Therefore, it is recommended that special attention is paid to the selection of the particular grade of stainless steel. The purpose of Stainless Steel Hollow Sections Handbook is to give guidance to choose suitable stainless steel grade for the application.



2. Use of stainless steel hollow sections

Supporting structures for facades



Columns visible

Supporting structures for roofs

Railings

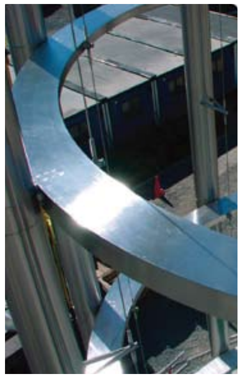
Residential construction

Transportation

Machinery for food industry

Industry buildings





Road and traffic route structures



3. Stainless steels

Steel is classified as a stainless steel if its chromium (Cr) content is a minimum of 10,5 % /EN 10088-2:2005/. There are approximately 200 standardised stainless steel grades which have been developed for a number of uses, many in highly demanding environments in the processing industry. The stainless steel types are classified on the basis of their metallurgical structure. The types are austenitic, ferritic, austenitic-ferritic (duplex), martensitic and precipitation hardened stainless steels. Stainless steel grades used in structures are presented in Table 3.1.1.

3.1 Stainless steel grades as hollow section material

The most commonly used materials for stainless steel hollow sections are austenitic grades 1.4301, 1.4307, 1.4404 and 1.4571. Stainless steel hollow sections made of austenitic steel grades 1.4541, 1.4318, 1.4372, 1.4432 and 1.4539, duplex steels 1.4162, 1.4362 and 1.4462 and ferritic steels 1.4003 and 1.4509 are available mainly for specialist applications.

The surface finishes of stainless steel hollow sections are mainly in compliance with the definitions of the standard EN 10088-2:2005 if material for hollow section is ordered in accordance with this standard. Stainless steel hollow section manufacturers have their own works-specific surface finishing facilities, examples of which are presented in section 4.6. It is recommended that contact should be made with the stainless steel hollow section manufacturers when choosing the surface finish and samples requested of the surface finish of the finished product.

Austenitic steel grades are also classified as CrNi, CrNiMo, CrMn and high alloy austenitic steels depending on alloying quantity of nickel (Ni), molybdenum (Mo) or manganese (Mn) in addition to chromium (Cr).

Austenitic CrNi steel grades

- Typical alloying is 18%Cr-8%Ni.
- Austenitic CrNi steel grades are the most commonly used steels. The main applications are structures located in rural, urban and non-aggressive industrial environments. The most common CrNi grades are 1.4301, 1.4307, 1.4318 and 1.4541. The low carbon content CrNi version of these steels is 1.4307. Steel grade 1.4318 differs from the former with slightly lower contents of Cr and Ni and higher nitrogen (N) content. Thanks to its nitrogen alloy, the strength values of steel grade 1.4318 are higher than those of basic steel grades. A small amount of titanium (Ti) is alloyed in steel grade 1.4541, which enables the mechanical strength to be sustained at elevated temperatures and decreases the risk of sensitisation when welding thicker materials. Carbon content lower than 0,03 % or titanium stabilisation is recommended for wall thicknesses exceeding 6 mm. In terms of corrosion resistance, steel grades 1.4318 and 1.4541 are comparable to steel grades 1.4301 and 1.4307.

Austenic CrNiMo steel grades

- Typical alloying is 18%Cr-10%Ni-2,0%Mo.
- The most common application is in structures located in aggressive urban or industrial environments as well as marine climates. The common CrNiMo grades are 1.4401, 1.4404, 1.4571 and 1.4432. The basic steel grade is 1.4404 and its higher carbon content version is 1.4401. Steel grade 1.4571 contains titanium (Ti) as an alloying element that, also in the case of CrNiMo steel, improves the strength values of the material at high temperatures and decreases the risk of sensitisation when welding thicker materials. Steel grade 1.4432 contains a slightly higher amount of molybdenum (Mo) as alloying element than the previously mentioned steel grades, which improves resistance to pitting. Therefore, this steel grade is most commonly used in more demanding industrial environments and marine climates.

Austenitic CrMn steel grades

- Typical alloying is 17%Cr-4%Ni-7%Mn-0,20%N.
- American standards have established the name '200 series steels' for these CrMn steels. The nickel content of these steels is decreased and austenitic crystal structure maintained by replacing nickel with manganese and nitrogen. CrMn steel grade 1.4372 has almost the same formability, corrosion resistance and weldability as grade 1.4301, but with better strength properties. Corrosion resistance, formability and weldability of less alloyed CrMn steels differ from those of CrNi steels depending on the alloying. Experience of the suitability of CrMn steels for applications already exists and can be requested from the steel mills and stainless steel hollow section suppliers.
- The following information bulletins on CrMn steel grades have been published: "New 200 Series Steel, an Opportunity or a Threat to the Image of Stainless Steel, ISSF, 2005" and "200 Series Stainless Steels CrMn Grades, ASSDA, 2006"

High alloy austenitic steel grades

- High alloy austenitic steel grades can contain over 50 % of alloying elements. No typical alloying element content can be given to describe these steel grades which have been developed for demanding corrosive environments. The main application area for high alloy austenitic steel grades is in highly demanding processing equipment and structures for aggressively corrosive industrial and marine environments.
- High alloy austenitic steel grades 1.4539, 1.4529, 1.4547 and 1.4565 are suitable for load-bearing structures located in climates with high chloride content which cannot be regularly cleaned, e.g. suspended ceilings above swimming pools (EN 1993-1-4:2006).
- Other advantages of high alloy steel grades are the extreme corrosion resistance amongst stainless steels and reasonable mechanical strengths of the annealed material.
- The availability of high alloy austenitic stainless steel hollow sections must be checked on a case-by-case basis.

Austenitic-ferritic steel grades: duplex

- Typical alloying is 22%Cr-4%Ni-3%Mo
- The alloying element content of duplex steel grades is defined in the same way as that of high alloy austenitic stainless steels: mainly in compliance with the requirements of the corrosive environment.
- The main application of medium alloyed duplex steel grades 1.4362, 1.4462 and 1.4410 is in structures located in aggressive industrial and marine environments and in the structures of bridges for bicycle and pedestrian traffic.
- The increasing use of stainless steel in load-bearing structures has created demand for new duplex steels ("lean" duplex), in which the mechanical and corrosion properties of duplex grades are achieved with a lean alloyed chemical composition. The low alloyed "lean" duplex steel grade 1.4162 is suitable for several structural applications.
- An advantage of duplex steels is their high mechanical strength, which is about twice as high as that of annealed austenitic steel grades.

Ferritic steel grades

- The ferritic grades used in hollow sections typically contain 10,5 %–18 % Cr. The content of chromium used as an alloying element is directly correlated with the corrosion resistance of the material. The most corrosion resistant grades of ferritic stainless steels include a small quantity of molybdenum.
- Steel grade 1.4003 is the most common material (10,5 %Cr) for ferritic stainless steel hollow sections. Another important stainless steel hollow section material is 1.4509 (18 %Cr). The use of other ferritic steel grades in hollow sections is rare.
- The use of steel grade 1.4003 unprotected in outdoor applications is suitable with modest requirements for surface appearance. The most typical application of hollow sections made of this steel grade is the load-bearing body and enclosure structures of buses.
- The thermal expansion coefficient of ferritic steel grades is smaller that that of austenitic steels and the value corresponds to that of carbon steels. Ferritic stainless steel grades are not susceptible to stress corrosion. Their impact strength at low temperatures and elongation after fracture are lower than those of austenitic steel grades.
- A publication on ferritic steel grades is: "The ferritic solution, properties, advantages, applications, ISSF, 2007".

Table 3.1.1. The most common stainless steel grades.

	Steel [2]			Typical chemical composition, %						$R_{p0,2}$ [N/mm²]	$R_{p1,0}$ [N/mm²]	Rm [N/mm²]	A_5 [%]	KV [J]	Description
[1]	EN	ASTM	OUTOK	C	N	Cr	Ni	Mo	Muut	RT [3]	RT [3]	RT [3]	RT [3]	RT [3]	
Ferritic stainless steels	**1.4003**	S40977	4003	0,02	-	11,5	0,5	-	-	280	-	450	20	-	12Cr multi-purpose stainless steel
	1.4016	430	4016	0,04	-	16,5	-	-	-	260	-	450	20	-	17Cr multi-purpose stainless steel
	1.4509	S43940	4509	0,02	-	18	-	-	Ti+Nb	230	-	430	18	-	18Cr multi-purpose stainless steel
	1.4512	409		0,03	-	11	-	-	Ti	210	-	380	25	-	Exhaust pipe and catalyzer stainless steel
	1.4521	444		0,02	-	18	-	2	Ti+Nb	300	-	420	20	-	Hot water accumulator stainless steel
Duplex steels	1.4162	S32101	LDX 2101®	0,03	0,22	21,5	1,5	0,3	5Mn	450	490	650	30	60	Low-alloy duplex steel
	1.4362	S32304	2304	0,02	0,10	23	4,8	0,3	-	400	-	630	25	60	Low-alloy duplex steel
	1.4462	S32205	2205	0,02	0,17	22	5,7	3,1	-	460	-	640	25	60	Medium-alloy duplex steel
	1.4410	S32750	2507	0,02	0,27	25	7	4	-	530	-	730	20	60	High-alloy duplex steel
Austenitic CrNi and CrMn steels	**1.4318**	301LN	4318	0,02	0,14	17,7	6,5	-	-	350	380	650	40	60	N-alloyed multi-purpose stainless steel
	1.4372	201	4372	0,05	0,15	17	5	-	6,5Mn	350	380	750	45	60	Mn-alloyed multi-purpose stainless steel
	1.4301	304	4301	0,04	-	18,1	8,3	-	-	210	250	520	45	60	Multi-purpose stainless steel
	1.4307	304L	4307	0,02	-	18,1	8,3	-	-	200	240	500	45	60	Low-carbon multi-purpose stainless steel
	1.4311	304LN	4311	0,02	0,14	18,5	10,5	-	-	270	310	550	40	60	Nitrogen alloyed stainless steel
	1.4541	321	4541	0,04	-	17,3	9,1	-	Ti	200	240	500	40	60	Ti stabilised stainless steel
	1.4306	304L	4306	0,02	-	18,2	10,1	-	-	200	240	500	45	60	Low-carbon stainless steel
Austenitic CrNiMo steels	**1.4401**	316	4401	0,04	-	17,2	10,2	2,1	-	220	260	520	45	60	CrNiMo steel
	1.4404	316L	4404	0,02	-	17,2	10,1	2,1	-	220	260	520	45	60	Low-carbon CrNiMo steel
	1.4436	316	4436	0,04	-	16,9	10,7	2,6	-	220	260	530	40	60	High molybdenum CrNiMo (2,6Mo) steel
	1.4432	316L	4432	0,02	-	16,9	10,7	2,6	-	220	260	520	45	60	Low-carbon, high molybdenum CrNiMo (2,6Mo) steel
	1.4406	316LN	4406	0,02	0,14	17,2	10,3	2,1	-	280	320	580	40	60	Nitrogen alloyed CrNiMo steel
	1.4571	316Ti	4571	0,04	-	16,8	10,9	2,1	Ti	220	260	520	40	60	Ti stabilised CrNiMo steel
	1.4435	316L	4435	0,02	-	17,3	12,6	2,6	-	220	260	520	45	60	Low-carbon CrNiMo steel
Austenitic high alloy steels	**1.4439**	317LMN	4439	0,02	0,14	17,8	12,7	4,1	-	270	310	580	40	60	Special stainless steel for the chemical industry
	1.4539	N08904	904L	0,01	-	20	25	4,3	1,5Cu	220	260	520	35	60	e.g. tension load bearing structures in swimming pools
	1.4529	N08926	4529	0,02	0,20	20	25	6,5	0,5Cu	300	340	650	40	60	e.g. tension load bearing structures in swimming pools
	1.4547	S31254	254 SMO®	0,01	0,20	20	18	6,1	Cu	300	340	650	40	60	e.g. tension load bearing structures in swimming pools
	1.4565	S34565	4565	0,02	0,45	24	17	4,5	5,5Mn	420	460	800	30	90	e.g. tension load bearing structures in swimming pools

[1] Classification on the basis of crystal structure (ferritic, duplex i.e. austenitic-ferritic, austenitic) or alloy.
[2] Steel grades EN 10088-2 / ASTM A240 / in compliance with Outokumpu. Mechanical values in compliance with EN 10088-2. Steel grades shown in bold are included in EN 1993-1-4. Other steel grades can also be used when design is based on section 7of the standard.
[3] Room temperature,minimum values.

3.2 Mechanical properties

Figure 3.2.1 presents typical stress-strain curves for stainless steel. The shape of the stress-strain curves is slightly non-linear and does not include a well defined yield point. For this reason, the yield strength for stainless steels is quoted as the proof strength defined at the 0,2 % permanent offset strain. Typical characteristics of stainless steels stress-strain behaviour are the work-hardening ability, a large value of elongation at fracture, and the high ratio of tensile strength to 0,2 % proof strength. These characteristics are the basis for enhancing the material mechanical strength values of austenitic grades by cold working; the yield and tensile strength values can be enhanced whilst maintaining adequate values for elongation and ductility.

The stress-strain curves of three stainless steels are given in Figure 3.2.1. The lowest curve portrays the stress-strain curve in the annealed condition for austenitic steel grades such as 1.4301 and 1.4401. The 0,2 % proof strength value of ferritic steel grade 1.4003 is similar to that of the austenitic grades mentioned above, but its elongation and tensile strength values are lower. The stress-strain curve for steel grade 1.4318 (17Cr-7Ni) is between the austenitic grades 1.4301/1.4401 and duplex steels. The 0,2 % proof strength of steel grade 1.4318 in the annealed condition corresponds to the carbon steel strength class S355. Duplex steel grades in the annealed condition are the strongest grades, as indicated by steel grade 1.4462 in Figure 3.2.1.

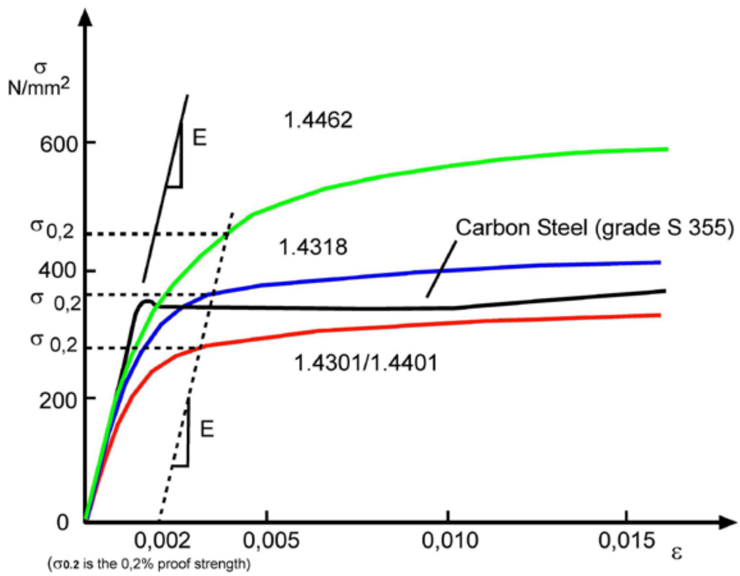


Figure 3.2.1. Typical stress-strain curves for stainless steel and carbon steel in the annealed condition / Design manual for structural stainless steel, Euro Inox, 2006/

The typical mechanical properties for austenitic steel grades as a function of degree of cold-working are presented in Figure 3.2.2. For austenitic steel grades, it is possible to obtain a yield strength of 355-500 N/mm², as is typical for structural steels, with moderate cold-working and without significantly changing the ductility properties of the material.

In compliance with EN 1993-1-4:2006, the nominal yield strength applied in design is limited to a maximum value of 480 N/mm². This limit, however, is valid only when designing in compliance with Eurocode standards. Stainless steel is widely used in industries other than the building industry and outside Europe in countries where local regulations may differ from EN 1993-1-4. It must therefore be taken into account that the yield strength of stainless steels higher than 480 N/mm² can be applicable.

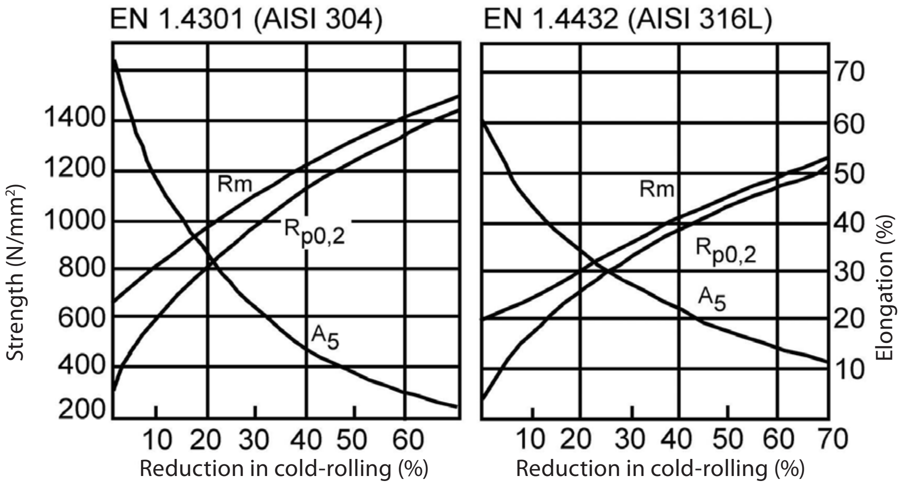


Figure 3.2.2. Mechanical properties of austenitic 1.4301 (left) and 1.4432 (right) stainless steels as a function of the degree of cold-working /Outokumpu Tornio Works /.

Anisotropy and asymmetry can be seen in the stress-strain behaviour of austenitic cold-worked steels. The lowest yield strength value is usually the longitudinal compression strength, i.e. the compression yield strength in the rolling direction. Stress-strain curves of typical cold-worked austenitic steels according to different stress types and directions are shown in Figure 3.2.3.

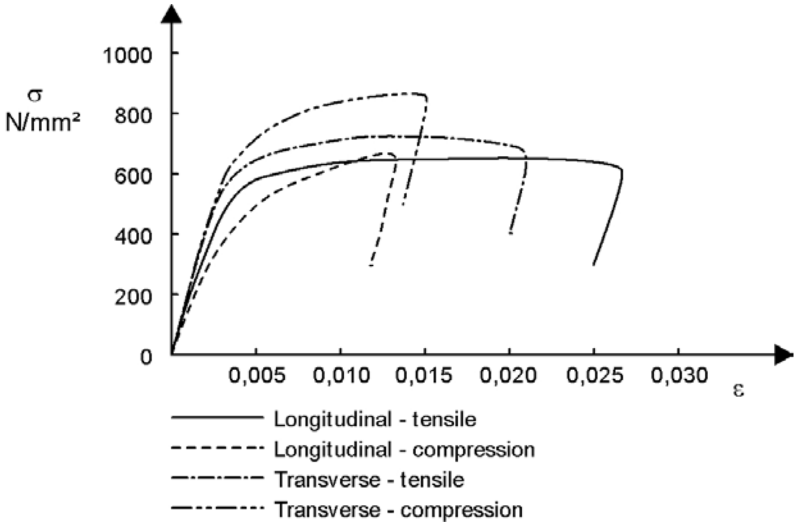


Figure 3.2.3. Typical stress-strain curves of cold-worked austenitic steel according to the rolling and loading directions / Design manual for structural stainless steel, Euroinox, 2006/

To take into account asymmetry of the cold worked material in those cases where compression in the longitudinal direction is a relevant stress condition (i.e. column behaviour or bending) and there exist no knowledge about the value of yield strength in that direction, the characteristic value should be taken as 0,8 x 0,2% proof strength in Table 3.2.1. A higher value may be used if supported by appropriate experimental data / Design manual for structural stainless steel, Euro Inox, 2006/.

Cold-worked stainless steels are classified in compliance with EN 10088-2 to strength classes either on the basis of the 0,2 % proof strength (e.g. CP350, in which 350 means R_p0,2,min = 350 N/mm²) or tensile strength (eg. C700, $R_{m,min}$ = 700 N/mm²). The strength classes used with structural calculations are defined in compliance with the standard EN 1993-1-4, the maximum yield strength being 480 N/mm². Materials with higher strength classes can be used if their properties are found to be appropriate in compliance with standard EN 1993-1-4 section 7. Table 3.2.1 shows the most commonly used strength classes and steel grades that satisfy the strength requirement.

Table 3.2.1. Cold-worked steels in compliance with EN 10088-2:2005 applicable when designing in accordance with EN 1993-1-4.

1)	$R_{p0,2}$ [MPa]	R_m [MPa]	Available steel grades in strip and plate products
CP350	350 - 500	-	1.4318 2), 1.4301, 1.4307, 1.4401, 1.4404
CP500	500 - 700	-	1.4318, 1.4301, 1.4307, 1.4401, 1.4404
C700	-	700 - 850	1.4318, 1.4301, 1.4307, 1.4401, 1.4404
C850	-	850 - 1000	1.4318, 1.4301, 1.4307, 1.4401, 1.4404
1) Property class in compliance with EN 10088-2, CP = proof strength, C = tensile strength			
2) Meets the property class requirements in soft annealed condition (designated 2B in EN 10088)			

3.3 Physical properties

The physical properties of stainless steels differ from those of carbon steel and among the grades of stainless steels. The most essential differences between the main stainless steel types lie in the thermal expansion coefficient and magnetic properties.

The value of thermal expansion coefficient for ferritic steels is close to that of carbon steels. However, the value for duplex steels is slightly greater and for austenitic steels the value is about 1.5 greater than that of carbon steels. Ferritic steels have the greatest thermal conductivity, which effect in practice can be seen as faster reactions of the material to changes in temperature. The thermal conductivity of austenitic stainless steels is about one third that of carbon steels.

Austenitic steel grades are not ferromagnetic in the annealed condition. However, martensite transformation occurs during the hollow section manufacturing process, which makes the steel slightly magnetic. The magnetic ferrite phase may exist in the longitudinal seam weld which is made without filler material or when heat treatment is not carried out after welding. Therefore, hollow sections made of austenitic stainless steels may be slightly magnetic. The hollow sections made of ferritic and duplex stainless steels are always magnetic.

3.4 Corrosion resistance

The good corrosion resistance properties of stainless steels are based on the development of a passive film on the steel surface. The passive film is a transparent chromium-rich oxide layer of a thickness of a few nanometres (nm). The chromium content of the steel and the oxidation capability of the environment affect the formation of the passive film. When damaged, the passive film can restore itself in an oxidizing environment. In addition to chromium, nickel also has an influence on the repassivation capability. Section 3.4 presents some basic concepts of corrosion, general and localised forms of corrosion of stainless steel and methods for preventing corrosion damage.

3.4.1 Basic concepts of corrosion

Corrosion of metals is divided into two categories depending on the surrounding medium:

1) Chemical corrosion ("dry corrosion") is mainly caused by gases when the metal surface reacts directly with the environment (e.g. hot exhaust gases or hydrogen sulphide gas).

2) Electrochemical corrosion ("wet corrosion") is the corrosion of metals in a liquid environment where the metal surface reacts through the exchange of electric charges (e.g. strong acids or chloride containing aqueous solutions).

Table 3.3.1 Physical properties of stainless steels /"Outokumpu Steel Grades, Properties and Global Standards" brochure/

	Steel			Physical properties					
Type	EN	ASTM	OUTOK	Density [kg/dm³]	E [GPa] RT / 400°C	α [10-6/°C] 100°C / 400°C	λ [W/m°C] RT / 400°C	c RT [J/kg°C]	ρ RT [μΩm]
Ferritic stainless steels	**1.4003**	S40977	4003	7,7	220 / -	11,0 / -	28 / -	460	0,58
	1.4016	430	4016	7,7	220 / 195	10,0 / 10,5	25 / 25	460	0,60
	1.4509	S43940	4509	7,7	220 / -	10,0 / -	25 / -	460	0,60
	1.4512	409		7,7	220 / -	10,0 / -	25 / -	460	0,60
	1.4521	444		7,7	220 / -	10,0 / -	25 / -	460	0,60
Duplex steels	1.4162	S32101	LDX 2101®	7,8	200 / 172	13,0 / 14,5	15 / 20	500	0,80
	1.4362	S32304	2304	7,8	200 / 172	13,0 / 14,5	15 / 20	500	0,80
	1.4462	S32205	2205	7,8	200 / 172	13,0 / 14,5	15 / 20	500	0,80
	1.4410	S32750	2507	7,8	200 / 172	13,0 / 14,5	15 / 20	500	0,80
CrNi and CrMn steels	**1.4318**	301LN	4318	7,9	200 / 172	16,0 / 17,5	15 / 20	500	0,73
	1.4372	201	4372	7,8	200 / 172	16,0 / 17,5	15 / 20	500	0,70
	1.4301	304	4301	7,9	200 / 172	16,0 / 17,5	15 / 20	500	0,73
	1.4307	304L	4307	7,9	200 / 172	16,0 / 18,0	15 / 20	500	0,73
	1.4311	304LN	4311	7,9	200 / 172	16,0 / 17,5	15 / 20	500	0,73
	1.4541	321	4541	7,9	200 / 172	16,0 / 17,5	15 / 20	500	0,73
	1.4306	304L	4306	7,9	200 / 172	16,0 / 17,5	15 / 20	500	0,73
CrNiMo steels	**1.4401**	316	4401	8,0	200 / 172	16,0 / 17,5	15 / 20	500	0,75
	1.4404	316L	4404	8,0	200 / 172	16,0 / 17,5	15 / 20	500	0,75
	1.4436	316	4436	8,0	200 / 172	16,0 / 17,5	15 / 20	500	0,75
	1.4432	316L	4432	8,0	200 / 172	16,0 / 17,5	15 / 20	500	0,75
	1.4406	316LN	4406	8,0	200 / 172	16,0 / 17,5	15 / 20	500	0,75
	1.4571	316Ti	4571	8,0	200 / 172	16,5 / 18,5	15 / 20	500	0,75
	1.4435	316L	4435	8,0	200 / 172	16,0 / 17,5	15 / 20	500	0,75
High alloy steels	**1.4439**	317LMN	4439	8,0	200 / 172	16,0 / 17,5	14 / 20	500	0,85
	1.4539	N08904	904L	8,0	195 / 166	15,8 / 16,9	12 / 18	450	1,00
	1.4529	N08926	4529	8,1	195 / 166	15,8 / 16,9	12 / 18	450	1,00
	1.4547	S31254	254 SMO®	8,0	195 / 166	16,5 / 18,0	14 / 18	500	0,85
	1.4565	S34565	4565	8,0	190 / 165	14,5 / 16,8	12 / 18	450	0,92

Key:
E = elasticity modulus
α = thermal expansion coefficient
λ = thermal conductivity
c = specific heat capacity
ρ = resistivity
RT = in room temperature

Electrochemical corrosion occurs more frequently than chemical corrosion. In electrochemical corrosion, two kinds of electrode areas are formed on the metal surface: one, where the metal is dissolved i.e. where the oxidation reaction takes place and the other where electrons leave the metal i.e. where the reduction reaction takes place. The area on the electrode where the metal is dissolved is called the anode. The area on the electrode where the reduction takes place is called the cathode. A potential difference is formed between the anodic and cathodic electrode areas. The metal is dissolved in the anodic area and the electrons are passed to the conductive electrolyte in the cathodic area. The corrosion rate is proportional to the current that flows through the electrolyte from the cathode to the anode. The formation of anodic and cathodic areas may be caused by a number of factors such as differences in the microstructure of the metal, the presence of crevices and dirt or local concentration differences in the electrolyte. The two electrodes forming on the surface of the metal are called a concentration couple. The mechanism of electrochemical corrosion is presented in Figure 3.4.1.1.

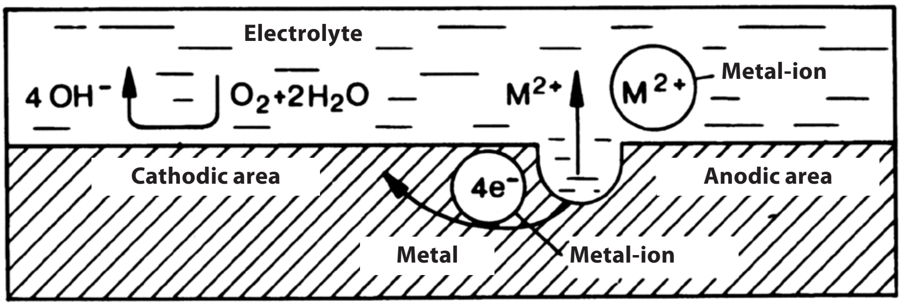


Figure 3.4.1.1 Concentration couple formed in electrochemical corrosion.

An electrochemical potential difference may also form between two different metals in electric contact. In this case, the more noble metal becomes the cathode and the less noble one becomes the anode and may corrode. The metals form a galvanic couple and the corrosion mode is known as galvanic corrosion. The tendency of a metal to form the cathode or the anode in a galvanic couple can be predicted using the galvanic series. The galvanic series presented in Table 3.4.1.1. refers to seawater as the electrolyte. The farther apart the metals in the galvanic series, the higher the potential difference (voltage) between them. The corrosion rate of the metal that forms the anode may be high.

The corrosion rate depends on the potential difference, on the diffusion rate of the metal ions in the solution and on the rate at which the electrons and metal ions can switch between the electrolyte and metal. The slowest of these processes defines the observed corrosion rate. Often the amount of metal ions above the anodic area on steel becomes so high that the corrosion reaction slows down. This effect is called concentration polarisation. The most powerful concentration polarisation, however, is caused by the formation of an oxide layer on the steel surface. The porous oxide layer that forms on carbon steel is normally not sufficient to hinder the progress of electrochemical

Galvanic series	
Graphite	
Silver	
CrNiMo stainless steel (passive)	
CrNi stainless steel (passive)	
Monel alloys	
Nickel (passive)	
Red brass	
Copper	
Aluminium bronze	**Potential increases and material comes more noble**
Nickel (active)	
(α+β)-brass alloys	
Lead	
CrNiMo stainless steel (active)	
CrNi stainless steel (active)	
Cast iron	
Low alloy steel	
Aluminium alloys	
Galvanized steel	
Zinc	
Magnesium alloys	

Table 3.4.1.1. Galvanic series in seawater

corrosion. Some metals are capable of forming oxide layer on the surface which is difficult to dissolve are called passivated metals. Stainless steels have this property to form a corrosion protective thin passive film already under mildly oxidising conditions.

Sufficiently low pH value or the presence of strongly reducing substances (e.g. special acids) may lead to the complete reductive destruction of a passive layer. Some ions like chloride and sulphide in sufficiently high concentrations may hinder the formation of the passive layer. Under these circumstances, the stainless steel becomes active and starts to corrode. On the other hand, strong alkaline solutions or oxidisers may shift the potential of the surface into the so-called transpassive range where the passive layer is destroyed and the stainless steel corrodes.

3.4.2 General corrosion

In case of general (uniform) corrosion, the entire steel surface is activated and the metal corrodes at the same rate everywhere. General corrosion can be found on stainless steel in cases where the steel grade used is completely unsuitable for the conditions (e.g. too strong acid or base) or if the environment has significantly changed from its original state. Problems related to corrosion can usually be avoided by choosing the correct material for the environments. Guidance on material selection for different environments can be found in, among others, DECHEMA (1987) and Corrosion Handbook, Outokumpu (2004).

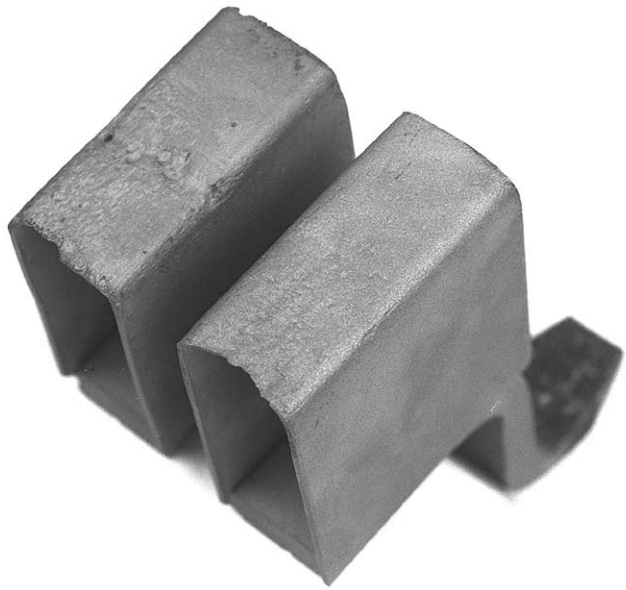


Figure 3.4.2.1. Lifting hooks made of steel grade 1.4401 have corroded when in contact with sulphuric acid (H_2SO_4, approximately 200 g/l, T = 40°C) (Outokumpu Tornio Works).

Figure 3.4.2.1. shows two lifting hooks in a sulphuric acid environment. The parts of the hooks that have been in contact with the solution have corroded.

3.4.3 Localised corrosion

Localised types of corrosion include among others, pitting, crevice and intergranular corrosion as well as stress corrosion cracking. When the process by which the component is to be manufactured and the surrounding environment are known well enough, corrosion can be avoided by selecting the correct material for the purpose. If the surrounding environment cannot be controlled well enough, there is a risk of localised corrosion. Damage by localised corrosion may affect only a small area, but its negative impact on the appearance, the structural integrity and functionality may be harmfull but still may allow the structural use of the component.

The critical details are often crevices in the structure which collect dirt or untreated weld seams. The use of wrong filler materials and joining of different metals together often cause problems. In humid environments, carbon steel dust on a stainless steel surface (carbon steel contamination) and high chloride content in aqueous solutions also cause pitting corrosion or staining. Some forms of localised corrosion and means to prevent them are presented below. Galvanic corrosion was presented earlier in section 3.4.3.1 Basic concepts of corrosion.

Pitting corrosion

Pitting corrosion starts from an area of localised damage in the passive film. The damage can be caused by a number of factors including surface defects, non-uniformities in the steel and a high chloride content in the surrounding solution. Pitting corrosion can also initiate from dust and sparks originating from the handling of carbon steel. The damaged area becomes the anode and the surrounding area the cathode. Because the anode is often small compared to the surrounding cathode, the local corrosion rate is high at the beginning. The corrosion rate slows down with time, but corrosion pits can penetrate through thin sheets. Figure 3.4.3.1 shows pitting corrosion originating in the heat tint area next to a weld seam in a chloride-containing environment.

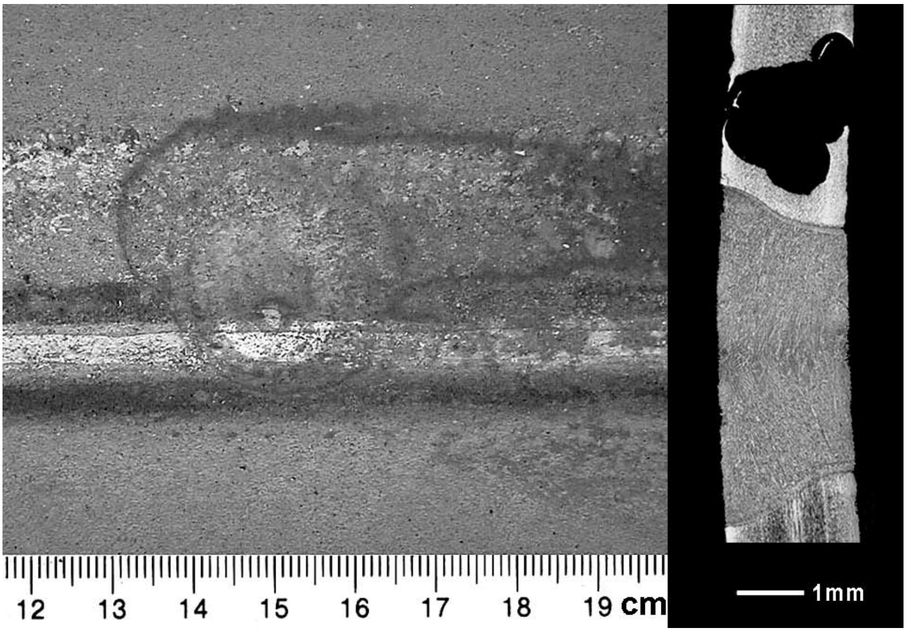


Figure 3.4.3.1. Pitting corrosion nucleated in the heat tint area next to a weld seam (Outokumpu Tornio Works).

In order to avoid pitting corrosion in the final product, the material must be handled with care. Carbon steel dust and sparks must be kept away from stainless steel surfaces, welds must be finished and it is recommended to clean finished steel surfaces regularly.

Particular care must be taken in chloride containing environments. Common stainless steel (1.4301) is not recommended for water pipes when the chloride content exceeds 200 mg/l. In Europe, the chloride content of tap water seldom exceeds 200 mg/l. The corresponding limit for CrNiMo steels, such as 1.4404 and 1.4432, is 500 mg/l. Problems may occur even when using higher alloyed steels e.g. in swimming pool environments due to the evaporation of sodium hypochlorite or near the sea due to chloride containing mists. Selection of the correct stainless steel grade and regular cleaning are of utmost importance in these applications.

Microbiological organisms can promote pitting corrosion particularly in stagnant water. Problems have occurred in e.g. firewater piping where weld root shielding had been insufficient. In addition to the correct protection or cleaning of weld roots, regular drainage of water or the use of inhibitors decreases the risk of microbiological corrosion.

The resistance to pitting corrosion of stainless steels can be compared with the help of the pitting resistance equivalent (PRE), which is calculated from the composition of steel using the equation PRE = % Cr + 3,3 x % Mo + 16 x % N. For example, the PRE of steel grade 1.4547 (254SMO), which is often used in seawater heat exchangers, is 43 whereas the PRE of steel grade 1.4301 is 19. Table 3.4.3.2 presents the pitting resistance equivalents (PRE) of several commonly used stainless steel grades and the corresponding critical pitting temperatures (CPT) obtained in laboratory measurements. The CPT describes the corrosion resistance giving the temperature that is required to damage the passive film. However, it must be noted that PRE does not correlate directly with the service life of the material.

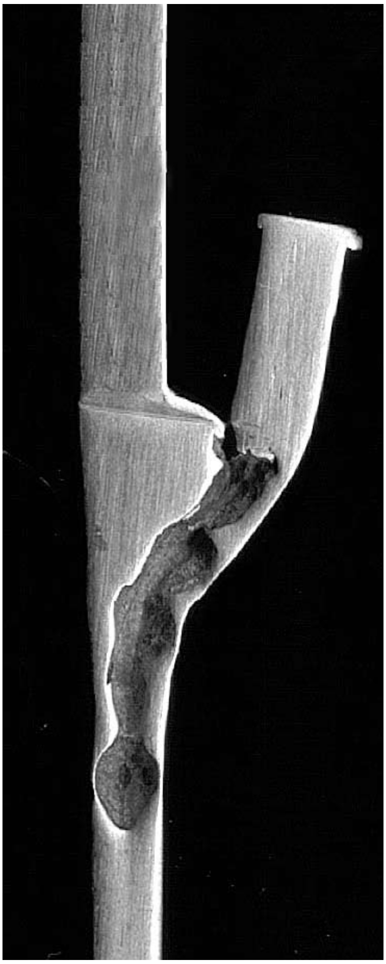
Steel grade		Cr% / Ni% / Mo% / N% (typical values)	PRE*	CPT (ASTM G150)
EN	ASTM			
1.4003	409	11,2 / - / - / 0,01	11	< 15°C
1.4016	430	16,2 / - / - / 0,03	17	< 15°C
1.4509	439	18,0 / - / - / 0,01 / Ti+Nb	18	< 15°C
1.4521	444	18,0 / - / 2,1 / 0,01 / Ti+Nb	25	-
1.4372	201	17,2 / 4,5 / - / 0,20 / Mn	20	< 15°C
1.4310	301	16,8 / 6,4 / - / 0,07	18	< 15°C
1.4318	301LN	17,5 / 6,5 / - / 0,16	20	< 15°C
1.4301	304	18,2 / 8,2 / - / 0,05	19	< 15°C
1.4404	316L	17,2 / 10,1 / 2,1 / 0,05	23	~ 17°C
1.4436	316L	16,8 /10,6 / 2,6 / 0,05	26	~ 22°C
1.4539	904L	20,0 / 25,0 / 4,3 / 0,06 / Cu	35	~ 61°C
1.4547	S31254	20,0 / 18,0 / 6,1 / 0,20 / Cu+Mn	43	~ 90°C
1.4162	S32101	21,5 / 1,6 / 0,3 / 0,22 / Mn	26	~ 20°C
1.4362	S32304	23,0 / 4,8 / 0,3 / 0,10	26	~ 18°C
1.4462	S32205	22,0 / 5,7 / 3,1 / 0,17	31	~ 52°C
1.4410	S32507	25,0 / 7,0 / 4,0 / 0,27 / Mn	43	~ 87°C

* PRE = Cr% + 3,3x Mo% + 16x N%

Table 3.4.3.2. Pitting resistance equivalents (PRE) of certain stainless steel grades and critical pitting temperatures (CPT) measured in 35 g/l NaCl solution. (Outokumpu Avesta Research Centre).
Note! Pitting corrosion resistance is not linearly related to the numerical values presented.

Crevice corrosion

Metals whose corrosion resistance is based on the formation of a passive film, such as stainless steels, are particularly susceptible to crevice corrosion. Substances causing corrosion often concentrate in crevices thus making structures that contain crevices susceptible to corrosion damages. The chloride content, for example, within a crevice can be significantly higher than in the bulk solution. In addition, the oxygen content,



which would promote the repassivation of a damaged passive film, is often low in crevices. Therefore, crevice corrosion is often present in a number of different solutions, even in natural waters. Solutions containing chloride ions are particularly harmful.

In terms of crevice corrosion, the most dangerous crevice width is 0,025 - 0,1 mm. Crevice corrosion may also initiate in weld undercuts and root defects. Figure 3.4.3.3 shows an example of crevice corrosion in a tank enclosure joint.

In order to prevent the formation of crevice corrosion, structures must be designed in such a way that there are no dirt-collecting surfaces or crevices. Special attention must be paid to riveted or threaded joints or welded structures. Crevices can also be sealed using different kinds of sealing compounds such as silicon. Regular cleaning of the structures and removal of precipitates from e.g. tanks also prevents the formation of crevice corrosion.

Figure 3.4.3.3. Example of crevice corrosion in a welded structure (Outokumpu Tornio Works).

Stress corrosion cracking

Stress corrosion cracking mainly affects austenitic stainless steels. It occurs in warm chloride or hydrogen sulphide environments, in hot alkaline solutions or in very hot steam if the components are under a sufficiently high level of tensile stress. Stress corrosion cracking creates a brittle fracture, the discovery of which before cracking is often difficult, and it may thus cause sudden, unexpected damage. Figure 3.4.3.4 shows stress corrosion cracking initiated on the surface of a hot water tank, which has leaked though the hatch.

Although stress corrosion cracking in austenitic steels has been extensively studied, it has been impossible to define the specific circumstances in which damage occurs. Usually, the combined effect of at least the following three factors are required before stress corrosion cracking may develop.

- Sufficiently tensile stress
  No exact minimum limit can be set for tensile stress, but in practice half of the yield strength can be enough. Tensile stress can be structural or attributed to residual

stresses caused by the manufacturing process, such as welding, bending and machining. Strain resulting from pressure and temperature may also cause sufficiently high stress levels. For example, thermal stress in heat exchangers may be sufficient to cause stress corrosion cracking in steel grade 1.4301 if the chloride content is as low as 15 mg/l.

- Corrosive environment or ions damaging the passive film
  Chloride ions (HCl, NaCl, $CaCl_2$, $MgCl_2$) even in very small quantities may cause damage if the temperature is higher than 50°C. Alkalis (e.g. NaOH, KOH and LiOH) are also harmful in strong (over 20 %) and hot (over 80°C) solutions. Hydrogen sulphide solution (H_2S) as a strongly reducing solution is harmful to steel grade 1.4301 in particular if pH ≤ 4.

- Temperature
  Stress corrosion cracking caused by chlorides rarely occurs in temperatures lower than 50°C. Despite low temperatures, special care must be taken in swimming pool environments for components that cannot be regularly cleaned (see 3.5.2). In alkaline environments, the risk of stress corrosion cracking increases at temperatures higher than 80°C. Hydrogen sulphide is harmful even at low temperatures.

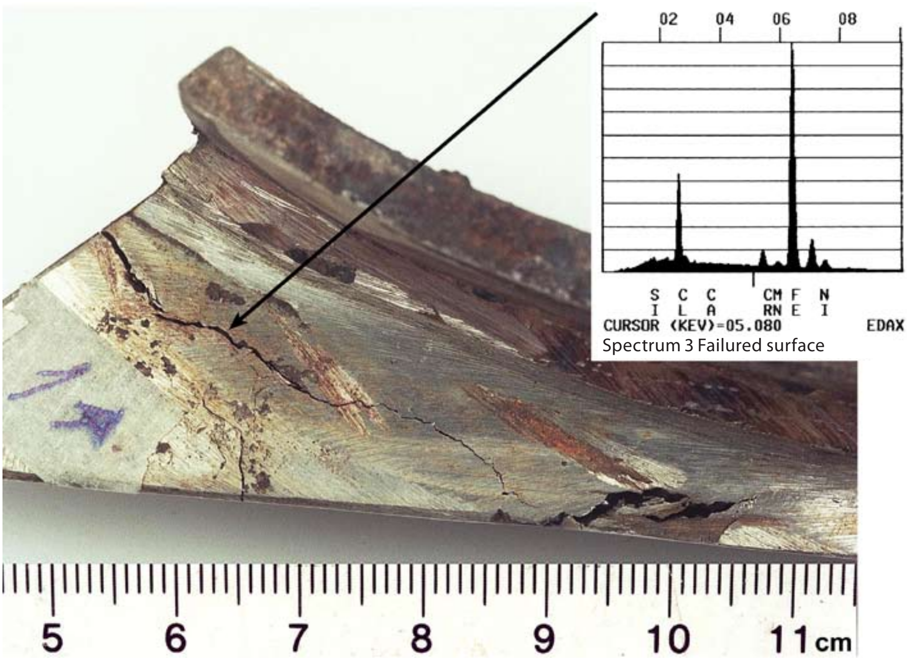


Figure 3.4.3.4. Stress corrosion cracking on the external surface of a leaking hot water tank. The surface has been polished in order to localise the crack. The SEM-EDS spectrum taken from the crack shows, among others, high chloride content (Outokumpu Tornio Works).

Sensitisation and intergranular corrosion

Sensitisation resulting in intergranular corrosion is rare in modern stainless steels. The problem may occur mainly in relatively thick welded stainless steel structures (thickness over 6 mm) or in products that have been heat-treated or used in the temperature range 450–800°C. In such cases, the carbon and chromium atoms in stainless steel containing relatively high amounts of carbon (over 0,05 %) form chromium carbides on the grain boundaries sufficiently quickly leaving chromium-depleted areas near the grain boundaries. The corrosion resistance of these chromium-depleted areas decreases, and the risk of intergranular corrosion increases. Figure 3.4.3.5 presents a diagram showing the impact of the carbon content of austenitic stainless steel and annealing time on the formation of chromium carbides.

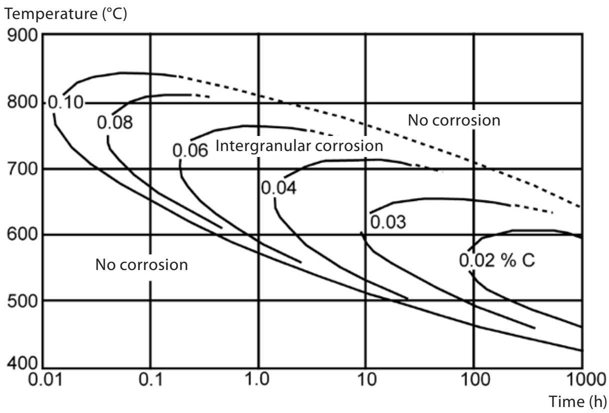


Figure 3.4.3.5. The effect of the carbon content on the risk of sensitisation in 18Cr-8Ni type stainless steel. (Korroosiokäsikirja 1988)

3.4.4 Corrosion prevention

Corrosion problems can be avoided in most cases by correct material selection, adequate structural design, use and maintenance. Some guidance on how to prevent corrosion is given below.

- General corrosion usually results from incorrect material selection. The suitability of the specified material for the chemical processes and transport containers must always be ensured using data given in literature, laboratory tests and, perhaps, field corrosion tests.

- Pitting and crevice corrosion can be prevented by keeping the stainless steel surfaces clean and by avoiding liquid becoming trapped in crevices and voids in the structure using sealing compounds. Figure 3.4.4.1 shows structural solutions that can be used to avoid crevices and dirt entrapment.

- Stress corrosion cracking can be avoided by decreasing the tensile stress in stainless steel structure e.g. by changing the design. In addition, decreasing the content of corrosive substances in the environment, increasing the pH value of the solution (not over pH = 12) and lowering the temperature of the environment (under 50°C) all decrease the risk of corrosion. Chloride induced stress cracking corrosion is not found in ferritic stainless steels. Duplex stainless steels and high-alloyed grades show increased resistance to stress corrosion cracking.

- Sensitisation and subsequent intergranular corrosion can in most cases be avoided by using low-carbon (e.g. 1.4307, AISI 304L) or titanium stabilised (e.g. 1.4541, AISI 321) steel grades when welding materials thicker than 6 mm. There is no risk of sensitisation in thin sheet applications when using normal manufacturing methods. Annealing and using austenitic stainless steel in the temperature range of 450–800 °C is, however, harmful when the material comes into contact with a detrimental corrosive environment. If sensitisation is suspected, the structure must be solution annealed in the temperature range between 1000–1100 °C and then quenched rapidly.

- The risk of galvanic corrosion can be avoided by not placing different metals in direct contact with each other. In the electrochemical series (Table 3.4.1.1, section 3.4.1), metals far away from each other are particularly susceptible to form a galvanic couple. If placing two different metals in contact with each other cannot be avoided, it is recommended to insulate them e.g. from the electrolyte by painting the joint area. In the case of screw joints, it is recommended that bushes and sealing rings be used that separate the different metal surfaces from each other. The durability of the insulation must be ensured in moving structures, in which case rubber pads may be the best solution. In the case of riveted joints in certain less challenging corrosive environments, a more noble metal can be used to fix less noble metal sheets. For example, using stainless steel rivets in fixing aluminium plates is often a successful solution.

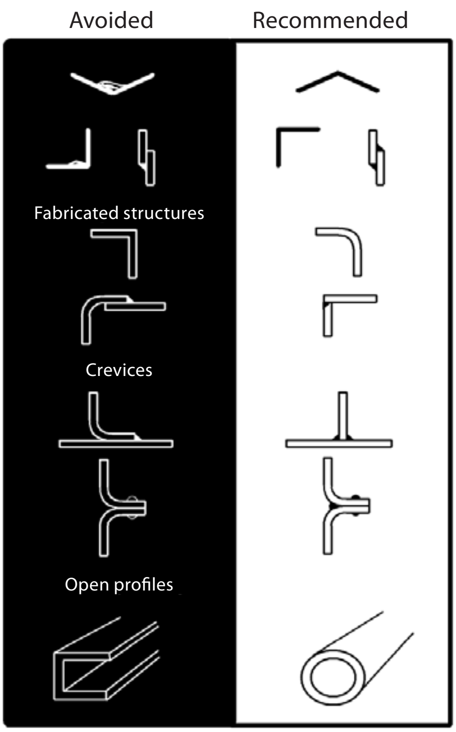


Figure 3.4.4.1. Good and unfavourable structural solutions for swimming pool environments and other demanding corrosive environments.

3.5 Examples of the selection of materials

In many cases, material selection is based on previous experience. The most commonly used steel grades in construction are 1.4301, 1.4404 and 1.4571. In the near future, these materials may be partly replaced by ferritic, manganese-alloyed austenitic and duplex stainless steels. Intensive material testing is often the only possibility to confirm the suitability of a steel grade in a novel environment. Some examples of the selection of a suitable stainless steel are briefly presented below.

3.5.1 Selection of material for a building site taking the requirements of mechanical strength into account

The support structure for a glass roof shall maintain its durability at normal temperature as well as under conditions equivalent to 30 minutes fire exposure. The glass roofing will be part of the façade of a small bay window in a public premises. Because the supporting structure will be visible from the inside and outside, an aesthetic natural steel grey surface was required. The supporting structure is made of a light lattice and columns. The components will be manufactured by welding in a workshop. The structure will be assembled on site using bolted joints.

The structure can be designed with the 2D element software WinRami-Stainless, which is briefly presented in 3.5.8.

The strength class selected for room temperature design is CP350, which enables 350 N/mm^2 to be used as the nominal value of the yield strength in structural design. Austenitic steel grades CrNi and CrNiMo in a cold-worked condition (but see also section 3.2) as well as steel grade 1.4318 and duplex steels in annealed condition meet this requirement. Nominal yield strength of 420-480 N/mm^2 can be utilised in design when using duplex stainless steels.

Fire resistance requirements must be met at steel temperatures equivalent to a 30-minute standard fire. The temperature of unprotected stainless steel after a 30-minute standard fire is 800–830 °C depending on the thickness of the material. There are significant differences in the values of the effective yield strengths used in structural design between stainless steel grades. Titanium stabilised steel grades 1.4541 and 1.4571 have higher strength values at elevated temperatures than other stainless steel grades. Therefore, the selection of steel grade involves balancing the need for elevated temperature strength; candidate grades are 1.4301, 1.4318, 1.4404, 1.4571 and duplex 1.4162.

The surface finish can be defined as, for example, the GRIT220/240 brushed and pickled. This surface is quite a smooth and can be cleaned reasonably easily. In addition, the surface finish can also be specified as matt surface. Surface finishes of stainless steel hollow sections are described in more detail in section 4.

The horizontal surfaces of hollow sections may collect dirt from the surrounding air. Consideration should be given to specifying that the steel structure should be washed with water and dried at the same times as the glass is washed.

A simple plan must be made for the assembly of the structure in such a way that the structures can be safely assembled without damaging the surfaces. Surfaces possibly damaged during assembly must be restored to correspond to their pristine appearance. In the case of brushed and polished stainless steel hollow section surfaces, this can be carried out on site if sufficient instructions are available.

3.5.2 Swimming pool environment

Object:	railings
Water temperature:	29 °C
Air temperature:	28 °C

The disinfectants sodium hypochlorite ($NaClO$) and chlorine (Cl2) may cause corrosion problems as they are a source of corrosive chlorine compounds that evaporate from the water into the swimming pool atmosphere. The higher the water temperature is with respect to the room temperature, the higher is the rate of evaporation. On the other hand, different forms of corrosion, such as staining, pitting and stress corrosion cracking, are more likely to occur at higher room temperatures. Generally speaking, corrosion attack in modern spa-like swimming pools is aggressive. Surfaces colder than the surroundings, such as refrigeration apparatus, lifts and air-conditioning systems also have a high risk of corrosion.

A rule of thumb in selecting materials is that molybdenum-alloyed CrNiMo steels, such as 1.4404 and 1.4432 are often used used in swimming pools. Standard EN 1993-1-4 recommends only using steel grades 1.4529, 1.4547 or 1.4565 in load-bearing structures that are located in climates with high chloride content and that cannot be regularly cleaned, e.g. suspended ceilings above swimming pools, unless the chloride ion concentration is < 250 mg/l (unusual), in which case steel grade 1.4539 is also suitable. Alternative steel grades with equivalent corrosion resistance properties in terms of stress corrosion cracking in corresponding environments can also be used.

In addition to the correct choice of material, attention must be paid to regular cleaning including, among others, rinsing and drying the railings daily.

3.5.3 Baltic Sea water

Object:	Water intake pipe screen
Location:	Gulf of Bothnia, coast line near Vaasa
Temperature:	max. 25 °C

The chloride content of the Baltic Sea varies in the different parts of the sea, as shown in Figure 3.5.3.1. When using molybdenum-alloyed CrNiMo steel 1.4432, the maximum chloride content in the water supply system is often considered to be 500 mg/l (Korroosiotaulukot, 1979). The said steel grade is, however, suitable for use in the Gulf of Bothnia and the Gulf of Finland if the water temperature is sufficiently low. Figure 3.5.2 shows the resistance of steel grade 1.4401 (AISI 316) to crevice corrosion at different temperatures and in water with different chloride contents. The use of this steel is therefore possible in the case site.

In sites with higher temperatures, such as seawater heat exchangers, or higher chloride content, higher alloyed stainless steels, such as 1.4462, 1.4539 and 1.4529 must be used (Erfahrungen bei der Anwendung Stähle in chlorhaltigen Wässern, Informationstelle Edelstahl Rostfrei, 1996).

Table 3.5.3.1 shows the suitability of materials to corrosive environments related to, among others, different natural waters (Ruostumaton teräs maa- ja vesirakentamisessa, VTT, 2006). Stainless steel hollow section applications in marine or freshwater environments include supporting pier structures, railing systems and piling.

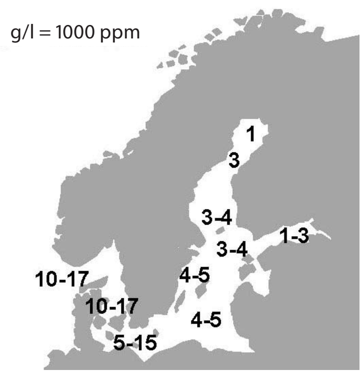


Figure 3.5.3.1. Chloride content in the Baltic Sea (Finnish Institute of Marine Research).

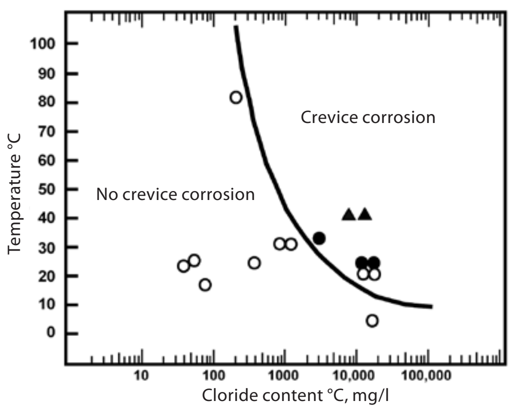


Figure 3.5.3.2. The resistance of steel grade 1.4401 (AISI 316) to crevice corrosion in different chloride content/temperature combinations. The measurements have been made in a practical process environment in neutral water solution (Kovach & Thackray, 1982).

Table 3.5.3.1. Corrosion behaviour of stainless steels and their suitability for different environments in earth and water construction (Ruostumaton teräs maa- vesirakentamisessa, VTT, 2006).

	Baltic Sea water (brackish water)	Fresh water	Fouling (accumulation of organisms in sea and fresh water)	Road salt	Canine urine
1.4301 (304) 1.4307 (304L) 1.4318 (301LN)	-	++ Cl < 200 (cr, pt)	+ cr	+ (pt, cr), st	++ (pt)
1.4162 (LDX 2101)	[+] (pt, cr)	[++] (pt, cr)	[+] cr	[+] (pt, cr)	[++] (pt)
1.4404 (316L) 1.4401 (316)	+ (pt, cr)	++ Cl < 500 (pt, cr)	+ cr	++ (pt, cr)	++ (pt)
1.4462 (Duplex 2205)	++ (pt, cr)	++	+ (cr)	[++]	++

-	=	not suitable to be used without protection
+	=	suitable
++	=	more suitable
(pt and cr)	=	risk of pitting and crevice corrosion must be taken into consideration in particular in structures requiring leakproof and if there is a risk that corrosion will occur in an unfavourable location in terms of load-bearing properties of the structure
cr	=	risk of crevice corrosion must be taken into consideration when designing the structures
(cr)	=	the same as cr, but reduced risk
st	=	risk of stress corrosion cracking in the presence of tensile stress and chlorides
[+],[++]	=	no user experience
Cl	=	chloride content (mg/l)

Further information on the selection of materials and surface finishes for more aggressive marine environments is published in ASSDA Technical Bulletin "Stainless Steel Tea Staining" No 2 February 2006. The publication gives information on selecting materials in ocean shores where the chloride content of seawater is significantly higher than that in the Baltic Sea and the air temperature is higher than in a typical Scandinavian summer. The instructions recommend the use of CrNiMo steel grades, if the structure is located within 5 km of a sea. The recommended surface finish is mechanically or electrolytically polished surface with Ra value better than 0,5µm. The recommendations are very similar to those presented in Table 3.5.3.1.

3.5.4 Urban building sites

Object: Cladding sheets for a building from the street level to the roof
Location: Medium-sized Finnish town

The corrosivity of the climate varies depending on the location of the site. Steel grade 1.4301 can typically be used in rural environments, but it is recommended to select the so-called acid proof grades 1.4404 or 1.4432 for urban environments. In addition, corrosion attack is significantly different in structures rinsed by rain, such as roofs, compared to street level wall cladding or structures that are difficult to clean. Structures susceptible to getting dirty must be cleaned, for example, by washing them with hot water once or twice a year. Table 3.5.2 gives instructions on selecting materials for different environments.

Table 3.5.4.1. Recommended steel grades for different climatic conditions (Architects Guide to Stainless Steel (1997); EN1993-1-4:2006)

Steel grade	Type of environment and corrosion attack classification											
EN 10088-2	Rural environment			Urban environment			Industrial environment			Marine environment		
	L	M	H	L	M	H	L	M	H	L	M	H
1.4003 1.4016	O	X	X	O	X	X	X	X	X	X	X	X
1.4301 1.4541 1.4318	OK	OK	OK	OK	OK	O	O	O	X	OK	O	X
1.4401 1.4404 1.4571	-	-	-	-	OK	OK	OK	OK	O	OK	OK	O
1.4439 1.4462 1.4529 1.4539	-	-	-	-	-	-	-	-	OK	-	-	OK

Corrosive environment:
L = Low. The lowest corrosion attack in the environment in question.
For example premises heated to a certain temperature with low humidity or low temperatures
M = Medium. Somewhat typical in the environment in question.
H = High. The likelihood for corrosion is higher than usual in the environment in question.
For example, corrosion attack increases due to high level of humidity,
high temperature or aggressive air pollutants.

Suitability markings:
OK = Probably the best choice in terms of corrosion resistance and cost.
o = Worth considering if appropriate precautions are taken
(i.e. designing a relatively smooth surface and wash it regularly).
- = Possibly overrated in terms of corrosion.
x = Excessive corrosion probable.

3.5.5 Transportation

Stainless steels are commonly used in the manufacture of trains and coaches both in load-bearing and non-load-bearing components. The main criterion governing material selection is the good corrosion resistance properties of stainless steel, which means that corrosion protection can be decreased or omitted. In addition, austenitic steels have good toughness properties in welded structures.

The relevant environment of use in the case of trains varies from rural and urban environments to marine climates. Therefore, requirements set for the corrosion resistance of steels vary. In addition to static strength, important design parameters are fatigue durability and collision safety. The most commonly used steel grades are 1.4301, 1.4307 and 1.4318 both in the annealed (2B or 2D) and hardened (2H) condition. The advantage of steel grade 1.4318 is its higher strength both in the annealed and cold-worked state. The joining methods used are arc welding (thicker load-bearing structures), spot welding, a combination of spot welding and adhesive bonding, and laser welding.

The use of stainless steels in the manufacture of coaches is increasing. The environment of use varies from rural areas to marine climates. A relatively large proportion of coaches operate in urban environments. A pertinent environmental characteristic is the use of highly corrosive road salt . The corrosion protection of structural components can be reduced by using stainless steels. Important design criteria include static strength, fatigue durability and weight of components. Commonly used steel grades in coach structures are the ferritic stainless steels 1.4003 (hollow sections) and 1.4016 (sheets) as well as the austenitic stainless steel 1.4301 (hollow sections and sheets). The main joining method for stainless steel hollow sections is MAG welding. Thin materials are traditionally joined by riveting, which makes ferritic steels popular, thanks to their good drilling properties. The corrosion resistance of ferritic steels can be enhanced, for example by painting.

There is also increasing interest in using stainless steel in the passenger car industry where the excellent impact strength and ability to absorb energy can be utilised when improving collision safety. The steel grades mainly used are 1.4301, 1.4318 and 1.4372, but due to their lower price, ferritic steels are the most commonly used materials in passenger cars.

3.5.6. Road and traffic route structures

The advantages of using stainless steels in traffic route structures are their mechanical strength and low maintenance costs, thanks to their good long-term durability. Applications include railings for cycling and pedestrian bridges, supporting beams of bridges, frameworks, road railings, sign and lamp posts, supporting structures for noise barriers, enclosures for large concrete columns, and frames for modern street furniture in indoor and outdoor public spaces. When selecting materials for traffic routes, the use of road salt must be taken into account. If no road salt is used, steel grades 1.4301, 1.4318 and 1.4162 are applicable. In other cases, commonly used steel grades are 1.4404, 1.4432 and 1.4462.

Corrosive environment /Ruostumaton teräs maa- ja vesirakentamisessa, VTT, 2006/

Road salt is used in the winter to reduce slippery surfaces caused by ice and in the summer to bind dust. Road salt increases environmental corrosion attack beside roads and areas where salt is transferred. Salt mist can be just as harmful as complete immersion, because the chloride concentration is created as a result of evaporation of water or formation of saline crystals. Noise barriers, railings, lampposts, traffic signs and roadside fences are exposed to the detrimental impacts of road salt. Furniture and fittings along streets are exposed not only to road salt but also to canine urine.
The effect of road salt is based on its ability to lower the freezing point of water. The most commonly used chemical in Scandinavia is sodium chloride (NaCl). Another commonly used chemical is calcium chloride ($CaCl_2$), mainly together with sodium chloride. The most harmful road salts are dust-binding hygroscopic salts such as calcium chloride and magnesium chloride. Road salts can cause localised corrosion in stainless steels.

Material selection /Ruostumaton teräs maa- ja vesirakentamisessa, VTT, 2006/

The impacts of road salts on stainless steels are presented in Table 3.5.3.1. Under these conditions, steel grades 1.4301 and 1.4318 are susceptible to pitting and crevice corrosion and in some cases also to stress corrosion cracking. Even the so-called acid-proof steels 1.4404 and 1.4432 may also be susceptible to stress corrosion cracking at room temperature, if the concentration of chlorides on the steel surface is allowed and the humidity of the air is low. However, stress corrosion cracking is not a risk in structures with no tensile stresses.

Factors to be taken into consideration in earth and water construction structures susceptible to road salt include, in particular, joints and possible crevices, because the risk of crevice corrosion is high when using stainless steels containing little or no molybdenum in structures where the accumulation of chlorides is possible. If there are flanged or welded joints, crevice corrosion may also form a starting point for the development of stress corrosion cracking.

Urine may cause pitting corrosion in austenitic stainless steels, but it is not considered to have an impact on their structural durability. There is no risk of pitting corrosion if the critical points are washed or rinsed often enough.

3.5.7 Earth and water construction

/Ruostumaton teräs maa- ja vesirakentamisessa, VTT, 2006/

In earth and water construction, stainless steel hollow sections are suitable for piling in earth or water, as pier structures or protective enclosures around concrete columns. The tables below show the classification of soil types on the basis of corrosion aggressiveness and the rate of pitting corrosion of materials in the said soil type. This is an application for which stainless steel is excellently suited. Product applications are currently under development.

Table 3.5.7.1. Classification of soil types on the basis of their corrosion sensitivity /Ruostumaton teräs maa- ja vesirakentamisessa, VTT, 2006/

1. Non-aggressive • Undisturbed natural soil with a low level of chlorides and sulphates (sand, silt, clay, slate). The proportion of organic material of the soil is less than 2 % by weight. If it is not possible to determine the non-aggressive nature of soil by means of ordinary soil surveys and conditions in the site, aggressiveness is primarily assessed on the basis of chloride and sulphate content of the soil and interstitial water.
2. Somewhat aggressive • Contaminated natural soil and soil in industrial areas (in general). • Uncompacted, non-aggressive earth fillings (sand, silt, clay, moraine, aggregate).
3. Aggressive soils and traffic route structures • Aggressive natural soils (clays, silts, sludge, bog, swamp and peat with chloride and sulphate content) and salted traffic routes with sulphate content of > 500 mg/soil kg or > 100 mg/l of interstitial water, chlorides > 100 mg/ soil kg or > 50 mg/l water solution. • Uncompacted aggressive earth fillings (ash, slag, fillings with aggressive natural soil). • All contaminated soils unless their non-aggressive status has been established. • Soils with a potential field caused by direct-current supplies.

Table 3.5.7.2. Recommended stainless steel grades on the basis of the aggressiveness of the soil and levels of average corrosion /Ruostumaton teräs maa- ja vesirakentamisessa, VTT, 2006/.

Steel grade	**Non-aggressive**	**Aggressive**
Low-alloy ferritic steels	No difference from carbon steels Average corrosion: 1,2 mm / 100 years	No difference from carbon steels Average corrosion: 3–6 mm / 100 years
Austenitic CrNi steels 1.4301 (304), 1.4307 (304L) 1.4318 (301LN)	Average corrosion: 0,04–0,1 mm / 100 years	Average corrosion: 0,4–1 mm /100 years
Low-alloy duplex 1.4162 (LDX 2101)	No user experience, likely to be better than the grades above	No user experience, likely to be better than the grades above
Acid proof CrNiMo steels 1.4401 (316 L) 1.4404 (316)	Average corrosion: 0,005–0,01 mm / 100 years	Average corrosion: 0,06–0,1 mm / 100 years
Medium-alloy duplex 1.4462 (Duplex 2205)	Average corrosion: 0,005–0,01 mm / 100 years	Average corrosion: 0,06–0,1 mm / 100 years

Note. It must be noted that the background data upon which this table is based is very limited and local conditions can have a significant effect.

3.5.8 Software for the selection of stainless steel hollow sections taking mechanical strength into account

The 2D software WinRami-stainless, developed in Finland, is a structural design software package for structures made from stainless rectangular, square and round hollow sections in compliance with Eurocode 3 EN 1993-1-4:2006. Design can be carried out at both room temperature and in conditions corresponding to a given period of fire exposure. CrNi and CrNiMo steel grades with a yield strength of annealed material and enhanced strength values CP350 can be utilised in room temperature design. The fire-state design is carried out in compliance with Eurocode 3 EN 1993-1-2:2005 taking the mechanical values of different steel grades into consideration in case of fire (informative annex). A description of the software's post-processing is given below. The Finnish and English version of software can be ordered from The Finnish Constructional Steelwork Association ry (www-site www.terasrakenneyhdistys.fi).

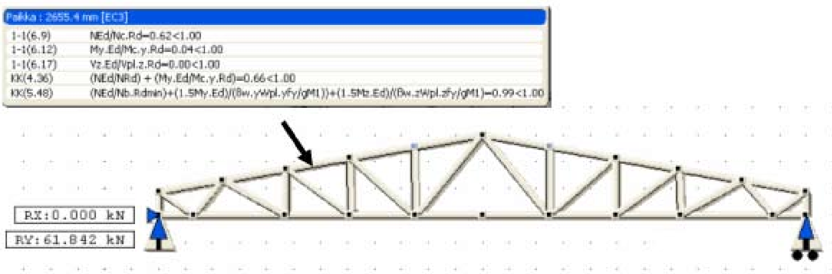
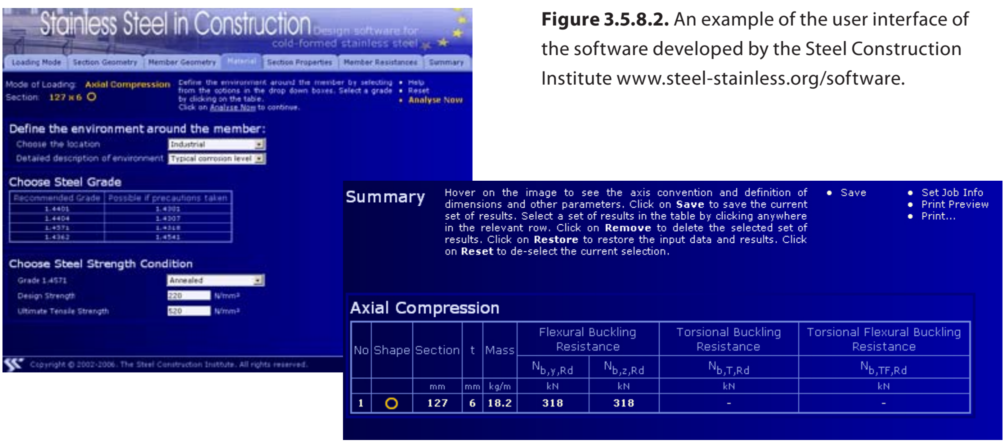


Figure 3.5.8.1. An example of the preprocessing of the model and the view of the resistance analysis of one member using the WinRami software.

The strength of a single member can be determined using software developed by SCI and available at http://www.steel-stainless.org/software/.
This software also includes a fire calculation facility.

Figure 3.5.8.2. An example of the user interface of the software developed by the Steel Construction Institute www.steel-stainless.org/software.



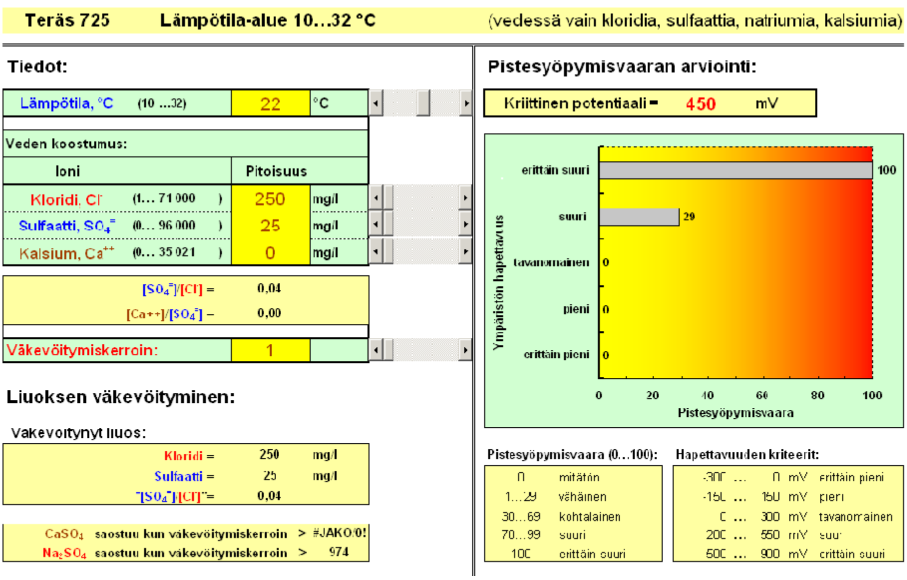
No	Shape	Section	t	Mass	Flexural Buckling Resistance		Torsional Buckling Resistance	Torsional Flexural Buckling Resistance
					$N_{b,y,Rd}$	$N_{b,z,Rd}$	$N_{b,T,Rd}$	$N_{b,TF,Rd}$
		mm	mm	kg/m	kN	kN	kN	kN
1	O	127	6	18.2	318	318	-	-

3.5.9 Software for the selection of stainless steel taking corrosion into account

/Ruostumattomien terästen korroosiovaaran ennustaminen
konsentroituvissa liuoksissa – kvantitatiivinen mallintaminen, VTT 2007/

The KORRKONS research project on the quantitative modelling of the prediction of corrosion risk of stainless steels in concentrating solutions developed an Excel-based design program to predict the likelihood of pitting corrosion in a structure when the surrounding corrosive environment is known. The software is suitable for corrosive environments containing chlorides, sulphates, sodium and calcium and a known temperature. The program can be used to assess the pitting corrosion risk caused by, for example, the evaporation of a pool of rainwater on the material surface. The first version of the program includes steel grades 1.4301, 1.4404, 1.4462 and 1.4003. An example of the program is below. The program can be ordered from the Finnish Technical Research Centre of Finland VTT and the Finnish Constructional Steelwork Association (web sites: www.vtt.fi and www.terasrakenneyhdistys.fi).

Figure 3.5.9.1. Example of the input values and results of the KORRKONS program.



4. Stainless steel hollow sections

This section describes the manufacturing process, dimensional ranges and properties of stainless steel hollow sections manufactured by Stalatube Oy and Oy Outokumpu Stainless Tubular Products Ab (Oy OSTP Ab). All hollow sections produced by these companies are made of stainless steel.

4.1 Manufacture of hollow sections

Stainless steel hollow sections are manufactured by cold forming and welding. Cold forming is carried out either by roll forming or by press braking. The welding methods used are TIG/plasma arc welding, HF and laser welding.

Roll forming

Roll forming is a continuous manufacturing method in which steel strip is cold-formed in the production line using a number of roll pair stands. The material used is coiled steel strip that is longitudinally cut to the width corresponding to the dimension of the hollow section. The steel strip is uncoiled, welded to the previous strip and fed into the roll forming line. If required, strip edge quality can be improved by using an edge preparation before forming. There are two different forming methods for square and rectangular hollow sections, round forming or direct forming.

In round forming, steel strip is first formed to create a circular hollow section, after which it is welded and formed using profiling rolls into a square or rectangular shape. In direct forming, the steel strip is directly formed into a square or rectangular shape by bending it from the corner zones and welding the seam after that. Direct forming method is used when manufacturing large hollow sections.

After welding, the joint is finished by grinding or scarfing. The quality of the weld is controlled by means of continuous eddy current testing and, if required, with other methods (e.g. a flattening test). The hollow sections are cut to the desired length, bundled, strapped and transferred either to the shipping warehouse or for further processing. The identification of hollow sections is ensured by continuous ink jet marking and bundle-specific tags.

The mechanical properties of hollow sections change due to cold-forming. The changes depend on the manufacturing method and dimensions of the hollow section. The mechanical properties of a hollow section can be measured by carrying out tests on specimens taken from the hollow section.

The stages of a roll forming line are presented in Figure 4.1.

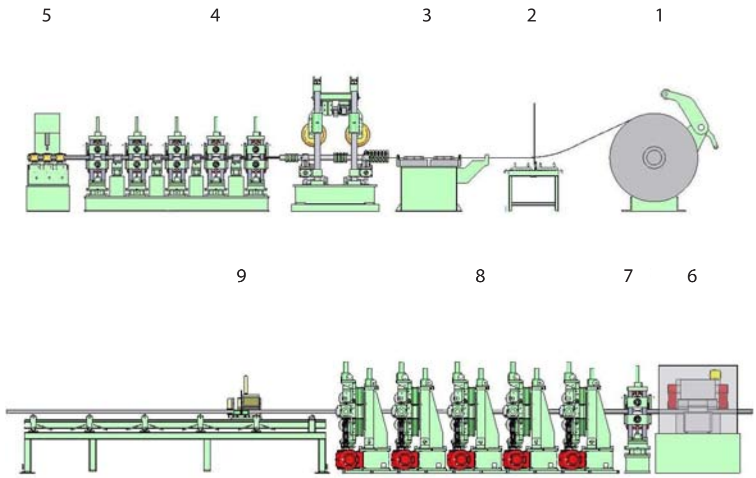


Figure 4.1. Stages of roll forming line (round forming).

Press braking

When a single hollow section is being produced, the base material is a cut sheet corresponding to the dimensions of the hollow section. The sheet is curved into a circular shape using a press braking machine in a number of work steps, after which the open profile is welded with a longitudinal weld into a hollow section in a welding station. The weld and surface are finished in separate work stations.

This method is used for manufacturing circular stainless steel hollow sections that are not economical to manufacture by roll forming due to their size or the size of the batch ordered.

4.2 Steel grades

The standard steel grades used in stainless steel hollow sections manufactured by Stalatube Oy and Oy OSTP Ab are presented in Table 4.2.1. The composition and properties of different steel grades are presented in section 3 Stainless Steels.

CrNi	CrNiMo
1.4301	1.4401
1.4307	1.4404
1.4541	1.4571

Table 4.2.1. The standard stainless steel grades of hollow sections manufactured by Stalatube Oy and Oy OSTP Ab.

Stainless steel hollow sections are also manufactured from other austenitic, ferritic and duplex steel grades presented in section 3. Availability of combination of grade and dimension must always be confirmed by the supplier.

4.3 Dimension ranges

The dimension ranges of stainless steel hollow sections manufactured by Stalatube Oy and Oy OSTP Ab are shown in Tables 4.3.1-4.3.3. Dimension ranges apply to steel grade 1.4301, the availability of other steel grades must be confirmed by the supplier. The delivery lengths of stainless steel hollow sections are from 2 to 18 m.

Stainless steel hollow sections are also manufactured in dimensional ranges indicated in inches. Further information can be requested from the Sales department.

Table 4.3.1. Stainless steel hollow sections with square cross-section (Stalatube Oy, Oy OSTP Ab). The dimension range apply to steel grade 1.4301, and the availability of other steel grades must be confirmed by the supplier.

H mm	B mm	1,2 mm	1,5 mm	2,0 mm	3,0 mm	4,0 mm	5,0 mm	6,0 mm	8,0 mm	10,0 mm	12,0 mm
20	20	■	■								
25	25	■	■	■	■						
30	30	■	■	■	■						
32	32	■	■	■	■						
35	35	■	■	■	■						
38	38	■	■	■	■						
40	40	■	■	■	■	■					
45	45		■	■	■	■					
50	50		■	■	■	■	■	■			
60	60		■	■	■	■	■	■			
70	70			■	■	■	■	■			
75	75			■	■	■	■	■			
80	80			■	■	■	■	■			
90	90			■	■	■	■	■			
100	100			■	■	■	■	■	■	■	
120	120				■	■	■	■	■	■	
140	140				■	■	■	■	■	■	
150	150				■	■	■	■	■	■	■
200	200				■	■	■	■	■	■	■
220	220					■	■	■	■	■	■
250	250						■	■	■	■	■
300	300						■	■	■	■	■

Table 4.3.2. Stainless steel hollow sections with rectangular cross-section (Stalatube Oy, Oy OSTP Ab). The dimension range apply to steel grade 1.4301, and the availability of other steel grades must be confirmed by the supplier.

H mm	B mm	1,2 mm	1,5 mm	2,0 mm	3,0 mm	4,0 mm	5,0 mm	6,0 mm	8,0 mm	10,0 mm	12,0 mm
30	20	■	■	■	■						
30	25	■	■	■	■						
35	25	■	■	■	■						
40	10	■	■	■							
40	20	■	■	■	■						
40	25	■	■	■	■						
40	30	■	■	■	■						
50	10	■	■	■							
50	20	■	■	■	■						
50	25	■	■	■	■						
50	30	■	■	■	■						
50	40		■	■	■						
60	10		■	■							
60	20		■	■	■						
60	30		■	■	■						
60	40		■	■	■	■					
70	20		■	■	■						
70	40		■	■	■	■					
70	50		■	■	■	■					
80	10		■	■							
80	20		■	■	■						
80	30		■	■	■						
80	40		■	■	■	■	■				
80	50			■	■	■	■				
80	60			■	■	■					
100	20		■	■	■						
100	30		■	■	■						
100	40			■	■	■	■				
100	50			■	■	■	■	■			
100	60			■	■	■	■	■			
100	80			■	■	■	■	■			
120	40			■	■	■					
120	60			■	■	■	■	■			
120	80			■	■	■	■	■			
120	100				■	■	■	■			
140	80				■	■	■	■			
150	50				■	■	■	■			
150	100				■	■	■	■	■	■	
160	80				■	■	■	■			
200	100				■	■	■	■	■	■	
250	100				■	■	■	■	■	■	
250	150				■	■	■	■	■	■	
300	100				■	■	■	■	■	■	
300	200						■	■	■	■	■
400	200						■	■	■	■	■

Table 4.3.3. Stainless steel hollow sections circular cross-section (Oy OSTP Ab).
The dimension range apply to steel grade 1.4301, and the availability of other steel grades must be confirmed by the supplier.

D mm / t mm	1 mm	1,2 mm	1,6 mm	2 mm	2,6 mm	3 mm	3,6 mm	4 mm	4,5 mm	5 mm	6 mm	7,1 mm	8 mm	8,8 mm	10 mm	11 mm	12 mm	14 mm
21,3	■	■	■	■	■													
25	■	■	■	■	■													
26,9	■	■	■	■	■	■												
32	■	■	■	■	■	■												
33	■	■	■	■	■	■												
33,7	■	■	■	■	■	■												
35	■	■	■	■	■	■												
38	■	■	■	■	■	■												
40	■	■	■	■	■	■												
42,4	■	■	■	■	■	■												
44,5	■	■	■	■	■	■												
48,3	■	■	■	■	■	■												
50	■	■	■	■	■	■												
50,8	■	■	■	■	■	■												
51	■	■	■	■	■	■												
54	■	■	■	■	■	■												
55	■	■	■	■	■	■												
57	■	■	■	■	■	■	■	■										
60	■	■	■	■	■	■	■	■										
60,3	■	■	■	■	■	■	■	■										
63,5	■	■	■	■	■	■	■	■										
76,1			■	■	■	■	■	■	■									
88,9			■	■	■	■	■	■	■									
101,6			■	■	■	■	■	■	■									
108			■	■	■	■	■	■	■									
114,3			■	■	■	■	■	■	■	■								
133			■	■	■	■	■	■	■	■								
139,7			■	■	■	■	■	■	■	■	■	■	■	■	■			
159			■	■	■	■	■	■	■	■	■	■	■	■	■			
168,3			■	■	■	■	■	■	■	■	■	■	■	■	■	■		
219,1			■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	
273				■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
323,9				■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
355,6					■	■	■	■	■	■	■	■	■	■	■	■	■	■
406,4					■	■	■	■	■	■	■	■	■	■	■	■	■	■
457						■	■	■	■	■	■	■	■	■	■	■	■	■
508						■	■	■	■	■	■	■	■	■	■	■	■	■
610						■	■	■	■	■	■	■	■	■	■	■	■	■
711								■	■	■	■	■	■	■	■	■	■	■
813								■	■	■	■	■	■	■	■	■	■	■
914								■	■	■	■	■	■	■	■	■	■	■
1016								■	■	■	■	■	■	■	■	■	■	
1118								■	■	■	■	■	■	■	■	■	■	
1219								■	■	■	■	■	■	■	■	■		

4.4 Dimensional tolerances

Product standard EN 10219-2 applies to stainless steel hollow sections.

It is general practice to manufacture austenitic stainless steel hollow sections up to wall thickness of 3 mm using tighter outer corner dimensions than specified in standard EN 10219-2.

The dimensional tolerances of stainless steel hollow sections made by Stalatube Oy and Oy OSTP Ab are presented in Table 4.4.1. Tolerances for ferritic and duplex stainless hollow sections must be confirmed by the supplier.

Table 4.4.1. Dimensional tolerances for austenitic hollow sections. The tolerances are in compliance with standard EN 10219-2, with the exception of outer corner dimensions.

<table>
<tr><th>Characteristic</th><th colspan="2">Square and rectangular hollow sections</th><th colspan="2">Circular hollow sections</th></tr>
<tr><td rowspan="2">External dimensions (D, B and H)</td><td>Side length
mm</td><td>Tolerance</td><td colspan="2" rowspan="2">± 1 %, however a minimum of ± 0,5 mm and a maximum of ± 10 mm</td></tr>
<tr><td>H, B < 100

100 ≤ H,B ≤ 200
H, B > 200</td><td>± 1 %, however a minimum of ± 0,5 mm
± 0,8 %
± 0,6 %</td></tr>
<tr><td rowspan="2">Outer corner dimensions
(C_1, C_2 or R) [1]</td><td>Wall thickness
T (mm)</td><td>Outer corner dimensions</td><td colspan="2" rowspan="2">-</td></tr>
<tr><td>T ≤ 3
T > 3</td><td>≤ 1,5T
1,6T...2,4T</td></tr>
<tr><td rowspan="4">Wall thickness (T)</td><td>Wall thickness T (mm)</td><td>Tolerance</td><td colspan="2">When D ≤ 406,4 mm:</td></tr>
<tr><td rowspan="3">T ≤ 5
T > 5</td><td rowspan="3">± 10 %
± 0,5 mm</td><td>Wall thickness T (mm)</td><td>Tolerance</td></tr>
<tr><td>T ≤ 5
T > 5</td><td>± 10 %
± 0,5 mm</td></tr>
<tr><td colspan="2">When D > 406,4 mm:
± 10 %, however a maximum of ± 2 mm</td></tr>
<tr><td>Out-of-roundness (O)</td><td colspan="2">-</td><td colspan="2">2 % for hollow sections whose outer diameter/wall thickness ratio is a maximum of 100 [2]</td></tr>
<tr><td>Concavity or convexity (x_1 , x_2) [3]</td><td colspan="2">Maximum 0,8 %, minimum 0,5 mm</td><td colspan="2">-</td></tr>
<tr><td>Perpendicularity of sides (θ)</td><td colspan="2">90° ± 1°</td><td colspan="2">-</td></tr>
<tr><td>Length (L)</td><td colspan="2">-0/+20 mm[4]</td><td colspan="2">-0/+5 mm[4]</td></tr>
<tr><td>Twist (V)</td><td colspan="2">2 mm + 0,5 mm/m</td><td colspan="2">-</td></tr>
<tr><td>Straightness (e)</td><td colspan="2">0,15 % of total length</td><td colspan="2">0,20 % of total</td></tr>
</table>

[1] Deviates from the requirement of standard EN 10219
[2] In cases where the ratio between outer diameter and wall thickness is greater than 100, out-of-roundness tolerance must be agreed upon
[3] The tolerances for concavity and convexity are independent from the tolerance of outer dimensions
[4] Deviates from the requirement of standard EN 10219 (0/+50 mm)

4.5 Strength classification

Table 3.1.1 presents strength values of base material for stainless steel hollow sections in the annealed condition. Values indicated in Table 3.1.1 are valid for stainless steel hollow sections when enhanced strength values are not guaranteed. In this case, the inspection document for the batch delivered shows the test results of the original material.

The strength values of stainless steel hollow sections can be enhanced by cold-working the material. This can either be done at the steel works by means of temper rolling the strip intended for hollow section manufacture or in the tube production line. In these cases, the mechanical values for the hollow section batch are given in an inspection document indicating values tested from the hollow section. The strength classification of stainless steel hollow sections with enhanced strength values supplied by Stalatube Oy and Oy OSTP Ab are presented in Table 4.5.1.

Table 4.5.1. Strength classification of austenitic stainless steel hollow sections supplied by Stalatube Oy and Oy OSTP Ab when hardening of the material during cold-working is taken into account.

Strength class	**Strength values**	
	f_y [N/mm^2]	f_u [N/mm^2]
CP350 [2)]	350	600[1)]
CP500 [2)]	500	650[1)]

[1)] Minimum tensile strength indicated by the hollow section supplier.
[2)] Availability of different dimensions of the steel grade must be confirmed by the hollow section supplier.

The enhanced strength values of stainless steel hollow sections are verified by means of tensile strength tests. The specimens are taken from the flat face of the hollow section in a longitudinal direction. Therefore, tensile strength tests verify the longitudinal yield strength of the hollow section. For stainless steel hollow sections with a guaranteed yield strength value of 350 N/mm^2, the same value can also be used as a design value for the compression yield strength.

4.6 Surface finishes

The surface finishes of stainless steel hollow sections supplied by different manufacturers vary. Therefore, it is usually beneficial to request samples of different alternatives from the manufacturer.

In the case of square and rectangular hollow sections, mechanical surface finishing methods usually only affect flat surfaces between corners and leave the corner area surface in the original state. Corner areas can be surface treated in a separate work phase.

In the case of circular hollow sections, the visible surface can be treated in such a way that no discontinuities are visible on the surface. Surface treatment can either be longitudinal or transverse.

The surface finishes of hollow sections supplied by Stalatube Oy and Oy OSTP Ab are presented in Table 4.6.1.

Surface finish
• As welded • Brushed • Polished • Mirror polished • Shot-blasted • Pickled

Table 4.6.1. Surface finishes of hollow sections supplied by Stalatube Oy and Oy OSTP Ab

4.7 Processing service

Significant cost savings can be made by using the hollow section supplier's processing service (e.g. less surplus material and lower labour costs). Table 4.7.1 lists the most common processing services offered by Stalatube Oy and Oy OSTP Ab.

Processing service	**Description**
Special length	2-18 m, tolerance 0/+20 mm
Precise cutting	20-9000 mm, tolerance ± 1 mm
Angle cutting 30-90°	Tolerance ± 1°
Laser cutting	Perforating
Tailored components	Components ready for installation

Table 4.7.1. The most common processing services offered by Stalatube Oy and Oy OSTP Ab

Delivery of components ready for installation is a value adding processing service for stainless steel hollow sections. Examples of laser processed components for easy assembly in applications with aesthetic requirements are shown in figure 4.7.1.

Figure 4.7.1. Laser processed components of stainless steel hollow sections

4.8 Order specification

The technical delivery conditions for stainless steel hollow sections can be defined either in accordance with the suppliers' own specification or to the specifications agreed upon with customers.

For dimensional tolerances, reference is normally made to standard EN 10219-2, even though it specifically relates to structural hollow section made of carbon steel. In the case of steel grades, reference is usually made to standard EN 10088-2.

It is recommended that all technical requirements should be defined in as much detail as possible when making the order. The minimum data requirement is:

- Outer dimensions
- Wall thickness
- Length
- Steel grade

E.g. 40x40x2 – 6000 – 1.4301

Technical delivery conditions for standard deliveries are presented in the suppliers' specifications. Additional requirements must always be defined. As a minimum the following technical issues must be taken into account:

- Surface finish
- Dimension tolerances
- Packaging method
- Cleanliness
- Finishing of hollow section ends
- Location of the weld
- Inspections and tests
- Type of inspection document

5. Manufacturing at the workshop

The structures or components made of stainless steel hollow sections are manufactured at the workshop. The manufacturing methods consist of machining, joining and surface treatment.

Joints in stainless steel hollow section components are most often made by welding. The requirements for the surface finish of the weld should be carefully considered in the design phase. Special attention should be paid when the surface finish of the weld is expected to be visually equivalent to the surrounding stainless steel hollow section; this can be difficult, especially for polished surfaces. Special finishing techniques may be utilised to achieve this. If no requirements have been specified for surface finish, the weld surface should be, at a minimum, brushed or polished clean and possibly pickled to improve corrosion resistance. There are no specific application related instructions for finishing the surfaces of welds.

Particular care must be taken during manufacturing steps and the cleanliness of surfaces must be ensured both before and after every work phase. Impurities on the surfaces may cause staining which can occur very early on after installation when the component is exposed to humidity.

5.1 Surface treatments

In addition to surface treatments presented in section 4, additional treatments can be carried out in the workshop or by the subcontractor. The most common treatments for stainless steel surfaces are presented in Table 5.1.1. Further information on surface finishing can be found in the Mechanical finishing of Decorative Stainless Steel Surfaces, Euro Inox, 2005.

Table 5.1.1. Surface treatments for stainless steel hollow sections.

Surface finish	Surface description
Polished grit 180-600	Directional belt polish-ing
Polished mirror	Shiny, mirror like surface
Electrolytically polished	Shiny surface, the original surface profile visible
Shot blasted [1)]	Dependent on the blasting beads, from matt-like to shiny surface
Pickled [2)]	Matt like

[1)] Surfaces can be grit blasted. However, grit that has already been used for carbon steel surface treatment must not be used;. glass beads, aluminium oxide and Cr-Ni are recommended. Residues must be removed from the surface after blasting.

[2)] Pickling is generally carried out by immersion in a tank using a mixed acidic solution (8-20 % HNO_3, 0,5-5 % HF, the rest H_2O, temperature 25-60°C, time 15-30 min)/ Stainless steels and welding/, but other acids can also be used. Pickling paste and spray solutions are comparable with those used in tank immersion. The pickling time is shorter in tank immersion compared to paste and spray processing. The alloying of the material also affects the selected pickling acid content and process time.

Coloured surfaces are prepared using electrochemical methods. A coloured surface can be obtained by electrochemically increasing the thickness of the chromium oxide film. Films of different thickness reflect light in a different way, which enable a wide range of colours to be produced. The service is available in Central Europe and the UK. The method is suitable for austenitic steel grades. If a chemically coloured surface is chosen for a structure, it is recommended that the suppliers are contacted at an early stage of the design in order to find out the requirements for a coloured surface in more detail.

Stainless steel hollow section surfaces can be painted with a wet paint system in the workshop. Guidance should be sought from the paint system suppliers. The main reason for painting austenitic and duplex steels is to enhance the aesthetic image. Although the use of stainless steels is based on the naturally occurring protection of the passive film without any surface treatments, painting may be needed for visual reasons. Steels with low chromium content, such as 1.4003 (Cr content 11 - 12 %) often require a painted coating if used outdoors. /Muokatut teräkset, Raaka-ainekäsikirja 2001, 3.painos/.

Most epoxy and polyurethane based paints with corresponding primers are suitable for painting stainless steel. Special attention must be paid to the pre-treatment of the painted surface. The surface must be carefully cleaned from grease and dirt using an alkaline or solvent solution, after which the surface is rinsed and dried. Best adhesion is obtained on a roughened surface. Shot blasting using aluminium oxide beads or glass beads as well as grinding can be carried out. Matt finished steel is suitable for being painted. Heavy shot blasting is not recommended because the resulting uneven surface may be visible through the paint layer. Blasting can be carried out using common equipment, but the blasting grit must be suitable for stainless steel. /Muokatut teräkset, Raaka-ainekäsikirja 2001, 3.painos/.

A more recent surface treatment method is the so-called nano coating, which is a very thin coating improving certain surface properties. Sol-gel coatings, which are liquid coating compounds spread on the surface, have been successfully used for e.g. plate materials. The composition of the compound affects the surface properties obtained by coating. Typical properties which can be improved by coatings are abrasion resistance, ease of cleaning – even self-cleaning – and corrosion resistance. Coatings for stainless steel hollow sections are still in the early stages of development.

5.2 Welding

Stainless steel hollow sections are well suited for welding using the most common welding methods: metal arc welding with covered electrode, MIG, TIG, plasma arc, MAG flux cored welding and beam welding. Welding is currently the most common method of joining stainless steel hollow sections.

Standard EN ISO 3834 "Quality requirements for fusion welding of metallic materials" presents the methods of implementing customers' requirements and verifying the quality of the welding. EN ISO 3834 is not a quality management system; it is a tool for applying standard ISO9000:2000 / EN ISO 3834/. Therefore, compliance with EN ISO 3834 supports the manufacturer's welding quality in general for the manufacture of industrial components. In particular, when assessing the quality of operations, qualifications for welding, inspection and coordination personnel as well as existence of welding instructions are important. For example, the manufacture and installation works of a structure subject to EN 1993 in the building industry shall be made in compliance with standard prEN 1090 that, in welding related issues, refers to standard EN ISO 3834.

According to CEN ISO/TR 15608:2004, stainless steels are divided into groups 7, 8 and 10 for welding as follows:

- **Group 7** Ferritic and martensitic stainless steels
- **Group 8** Austenitic and manganese-alloyed austenitic stainless steels
- **Group 10** Duplex (austenitic-ferritic) stainless steels

The weldability of stainless steels differs from that of carbon steels due to the lower melting point and, in the case of austenitic and duplex steels, higher thermal expansion coefficients and a lower conductivity factor. The lower melting point enables welding with lower currents or correspondingly with higher welding speed, which results in lower heat input.

Joining different steels together (incl. stainless steel and carbon steel) by welding is possible if the metallurgic changes in corrosion resistance and mechanical strength in the welded area are taken into consideration when selecting materials, filler metals and welding methods.

The table below present typical problems related to the welding and welds of stainless steels that may result in compromised quality of welds.

Table 5.2.1. Possible metallurgical problems in welding stainless steel grades.

Property	Austenitic	Ferritic	Duplex
Hot cracking risk	• No, if the ferrite content of the weld is over 5 % • High Mn is not a risk even if ferrite content < 5 % • Risk exists in fully austenitic CrNi steels	• No	• No
Grain growth embrittlement	• Not critical	• Yes	• Not critical
Service temperature range, impact strength critical	• Not critical	• Ductile in room temperature • Brittle depending on the alloy in lower temperatures	• Not critical
Critical temperature range	• 475 °C-800 °C In high alloy steels • Sensitisation 500 °C-700 °C	• 475 °C-800 °C	• 475 °C-800 °C
Porosity	• Not critical if nitrogen content in CrNi steels less than 0,20 %	• Not critical	• Not critical if nitrogen content in CrNi steels less than 0,20 %
Stress corrosion cracking	• Critical e.g. in swimming pool environments with high Cl- content when using less alloyed steel grades • Not critical in high-alloy austenitic steel grades	• Not critical	• May be critical in a swimming pool environment
Intergranular corrosion	• Depends on the alloy, not critical in low-carbon and alloyed steel grades	• Critical depending on the alloy	• Not critical
Hydrogen embrittlement	• Not critical	• Critical (no hydrogen in the shielding gas)	• Critical (no hydrogen in the shielding gas)

5.2.1 Welding consumables

Table 5.2.1.1. Welding consumables suitable for stainless steel welds / Design manual for structural stainless steel, Euro Inox, 2006/.

	Parent metal	Welding consumables		
	EN 10088	EN 1600	EN 12072	EN 12073
		Covered electrodes	Wires and rods	Flux cored electrodes
A	1.4301	E 19 9	G 19 9 L	T 19 9 L
A	1.4307	E 19 9 L	G 19 9 L	T 19 9 L
A	1.4318	E 19 9 L	G 19 9 L	T 19 9 L
A	1.4372	E 19 9	G 19 9 L	T 19 9 L
A	1.4541	E 19 9 Nb	G 19 9 Nb	T 19 9 Nb
A	1.4404	E 19 12 3 L	G 19 12 3 L	T 19 12 3 L
A	1.4432	E 19 12 3 L	G 19 12 3 L	T 19 12 3 L
A	1.4571	E 19 12 3 Nb	G 19 12 4 Nb	T 19 12 4 Nb
A	1.4539	20 25 5 Cu L	20 25 5 Cu L	20 25 5 Cu L
A	1.4529	NiCr22Mo9Nb	NiCr22Mo9Nb	NiCr22Mo9Nb
A	1.4547	NiCr22Mo9Nb	NiCr22Mo9Nb	NiCr22Mo9Nb
A	1.4565	NiCr25Mo16	NiCr25Mo16	NiCr25Mo16
F	1.4003	E 19 9 L[1)]	G 19 9 L[1)]	T 19 9 L[1)]
F	1.4016	E 19 9 L[1)]	G 19 9 L[1)]	T 19 9 L[1)]
D	1.4362	E 25 7 2 N L /2304[2)]	G 25 7 2 L /2304[2)]	T 22 9 3 N L /2304[2)]
D	1.4462	E 25 7 2 N L	G 25 7 2 L	T 22 9 3 N L
D	1.4162	E 25 7 2 N L /LDX2101[2)]	G 25 7 2 L /LDX2101[2)]	T 22 9 3 N L /LDX2101[2)]

1) Austenitic stainless welding consumables are commonly chosen for joining ferritic stainless steel due to its mechanical strength and corrosion resistance. If equal thermal expansion, colour or nickel-free weld is required, a ferritic stainless welding comsumable, such as E 13 4, must be chosen. Post-heat treatment is required for welds made using ferritic welding consumables.

2) The welding consumable is recommended and produced by Avesta Welding.
The welding consumable is not yet included in a standard.

Table 5.2.1.2. Mechanical properties of welding consumables /Design manual for structural stainless steel, Euro Inox, 2006/.

Filler metal	Yield strength [N/mm²]	Tensile strength [N/mm²]	Elongation min. [%]	Post-heat treatment
E 19 9	350	550	30	no
E/G/T 19 9 L	320	510	30	no
E/G/T 19 9 Nb	350	550	25	no
E 19 12 2	350	550	25	no
E/G/T 19 12 3 L	320	510	25	no
E/G/T 19 12 3 Nb	350	550	25	no
LDX2101[1)]	580[1)]	760[1)]	30[1)]	no[1)]
2304[1)]	550[1)]	750[1)]	30[1)]	no[1)]
E 25 7 2 N L	500	700	15	no
G 25 7 2 L	500	700	15	no
T 22 9 3 N L	500	700	15	no

1) The welding consumable is recommended and produced by Avesta Welding.
The welding consumable is not yet included in a standard. The values are typical values given by the producer.

5.2.2 Welding gases

Welding gases are defined in EN 439. The welding gas used for stainless steels is most often selected from standard groups R, I or M1. The welding method and material to be welded affect the selection of welding gas.

Gases containing hydrogen are not used as shielding gas when welding ferritic and duplex steels.

Table 5.2.2.1. Suitable shielding gas combinations for welding stainless steels /Euro Inox The welding of stainless steel/.

Welding process	Shielding gas	Backing gas
TIG welding and plasma arc welding	Ar Ar+H_2 (tot 20 %)[(1)] Ar+He (tot 70 %) Ar+He+H_2[(1)] Ar+N_2	Ar N_2 N_2+10 % H_2[(1)]
MAG welding	98 % Ar+2 % O_2 97 % Ar+3 % CO_2 95 % Ar+3 % CO_2+2 % H_2[(1)] 83 % Ar+15 % He+2 % CO_2 69 % Ar+30 % He+1 % O_2 90 % He+7,5 % Ar+2,5 % CO_2	Ar N_2 N_2+10 % H_2[(1)]
Flux cored electrode welding	Without shielding gas 97 % Ar+3 % CO_2 80 % Ar+20 % CO_2	Ar N_2 N_2+10 % H_2[(1)] Without backing gas
Ar: argon, H_2: hydrogen, He: helium, N_2: nitrogen, CO_2: carbon dioxide		

[(1)] Welding gases containing hydrogen must not be used for welding ferritic or duplex stainless steel grades because of the risk of embrittlement.

5.2.3 Weld preparation

Welds in hollow sections should be prepared in compliance with standard EN ISO 9692 and prEN1090-2 annex E.

Table 5.2.3.1. Weld preparation suitable for welds between hollow sections /EN ISO 9692/.

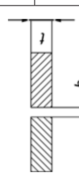
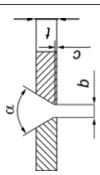
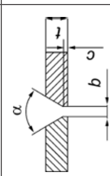
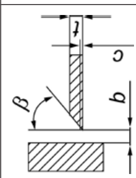
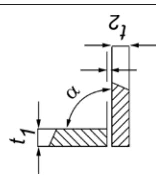
[Ref. nro]	t[mm]	Designation	Cross-section	Angle	Gap b [mm]	Thickness of root face	Depth of preparation	Recom-mended welding method	Remarks
1.2.1	≤4	square preparation		-	~t	-	-	111,141	
1.2.2	3<t≤8			-	6≤ b ≤8	-	-	13	with backing
				-	~t	-	-	141	
1.3	3<t≤10	single V-preparation		40°≤α≤60°	≤ 4	≤ 2	-	111,13,141	with backing if possible
1.5	5≤t≤40	single V-preparation with broad root face		~60°	1≤ b ≤4	2≤ c ≤4	-	111,13,141	
1.9.1	3<t≤10	single bevel preparation		35°≤β≤60°	2≤ b ≤4	1≤ c ≤2	-	111,13,141	
3.1.1	$t_1>2$ $t_2>2$	square preparation		70°≤α≤100°	b ≤2			111,13,141	

Table 5.2.3.2. Weld preparations suitable between round hollow sections /prEN 1090-2/.

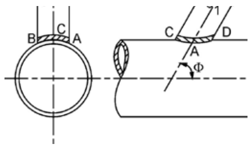
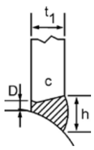
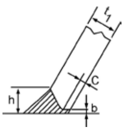
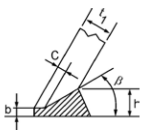
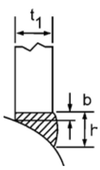
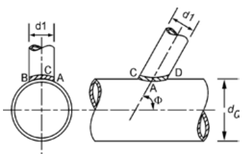
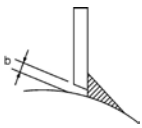
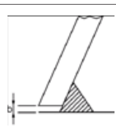
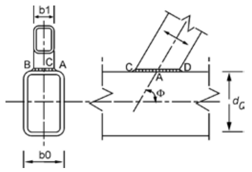
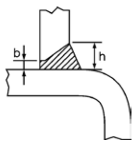
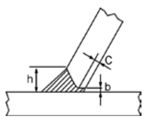
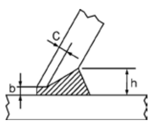
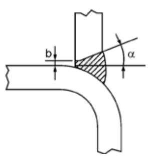
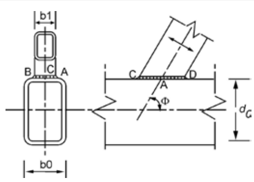
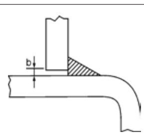
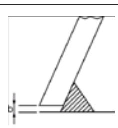
Joint	Detail	c[mm]	b[mm]	Remarks
Circular hollow sections, butt weld				
	$d_1 < d_0$, θ = 60° - 90°			
Points A ja B		1≤ c ≤2	2≤ b ≤4	
Point C		1≤ b ≤2	2≤ b ≤4	
Point D		1≤ c ≤2	2≤ b ≤4	if θ<60° a fillet weld detail should be used
	$d_1 = d_0$	1≤ c ≤2	2≤ b ≤4	
			b ≤2	
Circular hollow sections, fillet weld		1≤ c ≤2		
Points A ja B			b ≤2	
Point C			b ≤2	60°≤θ≤90°, if θ<60° a butt weld detail should be used
Point D			b ≤2	30°≤θ≤90° For smaller angles, full penetration is not required provided there is adequate throat thickness

Table 5.2.3.3. Weld preparation suitable for connections between rectangular hollow sections /prEN 1090-2/.

Joint	Detail			Remarks
Square and rectangular hollow sections, butt welds				
	b1<b0, θ = 30° - 90°	c[mm]	b[mm]	
Points A ja B		1≤ c ≤2	2≤ b ≤4	
Point C		1≤ b ≤2	2≤ b ≤4	
Point D		1≤ c ≤2	2≤ b ≤4	60°≤θ≤90°, for θ<60° a fillet weld detail is preferred to the detail at D
	b1=b0			
		1≤ c ≤2	b ≤2	20°≤α≤25°
Square and rectangular hollow sections, fillet welds				
Points A ja B			b ≤2	
Point C			b ≤2	60°≤θ≤90°, for θ<60° a butt weld detail should be used at C
Point D			b ≤2	30°≤θ≤90°

5.2.4 Selection of welding consumable for dissimilar metal joints

A dissimilar metal joint typically occur when stainless steel is welded to painted or galvanised carbon steel. During welding the metals and welding consumables are mixed in the liquid state. The mixing affects the microstructure created when the liquid metals cool down. An unfavourable microstructure reduces the mechanical strength and corrosion resistance of the weld. The greatest risk is that the microstructure of a weld turns into brittle martensite, i.e. the welded joint hardens. For this reason, high alloy welding consumables must be used when welding dissimilar metal joints, Table 5.2.4.1.

Table 5.2.4.1. Welding consumables for dissimilar metal joints /EN1600, EN12072 and EN12073/.

Welding consumables		
EN1600	EN12072	EN12073
Covered electrodes	Wires and rods	Flux cored electrodes
E 18 8 Mn	G 18 8 Mn	T 18 8 Mn
E 20 10 3	G 20 10 3	T 20 10 3
E 23 12 L	G 23 12 L	T 23 12 L
E 23 12 Nb	G 23 12 Nb	T 23 12 Nb
E 23 12 2 L	G 23 12 2 L	T 23 12 2 L
E 29 9	G 29 9	T 29 9

Welding consumables can also be selected using the so-called Schaeffler diagram. Figure 5.2.4.1 presents the assessment of covered electrode E 23 12 2 L suitable for the welding of stainless steel 1.4306 and carbon steel S235.

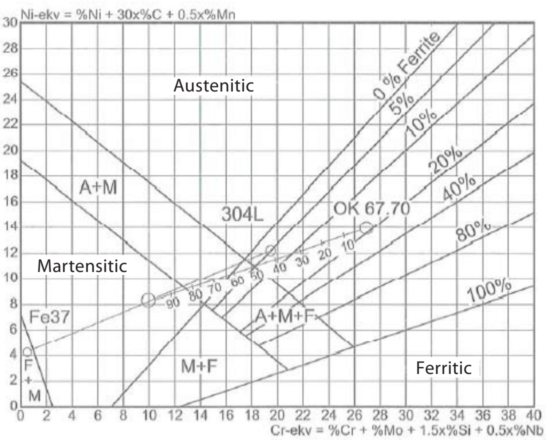
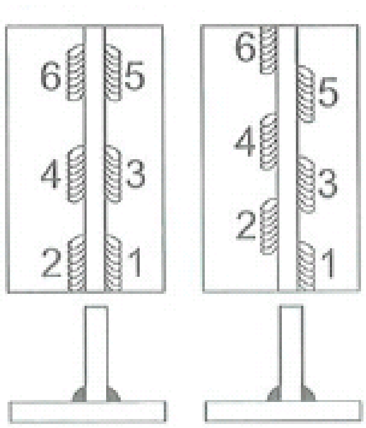


Figure 5.2.4.1 Formation of dissimilar metal joint according to the Schaeffler diagram, when high alloy stainless steel electrode E 23 12 2 L is used to weld Fe37(S235) to 1.4306 (AISI 304L) / Kyröläinen, Lukkari/.

The point indicating weld metal microstructure in dissimilar metal joints is in the middle of the line joining the compositions of the parent materials. A new line is drawn from this central point to the filler material used. The composition of the weld metal created can be predicted on the basis of the mixing ratio. The mixing ratio depends on the welding method used. The goal is to push the composition of weld metal to the austenitic area containing a small proportion of ferrite.

5.2.5 Welding sequence

The objective of defining a welding sequence is to minimise distortion caused by welding heat. The welding sequence is chosen in such a way that the welds can be used to decrease distortion caused by earlier welds. Distortion can also be minimised by avoiding overly large welds, designing small volume grooves, locating welds in the neutral axis of the structure and by using distortion preventing jigs and fixtures. In certain cases, intermittent welds can be used, but it must be taken into consideration that intermittent welds can reduce the corrosion resistance of the weld.



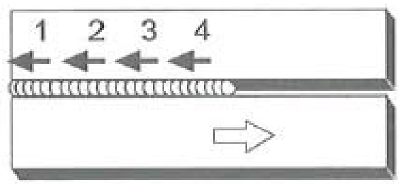


Figure 5.2.5.1. An example of welding sequence that can be used to minimise distortion / Muokatut teräkset, Raaka-ainekäsikirja 2001/. The image on the right indicates that the weld must be tack welded in order to keep the root gap width unchanged during welding.

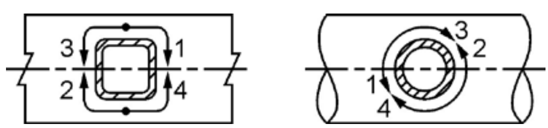
Thermal distortion is greatest in austenitic steel grades which have the highest thermal expansion coefficient. Distortion in ferritic stainless steel corresponds to that of the carbon steel. The degree of distortion in duplex steels is between ferritic and austenitic steel grades.

The recommended welding sequence of typical load carrying joints between hollow sections is presented in Figure 5.2.3 / prEN 1090-2:2007-07(E)/.

Welds must always be continuous around the corner radius of hollow sections. The corner radius area is the worst area to start or end a weld in terms of integrity; stress concentrations occurs in this area which, together with environmental pitting or crevice corrosion risk, may decrease the structural strength of the component.

The start and end points when welding round stainless steel hollow sections must be located at 30-60° angles compared to the longitudinal axis of the chord. Weld location at 90°/270° or 0°/90° angles to the longitudinal axis of the chord is unfavourable in terms of mechanical strength.

Figure 5.2.5.2. Recommended welding sequence of rectangular and round hollow sections / prEN 1090-2:2007-07(E)/.



5.2.6 Post-weld treatment

Welding creates an oxide film, spatter and slag on the stainless steel hollow section surface. The oxide film created by welding contains a high amount of chromium, which originates from the parent material, and impurities. Both the weld and the parent material (HAZ = Heat Affected Zone) are oxidised. This zone is susceptible to corrosion and must be removed if the component is intended for a more demanding environment or hygienic or aesthetic use. Therefore, post-weld treatment is carried out in order to improve the corrosion resistance properties and/or appearance. The objective of post-weld treatment is to remove the spatter, slag and the porous oxide film from the surface, the chromium-poor layer underneath the surface and irregularities in the geometry of the weld surface and joint, Figure 5.2.6.1 Good, uniform surface finish is essential for corrosion resistance.

Post-weld treatment can be carried out mechanically and/or chemically. The uniform distribution of alloying elements of the weld can be enhanced using heat treatment. Heat treatment of components made of stainless steel hollow sections, however, is very rare.

When stainless steel is welded to a structure made of carbon steel, galvanised steel or other less noble metal, the corrosion protection (painting or taping) of the less noble component must be extended for a short section on the stainless steel surface.

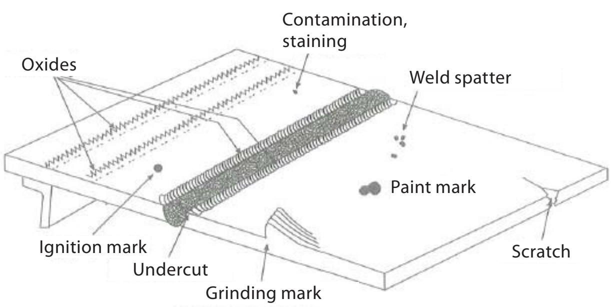


Figure 5.2.6.1. Corrosion initiation points in a welded joint /Ruostumattomat teräkset ja niiden hitsaus/.

Mechanical post-weld treatment methods are wire brushing, shot blasting, grinding and polishing. Chemical methods are picking and electrolytic polishing, see Table 5.2.6.1. Using separate tools and shot blasting grits is of utmost importance in post-weld treatment of stainless steels in order to avoid e.g. extraneous rust caused by carbon steel residues.

Table 5.2.6.1. Typical post-weld treatments for welded joints.

Method	Work method	Removal of material	Appearance after work	Corrosion resistance	Enhancing corrosion resistance
Mechanical					
Brushing	With wire brush, usually manual	Removes the oxide film and splatters.	The surface is rather coarse after brushing.	Corrosion resistance is not significantly better than that of an untreated weld.	The corrosion resistance of brushed surface can be enhanced by grinding or pickling the surface using chemical methods.
Grinding	With abrasive belts, brushes or wheels either manually or using an electric/pneumatic tool	Removes material from the weld and welded area. The weld can be ground to the same level with the parent material surface.	The coarseness of the abrasive band affects the coarseness of the surface. Smooth surface can be achieved if grinding is started with a coarser band and finer abrasive band is used as the work progresses.	Corrosion resistance depends on the coarseness of surface achieved. Once the chromium-poor layer has been removed and a very smooth surface has been achieved, corrosion resistance is almost as good as that of the parent material. Essential factors are to remove a thick enough layer of material in the heat affected zone and the coarseness of the surface.	The corrosion resistance of ground surface can be enhanced by pickling using chemical methods.
Shot/sand blasting	Carried out using machinery suitable for blasting, usually manually in a cabinet or closed blasting space	Removes the oxide film and splatters. Shot blasting forms the surface of the material and discontinuity points in the weld geometry.	The surface finish achieved depends on the blasting grit, geometry of the blast particles, shot/bead size, blasting pressure, distance and angle. Relatively rough, smooth, matt or shiny finish can be achieved.	Corrosion resistance is better than that of a brushed finish. Removes the oxidized but not the chromium poor layer. The impacts of different blasting grits and surface finish achieved by shot blasting on corrosion resistance are not known. Residues must be removed to avoid corrosion and improve appearance.	The corrosion resistance of shot blasted surface can be enhanced by pickling using chemical methods.
Chemical					
Pickling	Carried out as tank immersion, paste, brush or spray pickling taking the environmental and occupational safety requirements into consideration.	Removes surface impurities by corroding. Can also be used for passivating the surface depending on the composition of the pickling acid. Pickling acid must be rinsed thoroughly from the surface.	The appearance changes to be somewhat matt.	Pickling usually gives good corrosion resistance, almost the same as the parent material.	Passivation after pickling may improve corrosion resistance.
Passivation	Carried out as tank immersion or spraying. Aqueous solution of nitric acid is usually used as passivation solution.	The method does not remove material or impurities.	Creates a passive film on the surface. The appearance of the surface becomes slightly more matt.	Passivation is always preceded by a mechanical post-weld treatment. Corrosion resistance depends on the surface finish obtained by mechanical post-weld treatment.	Pickling before passivation improves corrosion resistance.
Electrolytic polishing	Carried out as tank immersion or manual polishing	Not as efficient as pickling, removes impurities and smoothens the roughness of the surface.	Surface appearance changes into bright and slightly smoother. The profile of the original surface will remain visible.	Very good corrosion resistance is achieved if surface roughness before electrolytic polishing is modest.	Corrosion resistance can be improved by pickling the weld first or grinding the surface smooth before electrolytic polishing.

Figure 5.2.6.3. shows the impact of different post-weld treatments on pitting corrosion resistance measured by CPT, Critical Pitting Temperature, above which pitting corrosion commences.

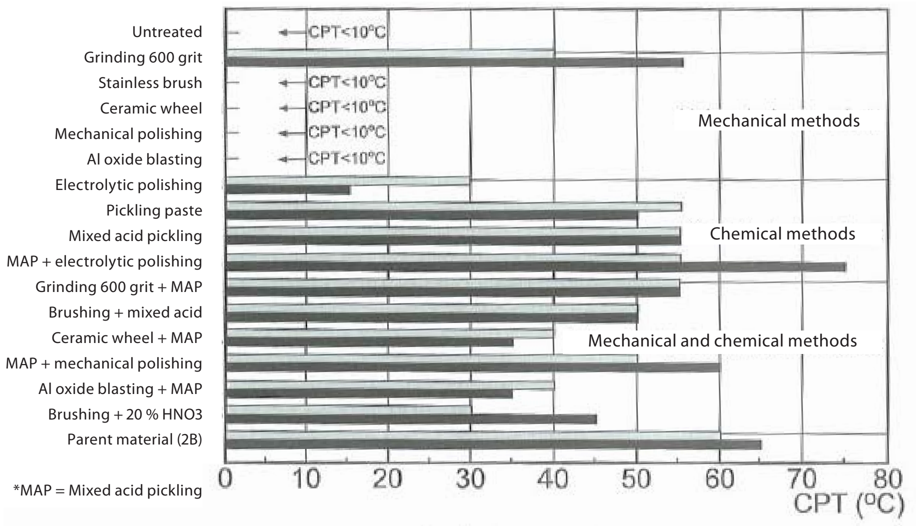


Figure 5.2.6.3. Impact of post-weld treatments on corrosion resistance /Ruostumattomat teräkset ja niiden hitsaus/.

Table 5.2.6.2 below summarises the impacts of the methods listed in the previous figure and their combinations on the corrosion resistance of welds divided into two categories: CPT > 10 °C and CPT < 10 °C.

Grade (CPT, Critical Pitting Temperature)	Method (MAP = Mixed acid pickling)
Good CPT > 10 °C	MAP + electrolytic polishing Grinding 600 grit + MAP MAP MAP + mechanical polishing (MAP), paste pickling Stainless steel brushing + MAP Ceramic wheel grinding + MAP Al oxide blasting + MAP Grinding (600 grit) Stainless steel brushing + 20 % HNO_3 passivation Electrolytic polishing
CPT < 10 °C	Mechanical polishing Stainless steel brushing Ceramic wheel grinding Al oxide blasting Untreated

Table 5.2.6.2. The selection of post-weld treatments and their impact on corrosion resistance / Ruostumattomat teräkset ja niiden hitsaus /.

5.3 Cutting and perforating

5.3.1 Cutting

In addition to traditional band sawing and disc sawing, laser cutting can be applied to stainless steel hollow sections.

In terms of the quality of the cut, essential parameters are the blade material, tooth profile and spacing, feed, cutting speed and cooling for which values suitable for stainless materials and profiles must be found. It is recommended that values given by the blade supplier are used as a starting point.

An automated laser cutting station is needed for cutting hollow sections by laser. When cutting rectangular hollow sections, the corner forms a point of discontinuity which must be taken into account when designing the cut. No similar point of discontinuity exists in round hollow sections. Suitable cutting stations are available in subcontractor workshops and service centres.

When using laser cutting, the thickness of material to be cut is restricted to 10 mm. The selection of cutting gas affects the cutting speed, quality of cut surface, burr formation and oxidisation. Oxygen, nitrogen or argon can be used as cutting gas.

In some cases, it may be necessary to place protection inside the hollow section. The function of protection plate is to collect spatter and prevent it from adhering to the opposite wall and to stop the cutting beam from hitting the opposite wall. The use of inside protection must be considered on a case-by-case basis when cutting stainless steel hollow sections.

When using laser cutting, a bevel for welding or other processing can be made on the edge.

5.3.2 Perforating

Stainless steel hollow sections can be perforated by plasma, laser or water jet cutting, in addition to which round holes can be made by drilling and, for thin material, punching.

When perforating with laser or plasma, special attention should be paid to the setting of parameters for the equipment in order to avoid spatter, uneven cut surface, oxidation of the surface and coniform surfaces. Protection can be placed on the inside of the hollow section to be perforated for the reasons given in the previous section. When perforating with a laser, a bevel for welding or other processing can be made on the edge.

When perforating with a laser, a material thickness of about 10 mm can be worked depending on the capacity of the laser. When using plasma cutting, the entire stainless steel hollow section wall thickness range from 2–14 mm can be perforated.

In water jet cutting, pressurised water and the added abrasive (particles improving cutting) form a cutting water jet. Water jet cutting can be used for the perforating of the entire stainless steel hollow section wall thickness range from 2–14 mm. Similar to the previous methods, the contact between the abrasive jet and the opposite wall must be taken into account. Abrasive must be washed off from the hollow section surfaces after perforating.

Circular openings can be made in the stainless steel hollow section walls by drilling. When drilling holes, attention must be paid to the material and geometry of the drilling edge, in addition to the drilling feed rate and speed of the machine. Stainless steel grades behave differently from each other when being drilled. Ferritic steels are the easiest to drill, whereas the austenitic and duplex steels with strong work-hardening properties have somewhat less advantageous behaviour. When drilling austenitic and duplex steels, the material under the drill hardens if the drill, its geometry or the other drilling parameter values have not been set for that stainless steel grade. The hardened area will be difficult to work when drilling continuously. In order to prevent local hardening, the drilling feed must be high and the rotation speed of the drill low. The rotation speed can be within the range of 8–30 m/min and the drilling feed rate 0,1–0,5 mm/rev. The values depend on the stainless steel grade to be worked. When drilling stainless steels, high-speed steels or hard metal spiral drills are commonly used. Drills can be coated with titanium nitride (TiN) to achieve better durability, in particular when drilling hard and high-strength stainless steel grades. Further information on the selection of parameter values is available from drill manufacturers and from the publication "Maskinbearbetning av rostfria Stål".

5.4 Bolted joints

When selecting the bolt or screw material, the galvanic couple created in the joint must be taken into consideration: the bolt or screw must be the most corrosion resistant – i.e. the noblest – component of the joint. Therefore, when joining materials with the same corrosion resistance, it is also recommended to use a bolt or a screw material that is more noble than the materials to be joined.

Holes for bolts can be made following the guidance for perforating stainless steel hollow sections presented in the previous section.

Bolts and nuts used in joints made of austenitic, ferritic and martensitic steels have been standardised in compliance with EN ISO 3506. Property classes 50, 70 and 80 describe the strength of screws and bolts made of austenitic steel grades. The figure shows how the strength class in the material has been achieved in austenitic steel grades.

Figure 5.4.1 Classification in compliance with EN ISO 3506-1 for corrosion resistant stainless-steel fasteners.

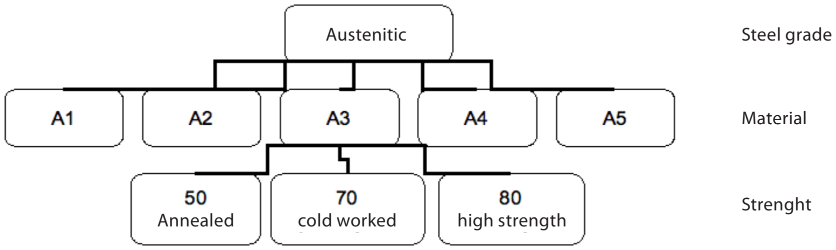


Table 5.4.1 Chemical composition of stainless steel bolts.

Steel group	Steel grade	Chemcial composition [%] (maximum values)									Remarks
		C	Si	Mn	P	S	Cr	Mo	Ni	Cu	
Austenitic	A1	0,12	1	6,5	0,2	0,15–0,35	16–19	0,7	5–10	1,75–2,25	1) 2) 3)
	A2	0,1	1	2	0,05	0,03	15–20	4)	8–19	4	5) 6)
	A3	0,08	1	2	0,045	0,03	17–19	4)	9–12	1	7)
	A4	0,08	1	2	0,045	0,03	16–18,5	2–3	10–15	1	6) 8)
	A5	0,08	1	2	0,045	0,03	16–18,5	2–3	10,5–14	1	7) 8)

1) Sulfur may be replaced by selenium.
2) If the nickel content is below 8 %, the minimum manganese content must be 5 %.
3) There is no minimum limit to the copper content provided that the nickel content is greater than 8 %.
4) Molybdenum may be present at the discretion of the manufacturer. However, if for some applications limiting of the molybdenum content is essential, this must be stated at the time ordering by the purchaser.
5) If the chromium content is below 17 %, the minimum nickel content should be 12 %.
6) For austenitic stainless steels having a maximum a maximum carbon content of 0,03 %, nitrogen may be present to a maximum of 0,22 %.
7) Must contain titanium ≥ 5 x C up to 0,8 % maximum for stabilization and be marked appropriately in accordance with this table, or must contain niobium (colombium) and/or tantalum ≥ 10 x C uo to 1,0 % maximum for stabilization and be marked appropriately in accordance with this table.
8) At the discretion of the manufacturer the carbon content may be higher where required to obtain the specified mechanical properties at larger diameters, but shall not exceed 0,12 % for austenitic steels.

Table 5.4.2. Mechanical properties of austenitic stainless steel bolts.

Steel group	Steel grade	Property class	Thread diameter range	Tensile strength [N/mm²]	0,2%-proof strength [N/mm²]	Elongation after fracture A min. [mm]
Austenitic	A1, A2 A3, A4 A5	50	≤M39	500	210	0,6d
		70	≤M24	700	450	0,4d
		80	≤M24	800	600	0,3d

In the case of lightweight structures, self-drilling screws without pilot hole can be used in material of thickness up to 2–3 mm. However, when drilling thicker materials, the making of a pilot hole is recommended both for self-drilling and self-tapping screws. The proportion of the pilot hole diameter to the screw diameter is critical in terms of both drilling/tapping properties and load-bearing capacity. There may be screw supplier-specific differences in terms of drilling properties and load-bearing capacity of the joint /Pull-out resistance tests of stainless steel screws with pre-drilled clearance holes, VTT, 2005/.

When using self-drilling/tapping screws, the suitable pilot hole diameter must be tested separately for each screw type or parent material. If the screw is subject to a pull-out force, the resistance of the joint must be ensured by means of tests.

When joining stainless steels with self-drilling screws, it is recommended to check the aforementioned issues from the screw supplier because no adequate general information is available. There is no European standard for self-drilling and self-tapping screws. National guidance on the use of such screws in stainless material may exist. In addition, screw suppliers have their own guidance for selecting screws.

Flow drill and tapping is used for joining stainless steel hollow sections with screws in thin materials. Flow drilling is used in e.g. fastening railing systems.

5.5 Other machining

Milling can be used for machining the cut end of stainless steel hollow sections for bevelling or straightening in cases where the tolerance requirement for straightness at the cut end is very strict or for the making of fastening surfaces for components to be joined on the sides. The principles presented for drilling also apply for milling.

Table 5.5.1 Machining values suitable for face milling
/Outokumpu - Ruostumattomat teräkset, Metals Handbook 1989/.

	Feed [mm/teeth]			
Speed[mm/mm] / cutter diameter	6mm	13mm	19mm	25-50mm
24	0,05	0,07	0,13	0,15
82	0,025	0,05	0,07	0,13

5.6 Bending

Stainless steel hollow sections can be bent using a number of different methods. The most common methods are 3-point bending, mandrel bending of round hollow sections and induction bending. Bending of stainless steel hollow sections causes heavy deformation at the point of bending, which leads to changes in the cross-section geometry. The magnitude of deformation correlates with the bending radius and bending method. In the case of a tight bending radius, large deformations tend to occur. Similarly, the deformation in bending hollow sections at room temperature is greater than in induction bending. In round stainless steel hollow sections, a rule of thumb for the tightest bending radius is the diameter measured from the middle of the cross-section multiplied by three /Architects' Guide to Stainless Steel/. There is no corresponding rule for rectangular and square profiles; deformation depends on the ratio of the side wall width to its thickness, h/t and b/t, and the height of profiles in the bending direction (h, b). In addition, the strength of the material, bending method and supporting the point of bending to prevent deformation affect the bending properties of a material. The impact of cross-section work-hardening and greater elastic recovery compared to carbon steel hollow sections, for example, affect the bending properties of austenitic and duplex steels.

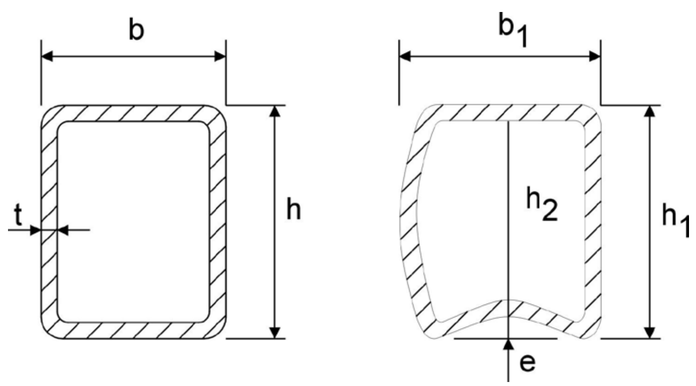


Figure 5.6.1. Cross-section deformation caused by bending.

Roll bending is carried out between the bending and support rolls. Three- and two-roll bending machines are commonly used, Figure 5.6.2. In three-point bending, the middle roll is changed to a position corresponding to the required bending radius, after which the hollow section is fed through the rolls. For two-roll bending, the bending radius is adjusted using the support rolls. Bending is cold forming. In general, stainless steel hollow sections are at room temperature during bending. Roll bending requires a great amount of power, in addition to which the minimum bending radius obtained is greater than that obtained with induction bending. Supporting the cross-section at the point of bending affects deformation in the cross section. The method is suitable both for rectangular and round hollow sections. Three-point bending of stainless rectangular profiles was studied in project / Development of lightweight train and metro cars by using ultra high strength stainless steels (DOLTRAC), ECSC/.

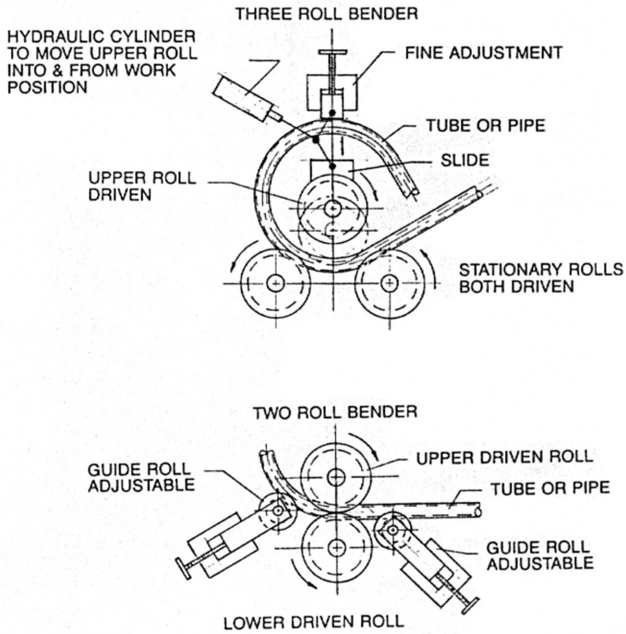


Figure 5.6.2 Operational drawing of roll bending /Pipe and Tube Bending Manual, John Gillanders/.

Round hollow sections can be bent against a mandrel by means of radial bending. One end of the hollow section is fixed and the bending radius is bent against a mandrel and former die. The cross-section of the point of bending is stabilised using bending tools, and the support prevents deformation in the cross-section. The method is suitable for hollow sections with small diameters to produce elbow pipes and short bends, if the compression tools in the machine are fixed. If the compression tools are movable, the machine produces longer bends with a continuous radius.

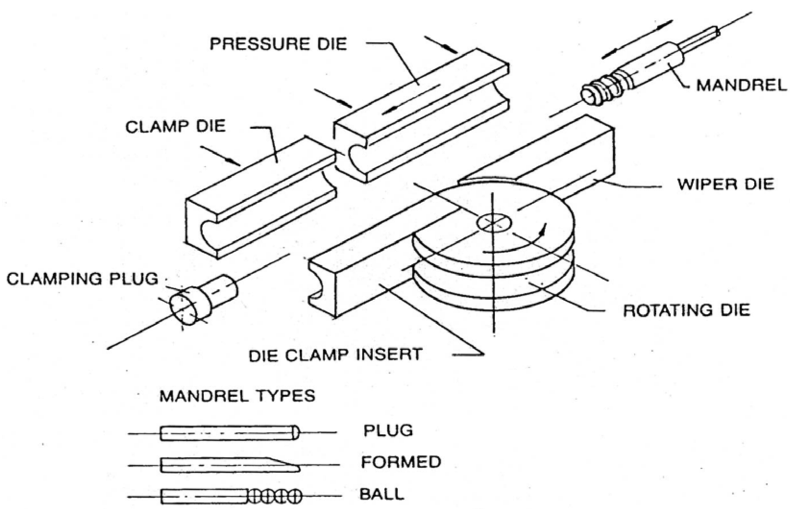


Figure 5.6.3a) Operational drawing on the radial bending tools for round stainless steel hollow sections /Pipe and Tube Bending Manual, John Gillanders/

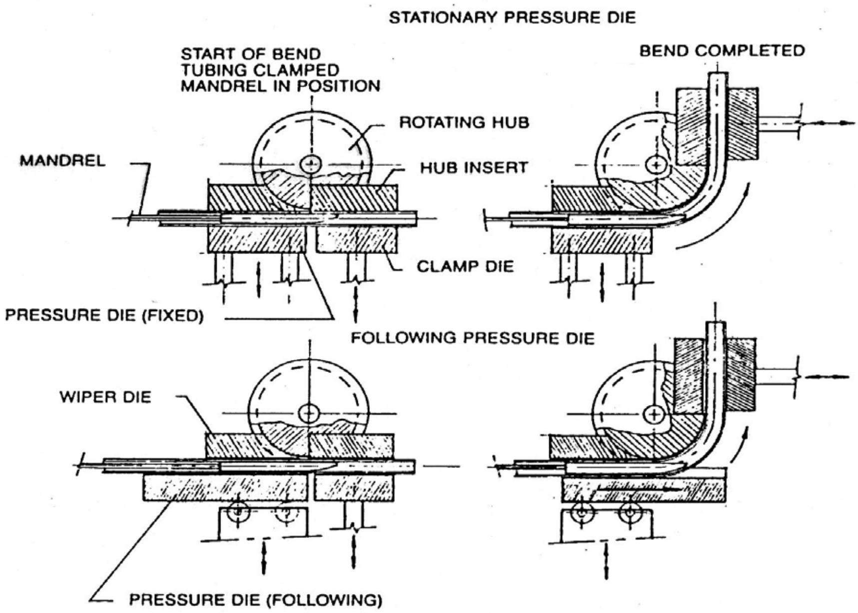


Figure 5.6.3b) Operational drawing on the radial bending of round stainless steel hollow sections /Pipe and Tube Bending Manual, John Gillanders/

A fixed structural profile is bent with transverse compression bending against a former die as shown in Figure 5.6.4.

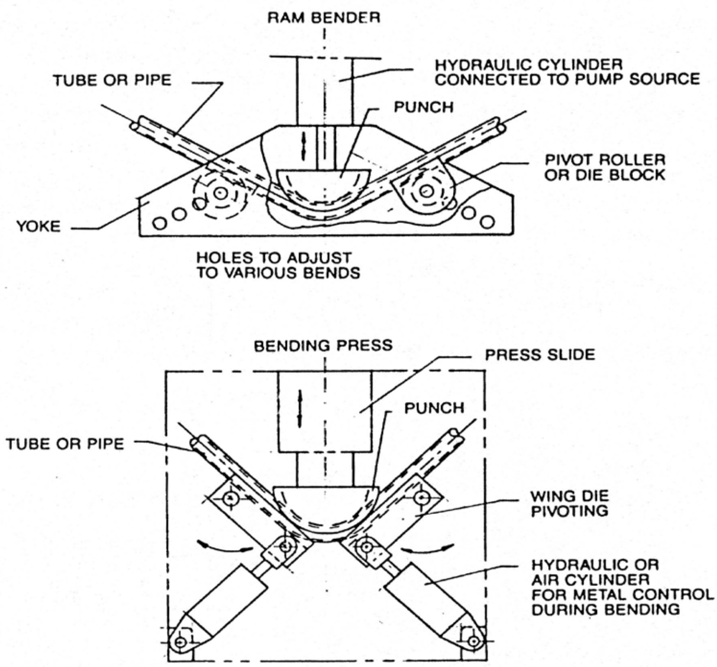


Figure 5.6.4 Operational drawing on transverse compression bending /Pipe and Tube Bending Manual, John Gillanders/.

Large bending radii can be made using transverse compression bending. The compression type bending machines are usually rather modest in terms of technology.

The point of bending is heated up to the bending temperature with an electric induction coil. The use of elevated temperature facilitates the bending process. The point of bending is heated locally in a very narrow area simultaneously with running the hollow section forward. Cross sectional deformation in the point of bending is minor and tighter bending radii can be achieved compared with the aforementioned bending methods. The temperature cycle may result in changes in the crystalline structure of stainless steel and in the formation of an oxide surface film. The oxide film can be removed either by pickling or using other methods (see Welding/Surface treatment). It is recommended that a material specialist is consulted for advice on the impact of heat on the properties of the material.

The bending method used in the workshop affects both the minimum radius achieved and deformation. Tighter bending radii can be achieved with induction bending.

The tables below show estimated bending radii in three-point bending when a deformation of 1 %, 2 % or 5 % is allowed in the web or flange of a cross-section. / CIDECT Report 11C-88/14-E/. Parameter P_b indicates the profile widening in proportion to the flange width and parameter P_e indicates the height of local deformation in compression loaded flange in proportion to the profile web height, Figure 5.6.1.

Table 5.6.1 Bending radius values for square stainless steel hollow sections /CIDECT Report 11C-88/14-E /

				1%		2%		5%	
h[mm]	b[mm]	t[mm]	I[mm^4]	P_b	P_e	P_b	P_e	P_b	P_e
20	20	2							
30	30	2	2,88	0,71	0,22	0,22	0,22	0,22	0,22
		2,6	3,49	0,22	0,22	0,22	0,22	0,22	0,22
		3,2	4,00	0,63	0,22	0,22	0,22	0,22	0,22
40	40	2,6	8,94	1,61	0,22	0,50	0,22	0,22	0,22
		3,2	10,40	1,53	0,22	0,47	0,22	0,22	0,22
		4	12,10	1,44	0,22	0,45	0,22	0,22	0,22
50	50	3,2	21,60	3,05	0,22	0,95	0,22	0,22	0,22
		4	25,50	2,88	0,22	0,90	0,22	0,22	0,22
		5	29,60	2,72	0,22	0,85	0,22	0,22	0,22
60	60	3,2	38,70	5,36	1,76	1,67	0,66	0,36	0,22
		4	46,10	5,07	0,95	1,57	0,35	0,34	0,22
		5	54,40	4,79	0,51	1,49	0,22	0,32	0,22
70	70	3,2	63,00	8,65	4,74	2,69	1,76	0,57	0,48
		4	75,70	8,17	2,55	2,54	0,95	0,54	0,26
		5	90,10	7,72	1,37	2,40	0,51	0,51	0,22
80	80	3,2	95,80	13,08	11,15	4,06	4,14	0,87	1,12
		4	116,00	12,36	5,99	3,84	2,23	0,82	0,60
		5	139,00	11,68	3,22	3,63	1,20	0,77	0,32
		6,3	165,00	11,02	1,69	3,42	0,63	0,73	0,22
90	90	3,2	139,00	18,83	23,72	5,85	8,82	1,25	2,38
		4	168,00	17,80	12,75	5,53	4,74	1,18	1,28
		5	202,00	16,83	6,85	5,23	2,55	1,11	0,69
		6,3	242,00	15,87	3,60	4,93	1,34	1,05	0,36
100	100	3,2	192,00	26,10	46,61	8,11	17,33	1,73	4,68
		4	234,00	24,67	25,05	7,67	9,31	1,63	2,52
		5	283,00	23,32	13,46	7,25	5,00	1,54	1,35
		6,3	341,00	22,00	7,07	6,83	2,63	1,46	0,71
		8	408,00	20,71	3,64	6,43	1,35	1,37	0,37
		10	474,00	19,58	1,95	6,08	0,73	1,30	0,22
120	120	3,2	338,00	45,92	150,01	14,27	55,76	3,04	15,07
		4	413,00	43,41	80,60	13,48	29,96	2,88	8,10
		5	503,00	41,03	43,31	12,75	16,10	2,72	4,35
		6,3	610,00	38,70	22,76	12,02	8,46	2,56	2,29
		8	738,00	36,44	11,70	11,32	4,35	2,41	1,18
		10	870,00	34,44	6,29	10,70	2,34	2,28	0,63
150	150	4	816,00	86,88	336,99	26,92	125,26	5,74	33,86
		5	994,00	81,91	181,06	25,45	67,30	5,43	18,19
		6,3	1212,00	77,27	95,15	24,00	35,37	5,12	9,56
		8	1471,00	72,75	48,93	22,60	18,19	4,82	4,92
		10	1741,00	68,76	26,29	21,36	9,77	4,55	2,64
200	200	5	2433	264,66	618,67	66,82	187,26	10,83	38,58
		6,3	2991,00	176,76	316,83	44,63	95,90	7,24	19,76
		8	3676,00	116,47	158,64	29,41	48,02	4,77	9,89
		10	4417,00	78,88	83,14	19,92	25,17	3,23	5,18
250	250	5,9	5637,00	422,55	623,69	106,69	188,78	17,30	38,89
		8	7404,00	248,27	258,27	62,69	78,17	10,16	16,10
		10	8974,00	168,15	135,35	42,46	40,97	6,88	8,44
300	300	7,1	11720,00	567,46	543,13	143,28	164,39	23,23	33,87
		8	13060,00	460,71	384,45	116,32	116,37	18,86	23,97
		10	15910,00	312,03	201,50	78,79	60,99	12,77	12,56

Table 5.6.2 Bending radius values for rectangular stainless steel hollow sections /CIDECT Report 11C-88/14-E /.

				1%		2%		5%	
h[mm]	b[mm]	t[mm]	I[mm⁴]	P_b	P_e	P_b	P_e	P_b	P_e
50	30	2,6	12,40	2,43	0,32	0,76	0,22	0,22	0,22
		3,2	14,50	2,31	0,22	0,72	0,22	0,22	0,22
		4	17,00	2,18	0,22	0,68	0,22	0,22	0,22
60	40	3,2	28,30	4,30	0,73	1,34	0,27	0,28	0,22
		4	33,60	4,07	0,39	1,26	0,22	0,27	0,22
		5	39,20	3,84	0,22	1,19	0,22	0,25	0,22
70	40	3,2	41,60	6,38	1,41	1,98	0,52	0,42	0,22
		4	49,60	6,03	0,76	1,87	0,28	0,40	0,22
		5	58,30	5,70	0,41	1,77	0,22	0,38	0,22
80	40	3,2	58,10	8,97	2,49	2,79	0,92	0,59	0,25
		4	69,60	8,48	1,34	2,63	0,50	0,56	0,22
100	50	3,2	117,00	17,90	10,39	5,56	3,86	1,19	1,04
		4	142,00	16,92	5,58	5,26	2,08	1,12	0,56
		5	170,00	15,99	3,00	4,97	1,12	1,06	0,30
100	60	3,2	132,00	19,77	15,42	6,14	5,73	1,31	1,55
		4	160,00	18,69	8,29	5,80	3,08	1,24	0,83
		5	192,00	17,66	4,45	5,49	1,66	1,17	0,45
		6,3	230	16,66	2,34	5,18	0,87	1,10	0,24
120	60	3,2	207,00	31,49	33,45	9,78	12,43	2,09	3,36
		4	252,00	29,77	17,97	9,25	6,68	1,97	1,81
		5	304,00	28,14	9,66	8,74	3,59	1,86	0,97
		6,3	366,00	26,54	5,07	8,25	1,89	1,76	0,51
120	80	3,2	251,00	36,83	62,36	11,44	23,18	2,44	6,27
		4	306,00	34,81	33,50	10,81	12,45	2,31	3,37
		5	370,00	32,90	18,00	10,22	6,69	2,18	1,81
		6,3	447,00	31,04	9,46	9,64	3,52	2,06	0,95
140	80	3,2	364,00	54,60	119,98	16,96	44,60	3,62	12,05
		4	445,00	51,61	64,47	16,03	23,96	3,42	6,48
		5	541,00	48,78	34,64	15,15	12,88	3,23	3,48
		6,3	656,00	46,01	18,20	14,29	6,77	3,05	1,83
150	100	3,2	500,00	73,53	260,70	22,84	96,91	4,87	26,19
		4	612,00	69,50	140,08	21,59	52,07	4,60	14,07
		5	747,00	69,59	75,26	20,41	27,98	4,35	7,56
		6,3	910,00	61,97	39,55	19,25	14,70	4,10	3,97
		8	1106,00	58,34	20,34	18,12	7,56	3,86	2,04
		10	1312,00	55,14	10,93	17,13	4,06	3,65	1,10
160	80	3,2	505,00	260,74	141,09	65,84	42,70	10,67	8,80
		4	618,00	176,59	73,94	44,59	22,38	7,23	4,61
		5	753,00	119,60	38,75	30,20	11,73	4,90	2,42
		6,3	917,00	79,88	19,85	20,17	6,01	3,27	1,24
200	100	4	1215,00	376,44	120,37	95,05	36,43	15,41	7,51
		5	1482,00	254,95	63,09	64,37	19,09	10,44	3,93
		6,3	1809,00	170,28	32,31	42,99	9,78	6,97	2,01
		8	2200	112,19	16,18	28,33	4,90	4,59	1,01
		10	2610,00	75,98	8,48	19,19	2,57	3,11	0,53
250	150	5	3341,00	548,84	187,23	138,58	56,67	22,46	11,68
		6,3	4112,00	366,57	95,89	92,56	29,02	15,00	5,98
		8	5061,00	241,53	48,01	60,98	14,53	9,89	2,99
		10	6092,00	163,58	25,16	41,30	7,62	6,70	1,57
300	200	5,9	7334,00	767,31	244,28	193,74	73,94	31,41	15,23
		8	9646,00	450,84	101,16	113,83	30,62	18,45	6,31
		10	11710,00	305,34	53,01	77,09	16,05	12,50	3,31
400	200	7,1	17444,00	1450,81	103,85	366,32	31,43	59,38	6,48
		8	19444,00	1177,85	73,51	297,40	15,14	48,21	4,58
		10	23720,00	797,71	38,52	201,41	11,66	32,65	2,40

5.7 Hydroforming

Hydroforming is a relatively common way to manufacture connection pieces for round hollow sections and components for the automotive industry. Hydroforming is relatively seldom used for square and rectangular hollow sections.

Examples of components made using hydroforming are presented below.

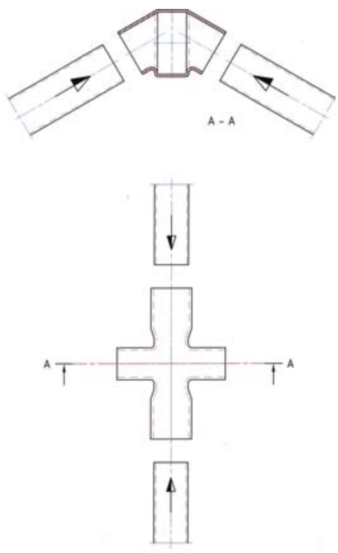


Figure 5.7.1 Connection pieces made by hydroforming are shown on the right. On the left, an operational solution for the use of hydroformed parts as components in a power transmitting structure. /Oy OSTP Ab/.

5.8 Joining different metals

A dissimilar metal joint is created when different materials are in contact. A dissimilar metal joint can become a corrosion risk in environments where the joint area is exposed to moisture and the components are not isolated from each other. Corrosion risk is considered to be modest in dry environments. Often stainless steels are the most noble materials used in common structures.

The risk of galvanic corrosion in contact surfaces between different materials can be minimised /Edelstahl Rostfrei in Kontakt mit Anderen Material/

- By preventing an electric current flowing between the surfaces by, for example, placing insulating material between the surfaces or selecting materials with the same potential, or
- By preventing the formation of electrolytes between the surfaces by, for example, ensuring a dry environment through ventilation, directing the formation of moisture on the surface of only one of the contact materials or by coating materials in the joint area.

Due to the above-mentioned possibilities, it may be useful to prepare detail-specific manufacturing instructions for workshops for joining different materials to stainless steel.

Section 3.4 on electrochemical corrosion presents the electrochemical series of materials in seawater. The series can be used for predicting the behaviour of material pairs. Materials that are far away from each other in the electrochemical series create a corrosion risk when in contact. Such pairs are stainless steel – carbon steel, stainless steel – galvanised steel, stainless steel – aluminium and stainless steel – copper. In practice, these are rather common combinations, for example, in façade structures, railings and fastenings.

In welded joints, a galvanic couple can occur both in a butt weld and fillet weld when full penetration is not obtained on the root side. In addition, a crevice is often created on the root side and moisture in the crevice creates the risk of galvanic corrosion. The details presented in the figure below show a typical weld joint. The selection of filler metal was discussed earlier in section 5.2.

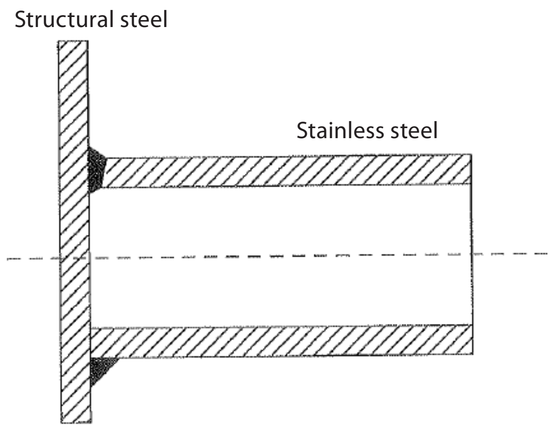


Figure 5.8.1. Detail susceptible to galvanic corrosion on the weld root side. The weld joint above is recommended.

In most cases, materials joined by welding are stainless steel and carbon steel. Carbon steel is protected against corrosion by a simple paint coating or galvanising and paint coating. Welding instructions must include removing the surface coating of carbon steel in a wide enough an area and cleaning the surfaces before welding. After welding, surfaces must be treated as they were originally and note that the paint coating must be, up to a certain length, extended on the stainless steel surface. In this way, the creation of a galvanic couple can be prevented in the joint area even in the case of localised damage in the carbon steel paint coating. In the case of galvanised materials, galvanisation is not extended on the stainless steel surface; instead, the joint area must be covered with paint coating or tape. The potential difference between zinc and stainless steel is relatively great, which can, in the presence of harmful electrolytes, cause rapid corrosion of zinc and thus corrosion damage also to the carbon steel underneath.

Bolted and screw joints are often used to join stainless steel to painted steel, galvanised steel, aluminium or copper.

When using sheet screws, the screw material must be as noble or more noble than the materials to be jointed in order to function as a non-corroding cathode in a corrosive environment. When joining materials to stainless steel, it is recommended that insulation is installed between the surfaces. An aluminium profile can be attached to a stainless steel hollow section, but if moisture is present, galvanic corrosion may cause the creation of a powder-like corrosion product on the surfaces. A similar corrosion product is created in the joint between stainless and galvanised steel.

Operational drawing of the loaded joint between different materials is shown below.

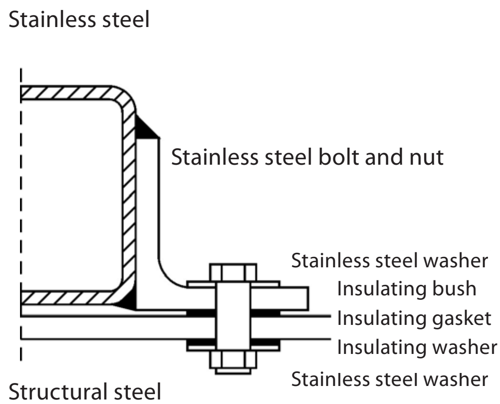


Figure 5.8.2. Operational drawing for the isolation of a dissimilar metal joint.

5.9 Tolerances of structural components

Tolerances for structures for the building industry which are made in workshops are defined in compliance with prEN1090-2. The tables below present class 1 and class 2 tolerances for hollow sections in compliance with the European standard. It must be noted that other requirements may be applied to structures for industries other than the building industry and workshops must apply all such different requirements.

Table 5.9.1. Functional manufacturing tolerances for components

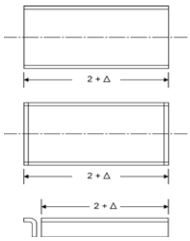
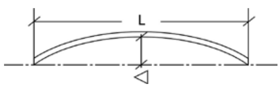
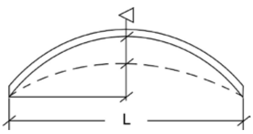
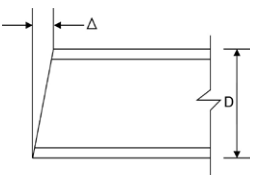
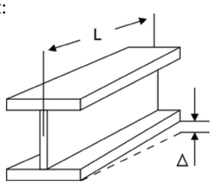
No	Criterion	Parameter	Permitted deviation Δ	
			Class 1	Class 2
1	Length: 	Cut length measured on the centreline (or on the corner of an angle) : • general case: • ends ready for full contact bearing NOTE Length L measured including welded end plates as applicable	|Δ| = L/5000 + 2 mm	
2	Length, where sufficient compensation with next component is possible:	Cut length measured on centreline:	|Δ| = 50 mm	|Δ| = 50 mm
3	Straightness: 	Deviation Δ is given in standard EN 10219-2 and section 4 (this handbook)		
4	Camber or intended curvature on plan: 	Offset f at mid-length:	|Δ| = L/500 but |Δ| ≥ 6 mm Larger of the two values is permitted	|Δ| = L/1000 but |Δ| ≥ 4 mm
6	Squareness of ends: 	Squareness to longitudinal axis: • ends intended for full contact bearing: • ends not intended for full contact bearing:	 |Δ| = D/1000 |Δ| = D/100	 |Δ|= D/1000 |Δ| = D/300 but |Δ| ≤ 10 mm
7	Twist: 	Overall deviation Δ in a piece length is given in standard EN 10219-2 and section 4 (this handbook)		

Table 5.9.2. Functional manufacturing tolerances for holes for fasteners and cut edges.

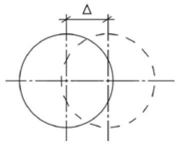
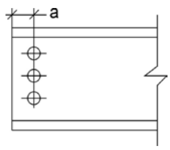
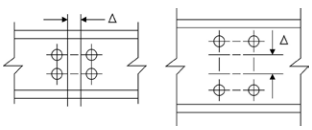
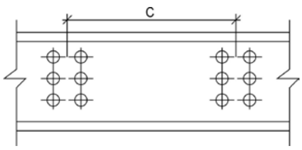
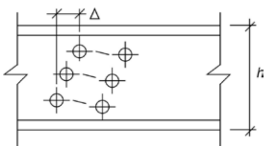
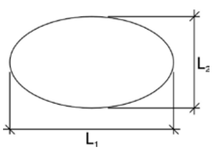
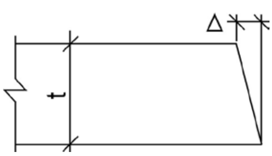
No	Criterion	Parameter	Permitted deviation Δ	
			Class 1	Class 2
1	Position holes for fasteners: 	Deviation Δ of centreline of an individual hole from its intended position within a group of holes:	$\lvert\Delta\rvert = 2$ mm	$\lvert\Delta\rvert = 1$ mm
2	Position of holes for fasteners: 	Deviation Δ in distance a between an individual hole and cut end:	$-\Delta = 0$ mm $+\Delta \leq 3$ mm	$-\Delta = 0$ mm $+\Delta \leq 2$ mm
3	Position of hole groups: 	Deviation Δ of a hole group form its intended position:	$\lvert\Delta\rvert = 2$ mm	$\lvert\Delta\rvert = 1$ mm
4	Spacing of hole groups: 	Deviation Δ in spacing c between cntres of hole groups: • general case • where a single piece is connected by two groups of fasteners	 $\lvert\Delta\rvert = 5$ mm $\lvert\Delta\rvert = 2$ mm	 $\lvert\Delta\rvert = 2$ mm $\lvert\Delta\rvert = 1$ mm
5	Twist of a hole group: 	Twist Δ: if h ≤ 1000 mm if h > 1000 mm	$\lvert\Delta\rvert = 2$ mm	$\lvert\Delta\rvert = 1$ mm
6	Ovalisation: 	$\Delta = L1 - L2$	$\lvert\Delta\rvert = 1$ mm	$\lvert\Delta\rvert = 0,5$ mm
8	Squareness of cut edges: 	Deviation Δ of a cut edge from 90° :	$\lvert\Delta\rvert = 0,1t$ mm	$\lvert\Delta\rvert = 0,05t$ mm

Table 5.9.3. Functional manufacturing tolerances for column splices and baseplates.

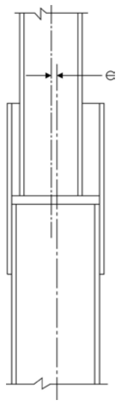
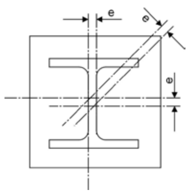
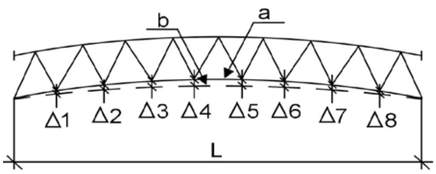
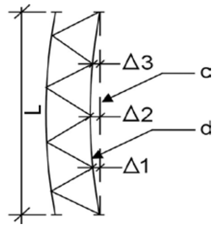
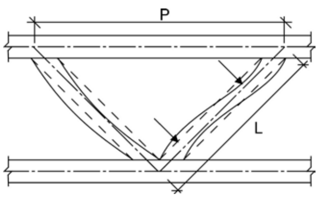
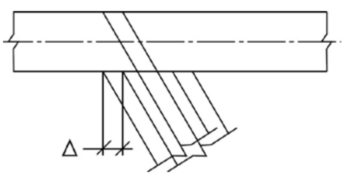
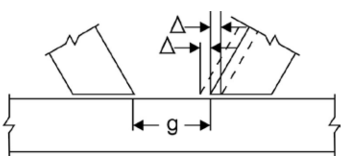
No	Criterion	Parameter	Permitted deviation Δ	
			Class 1	Class 2
1	Column splice 	Non-intended eccentricity e: (about neither axis)	5 mm	3 mm
2	Baseplate: 	Non-intended eccentricity e: (in any direction)	5 mm	3 mm

Table 5.9.4. Functional manufacturing tolerances for lattice structures.

No	Criterion	Parameter	Permitted deviation Δ	
			Class 1	Class 2
1	Straightness and camber:  			
	a actual camber b intended camber c actual line d intended	Deviation at each panel point, relative to a straight line – or to the intended camber or curvature	|Δ| = L/500 but |Δ| ≥ 12 mm	|Δ| = L/500 but |Δ| ≥ 6 mm
2	Panel dimensions: 	Deviation of individual distances p between intersections of centre lines at panel points: Cumulative deviation Σp of panel point position:	|Δ| = 5 mm |Δ| = 10 mm	|Δ| = 3 mm |Δ| = 6 mm
3	Straightness of bracing components:	Deviation of bracing from straightness:	|Δ| = L/500 but |Δ| ≥ 6 mm	|Δ| = L/1000 but |Δ| ≥ 3 mm
5	Intersecting joints: 	Eccentricity (relative to specified eccentricity):	|Δ| = B/20+5 mm	|Δ| = B/40+3 mm
6	Gap joints: 	Gap g between bracing components:	|Δ| = t1 + t2 but |Δ| ≤ 5mm	|Δ| = t1 + t2 but |Δ| ≤ 3mm

6. Structural design aspects for hollow section joints

When designing joints and connections, one must take into consideration the following:

- The mechanical strength and corrosion resistance of the joint and connections must be adequate
- The joints and connections must be able to be properly manufactured and inspected
- Defects arising from difficulties in installation should be avoided
- For welded joints
  - the weld should be located outside the high stress areas
  - the weld should be located outside the stress concentration areas
  - post-weld treatment must be possible

Typical joints in hollow section constructions are T, K, N and Y joints and butt joints between hollow sections. Joints are most commonly made by welding at the workshop. The limiting values for the geometry of load transmitting welded joints are given in standard EN 1993-1-8 and instructions published by CIDECT. Bolted joints are usually used when components are joined on the site. Meshed joints and laser beam machining have not been utilised in load transmitting joints to a large extent.

K joints

The requirements for K joints in hollow section fabrications are that the connection angle between brace and the chord is greater than 30°, the gap g on the chord member surface between brace member must be sufficient large to take care of production of welds and that the joint eccentricity e (point of connection of brace member centre lines in the chord) is not too large. If these limiting values are adhered to, load in the joint is distributed more evenly in the joint area.

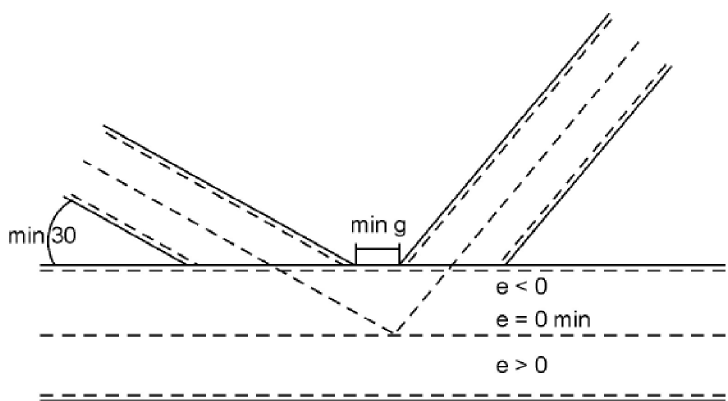


Figure 6.1.1 A typical K joint between hollow sections.

The brace member welds that are transverse to the chord member can be made as fillet welds when the joint angle θ is 60°- 90°. If the joint angle is smaller than 60°, the brace member side facing the gap must be bevelled and welded as a butt weld. The opposite side is welded with a fillet weld in which case the throat thickness should be sufficiently large.

The joint eccentricity e shows the intersection point of the brace members in proportion to the longitudinal axis of the chord member . With eccentricity values e≠0 mm, a bending moment is created in the joint, which must be considered as an additional load on the chord member. If the eccentricity is greater than the limiting value given in Tables 7.2.10.1 and 7.2.10.5 it must be taken into consideration when estimating localised loads in the joint.

A compromise must often be made in design when selecting values for the eccentricity and the gap. In order to be able to make the joint, the minimum value for gap g must be at least t_1+t_2, where t_1 and t_2 are the thicknesses of the two brace member s connected to the joint. The minimum value defined for the gap g_a between the weld edges of the joint is 1,5 times chord member wall thickness, CIDECT 1996 Project 5AQ/2. The selection of sufficient gap g and joint angle ensure that the joint can be made and inspected.

Figure 6.1.2 The end of the brace member must be bevelled if the joint angle is θ≤60°. In this case, the brace member facing the gap must be bevelled and the weld is made as a butt weld to a semi-V groove.

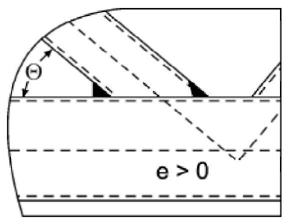
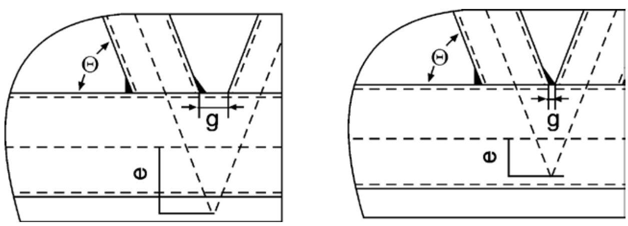


Figure 6.1.3. The impact of gap g between brace member s on the eccentricity e of the joint.



In Figure 6.1.3, the joint angle is greater (60°≤θ≤90°). Because of the greater joint angle, the weld facing the gap is easier to make as a fillet weld with a sufficient throat thickness. However, greater joint angle values also increase eccentricity. In the figure on the right, decreasing the eccentricity of the joint also leads to decreased gap g. Reducing the gap value will lower the deformability of the joint and make it more difficult to achieve a satisfactory weld. Both diagonals to be welded must always be welded separately or an overlapping joint presented in Figure 6.1.4 must be used.

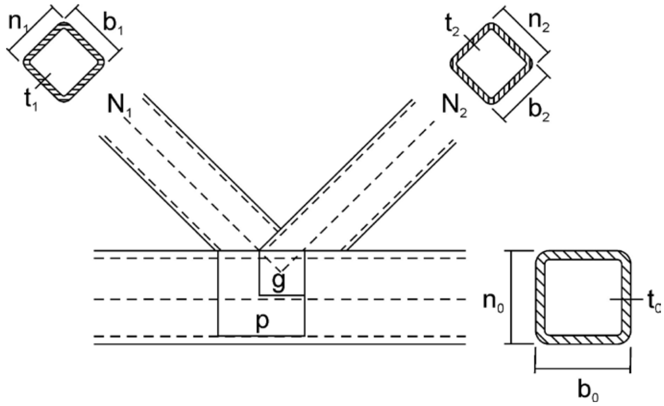


Figure 6.1.4. Overlapping joint.

The strength and rigidity of the joint can be improved by making the ends of the brace members' joint overlap (Figure 6.1.4). Due to overlapping, the brace member flanges also transfer load to the chord member. The chord member surface stresses therefore remain at a lower level and the strength of the joint is defined on the basis of the effective cross-sectional surface of the brace members. It is recommended to weld first the brace member end that remains invisible in overlapping joints

T and Y joints

In the case of T and Y joints, the joint between the brace member and the chord member is designed in the same way as in the case of K joints when the load acts on the level of the brace and chord.

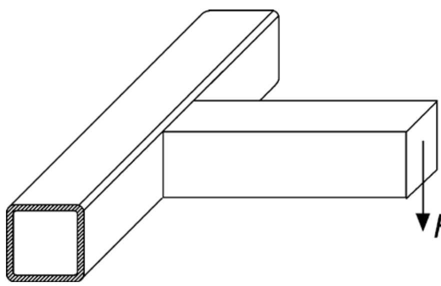


Figure 6.1.5. Typical loading of a T joint.

In the case of joints such as that in Figure 6.1.5, the load at the end of the member being joined to the chord generates a shearing load and torque load on the chord member, in addition to a bending load. Torque can be further divided into a torsional and distortion load acting on the cross-section of the chord member. The distortional load balances itself out, but it deforms the cross-section into a diamond shape (Figure 6.1.6). The distortional load causes deformation of the cross section as well as additional stress components that must be taken into consideration in design. Distortion does not occur if the chord member is a round profile. Further information on the distortion of a box sections can be found in the technical information bulletin MET 2/80 /19/.

Figure 6.1.5 presents a structure in which the joined member is welded on the side of the chord member without stiffeners inside the chord member. Distortion of the chord member cross-section is not prevented, and the deformation indicated in Figure 6.1.6 will occur.

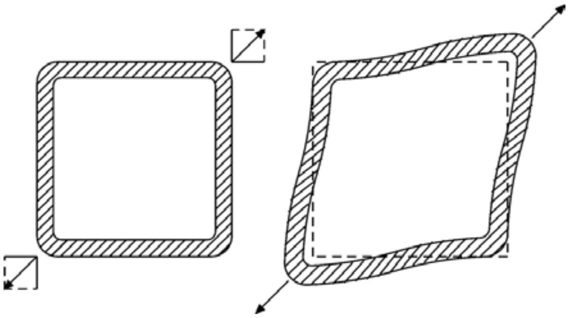


Figure 6.1.6. Loading causing distortion of the cross-section (on the left) and distorted member (on the right).

Figure 6.1.7 shows alternative ways of stiffening the cross-section to prevent distortional deformations. Distortion in the cross-section can also be prevented by means of transverse plates welded inside the hollow section, but this kind of work is very difficult to carry out.

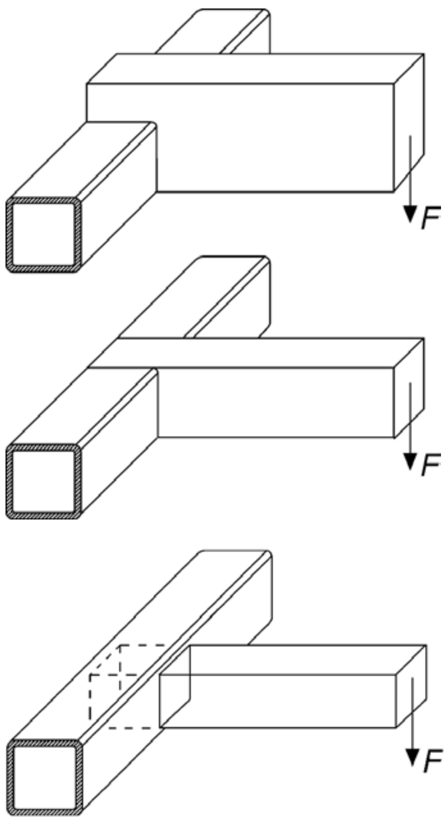
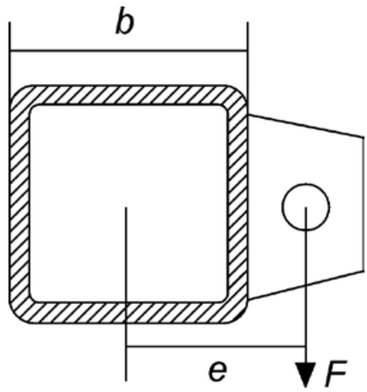


Figure 6.1.7. Alternative ways to prevent distortion of cross-section.

Figure 6.1.8 The load does not cause distortion of the cross-section if force F acts at a distance of e=b from the centre of the profile.



The most typical application of a lug is to transfer loading from a functioning machine, usually a hydraulic cylinder or from a mounting to a hollow section. The shape and location of the lug affect the strength of the joint and the hollow section.

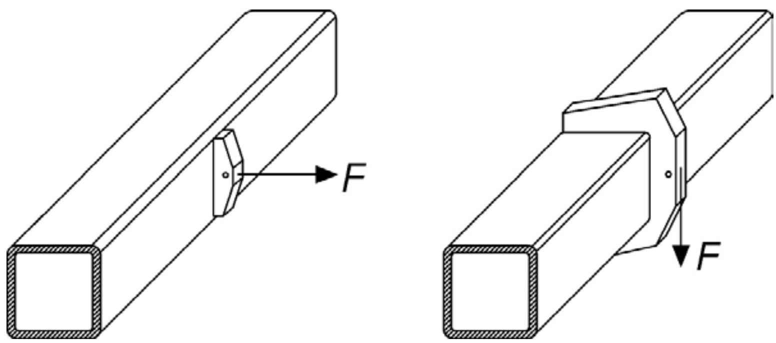


Figure 6.1.9. If load does not cause torque in the chord, the load can be transferred using a lug which is of the same height as the chord. The use of an equally high lug decreases deformations in the chord member side wall (on the left). If a load causes torque in the chord, it is recommended to design the lug in such a way that it can prevent deformations in the cross-section attributed to a distortion ing loading (on the right).

Stainless steel hollow section extensions

Some structures have to be delivered on site as components, for example very large structures.. Wherever, possible, on site connections should be bolted rather than welded. Instructions on extending hollow sections by welding can be found in section 5.2. In the case of bolted joints, the load is transferred from one component to another by means of plates welded on the hollow section.

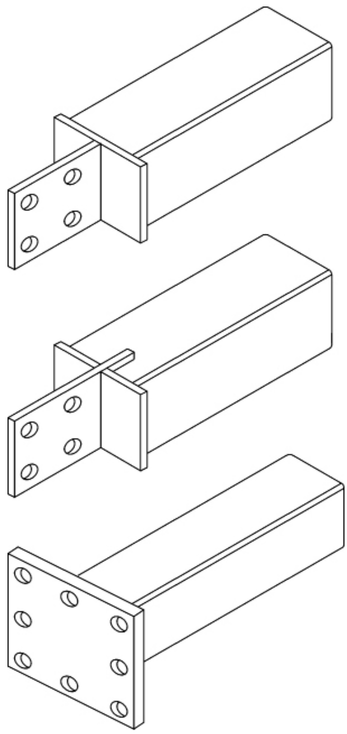


Figure 6.1.10, Some alternative solutions for extending hollow sections.

Small hollow sections and hollow sections with a low level of tensile load can be extended as shown in the picture. The load is not evenly distributed in the cross section near the extension plate.

A double-shear joint decreases the bending moment caused by eccentricity.

In the case of joints exposed to higher tensile load, the load can be more evenly distributed over on the cross section if the joint plate is extended to the hollow section having slots in side walls.

A transverse plate or bolted shanks can convey the load to compression and tensile loaded extension joints. The centre lines of the members to be joined must meet, in which case the eccentricity of the joint decreases. Eccentricity in members under compressive load may cause an initial bend, which decreases the strength of the structure.

7. Design of structures made of stainless steel hollow sections in compliance with standard EN 1993-1-4

The information presented in this section is mainly in compliance with standard EN 1993-1-4 for designing structures for building and civil engineering works. However, the building industry is only one field of application for structural stainless steel hollow sections. If any other application is defined for a structure, the designer must follow the design instructions appropriate for that application. Depending on the case, if no other instructions have been given, standard EN 1993-1-4 or the instructions given in Euro Inox Design Manual (2006) can be followed where appropriate.

7.1 Limit state design

The design of structures in EN 1993-1-4 is based on a limit state analysis. The limit states used are ultimate limit state and serviceability limit state. Ultimate limit states are those which, if exceeded, can lead to collapse of part or the whole of the structure. The serviceability limit state corresponds to a situation beyond which specified service criteria are no longer met. Durability can be regarded as a subset of the ultimate and serviceability limit states depending on whether, for example, corrosion affects the resistance of the structure or its aesthetic appearance / Euro Inox Design Manual, 2006/.

For ultimate limit states, relationships of the following form have to be satisfied:

$$E_d \leq R_d$$

Where E_d is the design value of the effects of an action.
R_d is the resistance design value, which is calculated in compliance with the design instructions.

Ultimate limit states are damage forms related to the resistance of the structure (including general yielding, rupture, buckling and transformation into a mechanism), over-turning and sway or fracture due to fatigue.

The combination of actions for limit states are defined according to EN 1990 and using the appropriate national annex (NA). The combination of actions for limit state design are given below in their general form, but the expressions have to be checked from the appropriate NA.

The following combination of actions is given for the ultimate limit state:

$$\sum_{j\geq 1}\gamma_{G,j}G_{k,j}+\gamma_{Q,1}Q_{k,1}+\sum_{i\succ 1}\gamma_{Q,i}\psi_{0,i}Q_{k,i} \tag{7.1.1}$$

or the ultimate limit state is defined to be the less favourable of the following expressions:

$$\sum_{j\geq 1}\gamma_{G,j}G_{k,j}+\gamma_{Q,1}\psi_{0,i}Q_{k,1}+\sum_{i\succ 1}\gamma_{Q,i}\psi_{0,i}Q_{k,i} \tag{7.1.2a}$$

$$\sum_{j\geq 1}\zeta_{j}\gamma_{G,j}G_{k,j}+\gamma_{Q,1}Q_{k,1}+\sum_{i\succ 1}\gamma_{Q,i}\psi_{0,i}Q_{k,i} \tag{7.1.2b}$$

where:
G_{kj} is the characteristic value of the permanent actions
$Q_{k,1}$ is the characteristic value of the leading variable action 1 (i.e. the most unfavourable variable action)
$Q_{k,i}$ are the characteristic values of the accompanying variable actions i
j is the index for permanent action
i is the index for variable action
$\psi_{0,i}$ is the combination factor of variable action Q

For serviceability limit states, relationships of the following form have to be satisfied:

$E_d \leq C_d$

where:
E_d is the design value of effects of action defined.
C_d is the limiting design value of the relevant serviceability criterion.

The terms examined in serviceability limit states give allowable values for deflection, vibration, repairable damage due to fatigue and creep.

The following combination of actions is usually examined in terms of serviceability limit states for steel structures:

A characteristic combination of actions for the calculation of deflections is usually used:

$$\sum_{j\geq 1}G_{k,j}+Q_{k,1}+\sum_{i\succ 1}\psi_{0,i}Q_{k,i} \tag{7.1.3}$$

Where the values for combination factors ψ_0, ψ_1 and ψ_2 are given in standard EN 1990 and its national annexes.

In the fire situation, the following combination of actions for a steel structure is usually used:

$$\sum_{j\geq 1} G_{k,j} + (\psi_{11} or \psi_{21}) Q_{k1} + \sum_{i\succ 1} \psi_{2,i} Q_{k,i} \tag{7.1.4}$$

Corrosion behaviour and long term aesthetic appearance is a part of the durability. Instructions for the selection of stainless steel grades are given in section 3.

7.2 Structural design with stainless steel hollow sections at room temperature

Structures made of stainless steel hollow sections are designed in compliance with standard EN 1993-1-4 taking the considerations stated in the NA into account. Standard EN1993-1-4 sets guidelines for design if there are any special characteristics that must be taken into consideration. Otherwise, design must be based on the instructions of other EN standards and their national annexes. Instructions for the execution of stainless steel structures are presented in pre-standard prEN 1090-2 (to become EN1090-2).

7.2.1 Material properties

The values of mechanical material properties used for load-bearing structures must meet the requirements of the applied instructions. Requirements for the material in EN1993-1-1 are as follows:

- Elongation at failure: a minimum of 15 %
- Tensile to yield strength ratio $f_u / f_y \geq 1{,}10$
- Ultimate strain $\varepsilon_u \geq 15\ \varepsilon_y$, where ε_y is the yield strain
- The material must have sufficient fracture toughness in order to avoid brittle fracture of tension components at the lowest temperature of use that is expected to occur during the design service life of the structure. It can be assumed that austenitic and duplex steel grades that are in compliance with EN 1993-1-4 have sufficient toughness and are not susceptible to brittle fracture in temperatures above -40°C. Stainless steels can also be used at temperatures lower than -40°C, but the requirements for use must be defined on a case-by-case basis.

The design rules presented in standard EN 1993-1-4 are suitable for annealed materials up to yield strength $f_y = 480\ N/mm^2$ and cold worked materials up to strength classes C700 and CP350.

Table 7.2.1. Recommended partial factors in compliance with EN 1993-1-4.

Resistance of cross-sections to excessive yielding including local buckling	γ_{M0}	Recommended value 1,1
Resistance of members to instability assessed by member checks	γ_{M1}	Recommended value 1,1
Resistance of cross-sections in tension to fracture	γ_{M2}	Recommended value 1,25
Resistance of bolts, rivets, welds pins and plates in bearing	γ_{M2}	Recommended value 1,25

7.2.2 Classification of cross-section for stainless steel hollow sections

The cross-section class for stainless steel hollow section subject to axial compression is defined as follows:

	Rectangular/square	Circular
Class 1 cross-section:	$c/t \leq 25{,}7\varepsilon$	$d/t \leq 50\varepsilon^2$
Class 2 cross-section:	$c/t \leq 26{,}7\varepsilon$	$d/t \leq 70\varepsilon^2$
Class 3 cross-section:	$c/t \leq 30{,}7\varepsilon$	$d/t \leq 90\varepsilon^2$

The cross-section class for stainless steel hollow sections subject to bending moment is defined as follows:

	Rectangular/square	Circular
Class 1 cross-section:	$c/t \leq 56{,}0\varepsilon$	$d/t \leq 50\varepsilon^2$
Class 2 cross-section:	$c/t \leq 58{,}2\varepsilon$	$d/t \leq 70\varepsilon^2$
Class 3 cross-section:	$c/t \leq 74{,}8\varepsilon$	$d/t \leq 280\varepsilon^2$

The cross-section class for square stainless steel hollow sections subject to combined axial compression and bending moment is defined as follows:

Class 1 cross-section: $\alpha > 0{,}5$: $c/t \leq \dfrac{308\varepsilon}{13\alpha - 1}$

$\alpha \leq 0{,}5$: $c/t \leq \dfrac{28\varepsilon}{\alpha}$

Class 2 cross-section: $\alpha > 0{,}5$: $c/t \leq \dfrac{320\varepsilon}{13\alpha - 1}$

$\alpha \leq 0{,}5$: $c/t \leq \dfrac{29{,}1\varepsilon}{\alpha}$

Class 3 cross-section: $c/t \leq 15{,}3\varepsilon\sqrt{k_\sigma}$

- c may conservatively be taken as h-2t or b-2t
- $\varepsilon = \sqrt{\frac{235}{f_y} \cdot \frac{E}{210000}}$
- α describes the ratio of a compression part width to flat side width c in class 1 and 2 cross-sections.
- $\alpha = \frac{1}{2}\left(1 + \frac{N_{Ed}}{f_y c \sum t_w}\right)$ (Euroinox Design Manual 2006)
-
- k_σ is determined as follows, in compliance with EN 1993-1-5.

The resistance of a cross-section loaded with shear force in cases where shear buckling resistance is critical is calculated in compliance with EN 1993-1-5. In other cases, shear resistance is calculated as shown in section 7.2.7.

In rectangular and square profiles, shear buckling resistance is determined when the following condition applies:

$h_w / t \geq 52\varepsilon / \eta$ where η =1,20

7.2.3 Resistance of hollow sections subject to tension

The tensile resistance of gross cross-sections of stainless steel hollow sections is calculated as follows:

$$N_{pl,Rd} = \frac{A \cdot f_y}{\gamma_{M0}} \qquad (7.2.3.1)$$

Whereas the tensile resistance of the net cross-section is calculated as follows:

$$N_{u,Rd} = \frac{k_r \cdot A_{net} \cdot f_u}{\gamma_{M2}} \qquad (7.2.3.2)$$

where:

$k_r = (1 + 3 \cdot r \cdot (\frac{d_0}{u} - 0.3))$, however ≤ 1,0

r is the number of bolts at the cross-section / total number of bolts in the connection

u is $2e_2$, however ≤ p_2

d_0 is the nominal bolt hole diameter

e_2 is the distance from the centre of the hole to the profile edge perpendicular to the load affecting the connection

p_2 is the distance between hole centres perpendicular to the load affecting the connection.

7.2.4. Resistance of hollow sections subject to bending moment

7.2.4.1 The cross-section resistance of stainless steel hollow sections subject to bending moment

Class 1 and 2 cross-sections:

$$M_{c,Rd} = M_{pl,Rd} = \frac{W_{pl} \cdot f_y}{\gamma_{M0}} \qquad (7.2.4.1)$$

Class 3 cross-sections:

$$M_{c,Rd} = M_{el,Rd} = \frac{W_{el} \cdot f_y}{\gamma_{M0}} \qquad (7.2.4.2)$$

Class 4 cross-sections:

$$M_{c,Rd} = M_{eff,Rd} = \frac{W_{eff} \cdot f_y}{\gamma_{M0}} \qquad (7.2.4.3)$$

W_{pl} is the plastic section modulus

W_{el} is the elastic section modulus

W_{eff} is the elastic modulus of the effective cross-section

7.2.4.2 Lateral-torsional buckling resistance of hollow sections subject to bending moment

This type of failure may occur when the h/b ratio of a rectangular hollow section is large.

It is not necessary to calculate the resistance if:

- the member is loaded in bending only about the weaker axis
- the member is restrained along the whole of its length
- the non-dimensional slenderness

  $\bar{\lambda}_{LT} \le 0{,}4$ or $\frac{M_{Ed}}{M_{cr}} \le 0{,}16$.

$$M_{b,Rd} = \chi_{LT} \cdot \frac{W_y \cdot f_y}{\gamma_{M1}} \qquad (7.2.4.4)$$

W_y is $W_{pl,y}$ for Class 1 and 2 cross-sections

W_y is $W_{el,y}$ for Class 3 cross-sections

W_y is $W_{eff,y}$ for Class 4 cross-sections

$$\chi_{LT} = \frac{1}{{}_{LT}^{2} + \sqrt{{}_{LT}^{2} - \bar{\lambda}_{LT}^{2}}} \text{ however} \le 1{,}0 \qquad (7.2.4.5)$$

$$\varphi_{LT} = 0{,}5\left(1 + 0{,}34\left(\bar{\lambda}_{LT} - 0{,}4\right) + \bar{\lambda}_{LT}^{2}\right) \qquad (7.2.4.6)$$

$$\bar{\lambda}_{LT} = \sqrt{\frac{W_y \cdot f_y}{M_{cr}}} \qquad (7.2.4.7)$$

M_{cr} is the elastic critical moment for lateral-torsional buckling .

7.2.5 Resistance of hollow sections subject to axial compression

7.2.5.1 Cross-section resistance

The cross-section resistance of an axially compression loaded member is calculated using the following equation:

$$N_{pl,Rd} = Af_y / \gamma_{M0} \tag{7.2.5.1}$$

where:
A is the cross-section area in class 1, 2 and 3 cross-sections
A is the effective cross-section area A_{eff} in class 4 cross-sections.

When calculating the cross-section resistance for class 4 cross-sections, plate buckling of the side wall is taken into consideration as a resistance-limiting factor. The cross-section area subject to compression loading is reduced as shown below. This is done by using the effective cross-section area A_{eff}, which is smaller than the gross cross-section area in equation (7.2.5.1).

The effective cross section area A_{eff} of the compressed part of the side wall is:

$$A_{c,eff} = \rho A_c \tag{7.2.5.2}$$

where:
ρ is the reduction factor taking plate buckling into consideration
A_c is the cross section area of the compressed part of the panel

The effective width of class 4 cross-sections is defined as follows:

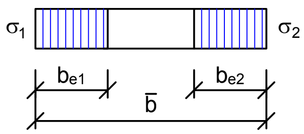
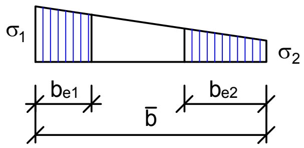
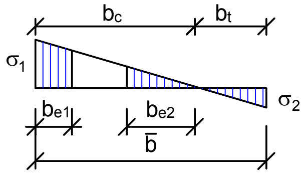
$$\rho = \frac{0.772}{\bar{\lambda}_p} - \frac{0.125}{\bar{\lambda}_p^2} \text{ but } \leq 1,0 \tag{7.2.5.3}$$

where:
$\bar{\lambda}_p$ is the non-dimensional slenderness of the side wall and is defined as follows:

$$\bar{\lambda}_p = \frac{\bar{b}/t}{28,4\varepsilon\sqrt{k_\sigma}}$$

where:
t is the wall thickness of the stainless steel hollow section;
k_σ is the buckling factor, which corresponds to stress ratio ψ and boundary conditions, in compliance with Table 4.1 or Table 4.2 in standard EN 1993-1-5; When the side wall is loaded with uniform compression, k_σ= 4,0. Other loading types are presented in Table 7.2.5.1.
$\bar{b}$ is the side length of the stainless steel hollow section and can be taken as h-2t or b-2t for a conservative value.

Table 7.2.5.1 Determination of effective width for internal compression elements / EN 1993-1-1/

Stress distribution (compression positive)	Effective width b_{eff}
	<u>ψ = 1</u>: $b_{eff} = \rho\ \bar{b}$ $b_{e1} = 0,5\ b_{eff}$ $b_{e2} = 0,5\ b_{eff}$
	<u>1 > ψ ≥ 0</u>: $b_{eff} = \rho\ \bar{b}$ $b_{e1} = \frac{2}{5-\psi} b_{eff}$ $b_{e2} = b_{eff} - b_{e1}$
	<u>ψ < 0</u>: $b_{eff} = \rho\ b_c = \rho\ \bar{b} / (1-\psi)$ $b_{e1} = 0,4\ b_{eff}$ $b_{e2} = 0,6\ b_{eff}$

$\Psi = \sigma_2/\sigma_1$	1	1 > ψ > 0	0	0 > ψ > -1	-1	-1 > ψ > -3
Buckling factor k_σ	4,0	8,2 / (1,05 + ψ)	7,81	$7,81 - 6,29\psi + 9,78\psi^2$	23,9	$5,98\ (1 - \psi)^2$

7.2.5.2 Buckling resistance of a member subject to axial compression

The resistance of a member against axial force is defined as follows:

$$N_{b,Rd} = \chi \cdot A \cdot f_y / \gamma_{M1} \qquad (7.2.5.4)$$

$A = A_{eff}$ Class 4 cross section

$$\chi = \frac{1}{\varphi + \sqrt{\varphi^2 - \bar{\lambda}^2}} \quad \text{but } \chi \leq 1,0 \qquad (7.2.5.5)$$

$$\varphi = 0,5\left[1 + 0,49\left(\bar{\lambda} - 0,4\right) + \bar{\lambda}^2\right]$$

$$\bar{\lambda} = \sqrt{\frac{Af_y}{N_{cr}}}$$ Class 1, 2 and 3 cross-sections;

$$\bar{\lambda} = \sqrt{\frac{A_{eff} f_y}{N_{cr}}}$$ Class 4 cross-section;

N_{cr} is the elastic critical force for the relevant buckling calculated on the basis of gross cross-sectional properties.

7.2.6 Resistance of hollow section member subject to axial compression and bending moment

Axial compression and uniaxial major axis bending moment:

To prevent premature buckling about the major axis:

$$\frac{N_{\mathrm{Ed}}}{(N_{\mathrm{b,Rd}})_{\min}} + k_y \left(\frac{M_{\mathrm{y,Ed}} + N_{\mathrm{Ed}}\, e_{\mathrm{Ny}}}{\beta_{\mathrm{W,y}} W_{\mathrm{pl,y}} f_{\mathrm{y}} / \gamma_{\mathrm{M1}}} \right) \leq 1 \qquad (7.2.6.1)$$

To prevent premature buckling about the minor axis (for members subject to lateral-torsional buckling):

$$\frac{N_{\mathrm{Ed}}}{(N_{\mathrm{b,Rd}})_{\min 1}} + k_{LT} \left(\frac{M_{\mathrm{y,Ed}} + N_{\mathrm{Ed}}\, e_{\mathrm{Ny}}}{M_{\mathrm{b,Rd}}} \right) \leq 1 \qquad (7.2.6.2)$$

Axial compression and uniaxial minor axis bending moment:

To prevent premature buckling about the minor axis:

$$\frac{N_{\mathrm{Ed}}}{(N_{\mathrm{b,Rd}})_{\min}} + k_z \left(\frac{M_{\mathrm{z,Ed}} + N_{\mathrm{Ed}}\, e_{\mathrm{Nz}}}{\beta_{\mathrm{W,z}} W_{\mathrm{pl,z}} f_{\mathrm{y}} / \gamma_{\mathrm{M1}}} \right) \leq 1 \qquad (7.2.6.3)$$

Axial compression and biaxial bending moments:

All members should satisfy:

$$\frac{N_{\mathrm{Ed}}}{(N_{\mathrm{b,Rd}})_{\min}} + k_y \left(\frac{M_{\mathrm{y,Ed}} + N_{\mathrm{Ed}}\, e_{\mathrm{Ny}}}{\beta_{\mathrm{W,y}} W_{\mathrm{pl,y}} f_{\mathrm{y}} / \gamma_{\mathrm{M1}}} \right) + k_z \left(\frac{M_{\mathrm{z,Ed}} + N_{\mathrm{Ed}}\, e_{\mathrm{Nz}}}{\beta_{\mathrm{W,z}} W_{\mathrm{pl,z}} f_{\mathrm{y}} / \gamma_{\mathrm{M1}}} \right) \leq 1 \qquad (7.2.6.4)$$

Members potentially subject to lateral-torsional buckling should also satisfy:

$$\frac{N_{\mathrm{Ed}}}{(N_{\mathrm{b,Rd}})_{\min 1}} + k_{LT} \left(\frac{M_{\mathrm{y,Ed}} + N_{\mathrm{Ed}}\, e_{\mathrm{Ny}}}{M_{\mathrm{b,Rd}}} \right) + k_z \left(\frac{M_{\mathrm{z,Ed}} + N_{\mathrm{Ed}}\, e_{\mathrm{Nz}}}{\beta_{\mathrm{W,z}} W_{\mathrm{pl,z}} f_{\mathrm{y}} / \gamma_{\mathrm{M1}}} \right) \leq 1 \qquad (7.2.6.5)$$

In the above expressions:

- e_{Ny} and e_{Nz} are the shifts in the neutral axes when the cross-section is subject to uniform compression;
- N_{Ed}, $M_{y,Ed}$ and $M_{z,Ed}$ are the design values of the axial compression load and the maximum bending moments about the y-y and z-z axis along the member;
- $(N_{b,Rd})_{min}$ is the smallest value of $N_{b,Rd}$ for the following four buckling modes: flexural buckling about the y-y axis, flexural buckling about the z-z axis, torsional buckling and torsional-flexural buckling;

- $(N_{b,Rd})_{min1}$ is the smallest value of $N_{b,Rd}$ for the following three buckling modes: flexural buckling about the z-z axis, torsional buckling and torsional-flexural buckling;
- $\beta_{W,y}$ ja $\beta_{W,z}$ are the values of β_W determined for the y-y and z-z axes, in which:
- $\beta_W = 1,0$ for class 1 and 2 cross-sections;
- $\beta_W = W_{el}/W_{pl}$ for class 3 cross-sections;
- $\beta_W = W_{eff}/W_{pl}$ for class 4 cross-sections;
- $W_{pl,y}$ and $W_{pl,z}$ are the plastic moduli for the y-y and z-z axes respectively;
- $M_{b,Rd}$ is the lateral-torsional buckling resistance;
- k_y, k_z, k_{LT} are the interaction factors.

  The interaction factor values are calculated as follows, in compliance with EN 1993-1-4:

$$k_y = 1,0 + 2\left(\bar{\lambda}_y - 0,5\right)\frac{N_{Ed}}{N_{b,Rd,y}}, \qquad \text{but} \qquad 1,2 \le k_y \le 1,2 + 2\frac{N_{Ed}}{N_{b,Rd,y}}$$

$$k_z = 1,0 + 2\left(\bar{\lambda}_z - 0,5\right)\frac{N_{Ed}}{\left(N_{b,Rd}\right)_{\min 1}}, \qquad \text{but} \qquad 1,2 \le k_z \le 1,2 + 2\frac{N_{Ed}}{\left(N_{b,Rd}\right)_{\min 1}}$$

$k_{LT}=1,0$

7.2.7 Resistance of hollow sections subject to shear

The plastic shear resistance of a cross-section can be calculated as follows:

Design value of plastic shear resistance, when shear buckling resistance is not critical, can be calculated as:

$$V_{pl,Rd} = A_v\,(f_y / \sqrt{3}) / \gamma_{M0} \qquad (7.2.7.1)$$

where A_v is the shear area:

- For rectangular stainless steel hollow sections
  - Load parallel to height : $Ah/(b+h)$
  - Load parallel to width: $Ab/(b+h)$
- For circular hollow sections: $2A/\pi$

7.2.8 Resistance of welded joints

The method of calculation of resistance of welds depends on the standard used. Applicable standards are EN 1993-1-4:2006 and Australian/New Zealand standard AS/NZS 4673:2001 Cold-formed stainless steel structures. There is also guidance in the Euro Inox – Design Manual for Structural Stainless Steel and the data sheet 15/2002 “Butt welds in cold-worked austenitic stainless steel hollow sections” of the Finnish Constructional Steelwork Association (in Finnish).

The design of welds according to EN 1993-1-4:2006 is based on standard EN 1993-1-8:2005. The design is based on the resistance of the weaker joined member in the case of butt welds and the resistance of the weld material in the case of fillet welds, in addition to the experimentally defined correlation factor β_w. The mechanical properties of the filler metal to be used must be at least as good as those of the materials to be joined.

According to EN 1993-1-4:2006, in determining the design resistance of fillet welds, the value of the correlation factor β_W should be taken as 1,0 for all stainless steels unless a lower value is justified by tests. When designing the materials to be joined, the strength used is chosen in compliance with Table 3.1 or, when using cold-rolled materials, to correspond to strength class CP350, in which case it is recommended to select the tensile strength value that is equivalent to the nominal tensile strength of the annealed material. Using enhanced strengths higher than CP350 for austenitic stainless steel grades can be justified on the basis of tests.

The design resistance of fillet welds can be determined by using the directional method or the simplified method.

When using the directional method, the following must be satisfied:

$$\left[\sigma_{\perp}^{2}+3\left(\tau_{\perp}^{2}+\tau_{II}^{2}\right)\right]^{0,5} \leq \frac{f_u}{\beta_w \gamma_{M2}} \text{ and } \sigma_{\perp} \leq \frac{0.9 f_u}{\gamma_{M2}} \quad (7.2.8.1)$$

where:

f_u is the nominal ultimate tensile strength value of the weaker component;

β_w is the correlation factor, the value of which for stainless steels is 1,0.

When using the simplified method, the resultant of all forces per unit length affecting the weld at every point along its length must satisfy:

$$F_{w,Ed} \leq F_{w,Rd} \quad (7.2.8.2)$$

where:

$F_{w,Ed}$ is the design value of the force affecting a unit length of weld;

$F_{w,Rd}$ is the design resistance value for a unit length.

$$F_{w,Rd} = \frac{f_u / \sqrt{3}}{\beta_w \gamma_{M2}} \cdot a \quad (7.2.8.3)$$

where:

f_u is the nominal ultimate tensile strength of material in compliance with Table 3.1

The design resistance value for full penetration butt welds can be determined using the following equation:

$$F_{w,Rd} = \frac{f_y \cdot A}{\gamma_{M0}} \tag{7.2.8.4}$$

which is equal to the design resistance value of the weaker material. Filler metal is chosen in such a way that the yield strength and tensile strength values obtained for the filler metal in a weld metal tensile test are, at least equal to those specified for the base material. The suitability of the filler metal for the joined materials can be verified from section 5.

The resistance of partial penetration butt welds is calculated as that of a fillet weld whose effective throat thickness corresponds to the constantly achieved butt weld penetration.

7.2.9 Resistance of lattice girders

The resistance of hollow section lattice girders is carried out in compliance with EN 1993-1-8:2005. This section introduces the bases for the design of lattice girders as well as the design of joints when the chord and brace members are made of rectangular, square or circular hollow sections. The resistance calculation formulae for axial load and bending moments for same type of joint are given in a single table.

When designing lattice girders, the effects of actions of members are defined on the basis of the assumption that brace members are joined to chord members with pin joints at nodal points. Therefore, brace and vertical members are loaded in axial compression or tension. The chord members of the lattice act as continuous beams being simply supported at nodal points. The cross-sections of brace member ends must not be flattened or widened when the resistance of joints is defined in compliance with Tables 7.2.10.2 –7.2.10.9.

The wall thickness of lattice girder profiles must be at least 2,5 mm. The yield strength of profiles can be utilised in design up to 460 N/mm^2. An enhanced yield strength of 350 N/mm^2 can be utilised in welded joints between austenitic stainless steels that have been hardened by cold-working. When using higher yield strength values, the resistance of the welded joint between austenitic stainless steel hollow sections must be verified by tests. The yield strength of 460 N/mm^2 can be utilised in joints between stainless steel hollow sections made of duplex steel.

The profiles for compression loaded members must be selected amongst profiles meeting class 1 or class 2 cross-section requirements for axial compression.

Buckling length L_{cr} of chord members may be taken as 0,9L for in-plane buckling and out-of-plane buckling, where L is the system length. The system length for in-plane buckling is the distance between nodal points. System length for out-of-plane buckling is the distance between lateral restraints.

In the case of lattice girders with parallel chords and the ratio β between the diameters of the brace member and chord member is less than 0,6, the buckling length L_c for a brace member, which is welded to the hollow section chord, may be taken as 0,75L for in-plane buckling and out-of-plane buckling. The national annex (to EN 1993-1-1) may have more advice to buckling lengths.

The rotational stiffness of the joint is not taken into consideration in the design of the joint or the member if the geometry requirements of Tables 7.2.10.1 and 7.2.10.5 are satisfied and if the ratio of the member length to its side dimension is greater than 6. The members are loaded with a moment load if there are in-plane or out-of-plane loads acting between nodal points. Moment loading may be created due to the eccentricity of joints. If the eccentricity of a joint is within the following limiting values:

$$-0{,}55d_0 \leq e \leq 0{,}25\, d_0 \qquad (7.2.9.1a)$$

$$-0{,}55h_0 \leq e \leq 0{,}25\, h_0 \qquad (7.2.9.1b)$$

the bending moment attributed to this eccentricity should be taken into consideration in the design of the compressed chord. The moment caused by eccentricity should be distributed in the chord members joined in the connection in proportion to the relative stiffnesses (I/L) of the member chords. If the eccentricity of a joint exceeds the above-mentioned limiting values, the bending moment created must be taken into consideration in the design of the joint, compressed chord and brace members. In this case, the bending moment created is distributed to all members joined in the connection in proportion to their stiffness.

In the case of joining circular profiles where brace members are connected to the chord member, the impact of the combination factor on the axial forces in the direction of the member and bending moments can be verified using the following equation:

$$\frac{N_{i,Ed}}{N_{i,Rd}} + \left(\frac{\left| M_{ip,i,Ed} \right|}{M_{ip,i,Rd}} \right)^2 + \frac{M_{op,i,Ed}}{M_{op,i,Rd}} \leq 1.0 \qquad (7.2.9.2)$$

The combined load of rectangular stainless steel hollow sections must satisfy:

$$\frac{N_{i,Ed}}{N_{i,Rd}} + \frac{M_{ip,i,Ed}}{M_{ip,i,Rd}} + \frac{M_{op,i,Ed}}{M_{op,i,Rd}} \leq 1.0 \qquad (7.2.9.3)$$

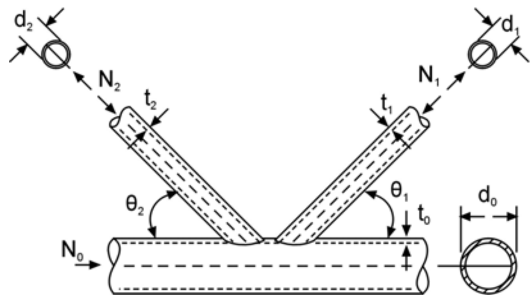
7.2.10 Resistance of stainless steel hollow section joints in lattice girders

Resistance of circular hollow sections joints when circular brace members are connected to a circular chord member are presented in Tables 7.2.10.1–7.2.10.4. Resistance of square and rectangular hollow sections joints when square or rectangular hollow section brace members are connected to a square or rectangular chord member are presented in Tables 7.2.10.5-7.2.10.9.

Table 7.2.10.1

Ratio of diameter of the brace member to diameter of chord	$0,2 \leq d_i/d_0 \leq 1,0$
Cross section classification:	
Chord members	Class 1 or class 2 and $10 \leq d_0/t_0 \leq 50$ generally but $10 \leq d_0/t_0 \leq 40$ for X-joints
Brace members	Class 1 or class 2 and
	$10 \leq d_0/t_0 \leq 50$
Overlap ratio:	$\lambda_{ov} \geq 25$ %
Gap between brace members:	$g \geq t_1+t_2$

Table 7.2.10.2. K and N – joint, round hollow section braces and chords



Failure mode : Chord face failure

$$N_{1,Rd} = \frac{k_g k_p f_{y0} t_0^2}{\sin\theta_1}\left(1{,}8 + 10{,}2\frac{d_1}{d_0}\right)/\gamma_{M5}$$

$$N_{2,Rd} = \frac{\sin\theta_1}{\sin\theta_2} N_{1,Rd}$$

$$M_{op,1,Rd} = \frac{f_{y0} t_0^2 d_1}{\sin\theta_1}\frac{2{,}7}{1-0{,}81\beta} k_p \,/\, \gamma_{M5}$$

Failure mode : Chord punching shear
when $d_i \leq d_0 - 2t_0$

$$N_{i,Rd} = \frac{f_{y0}}{\sqrt{3}} t_0 \pi d_i \frac{1+\sin\theta_i}{2\sin^2\theta_i}/\gamma_{M5}$$

$$M_{ip,1,Rd} = \frac{f_{y0} t_0 d_1^2}{\sqrt{3}}\frac{1+3\sin\theta_1}{4\sin^2\theta_1}/\gamma_{M5}$$

$$M_{op,1,Rd} = \frac{f_{y0} t_0 d_1^2}{\sqrt{3}}\frac{3+\sin\theta_1}{4\sin^2\theta_1}/\gamma_{M5}$$

Parameters:

$$k_g = \gamma^{0,2}\left(1 + \frac{0{,}024\gamma^{1,2}}{1+\exp(0{,}5\, g/t_0 - 1{,}33)}\right)$$

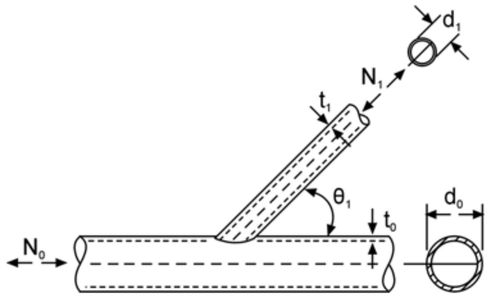
$$\beta = \frac{d_1}{d_0}, \quad \gamma = \frac{d_0}{2t_0}$$

$n_p > 0$ (compression) : $k_p = 1 - 0{,}3 n_p (1 + n_p)$, but $k_p \leq 1{,}0$

$n_p \leq 0$ (tension) : $k_p = 1{,}0$

$$n_p = \left(\frac{\sigma_{p,Ed}}{f_{y0}}\right)\cdot\frac{1}{\gamma_{M5}}$$

Table 7.2.10.3 T- and Y – joint, round hollow section braces and chords



Failure mode : Chord face failure

$$N_{1,Rd} = \frac{\gamma^{0,2} k_p f_{y0} t_0^2}{\sin\theta_1}\left(2,8 + 14,2\beta^2\right) / \gamma_{M5}$$

$$M_{ip,1,Rd} = 4,85 \frac{f_{y0} t_0^2 d_1}{\sin\theta_1}\sqrt{\gamma}\beta \cdot k_p \,/\, \gamma_{M5}$$

$$M_{op,1,Rd} = \frac{f_{y0} t_0^2 d_1}{\sin\theta_1}\frac{2,7}{1 - 0,81\beta} k_p \,/\, \gamma_{M5}$$

Failure mode : Chord punching shear
when $d_i \leq d_0 - 2t_0$

$$N_{i,Rd} = \frac{f_{y0}}{\sqrt{3}} t_0 \pi d_i \frac{1 + \sin\theta_i}{2\sin^2\theta_i} / \gamma_{M5}$$

$$M_{ip,1,Rd} = \frac{f_{y0} t_0 d_1^2}{\sqrt{3}} \frac{1 + 3\sin\theta_1}{4\sin^2\theta_1} / \gamma_{M5}$$

$$M_{op,1,Rd} = \frac{f_{y0} t_0 d_1^2}{\sqrt{3}} \frac{3 + \sin\theta_1}{4\sin^2\theta_1} / \gamma_{M5}$$

Parameters:

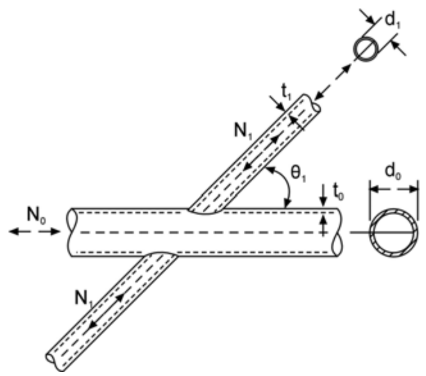
$$\beta = \frac{d_1}{d_0}, \quad \gamma = \frac{d_0}{2t_0},$$

$n_p > 0$ (compression) : $k_p = 1 - 0,3 n_p (1 + n_p)$, but $k_p \leq 1,0$

$n_p \leq 0$ (tension) : $k_p = 1,0$

$$n_p = \left(\frac{\sigma_{p,Ed}}{f_{y0}}\right) \cdot \frac{1}{\gamma_{M5}}$$

Table 7.2.10.4. X – joint, round hollow section braces and chords



Failure mode : Chord face failure

$$N_{1,Rd} = \frac{k_p f_{y0} t_0^2}{\sin\theta_1} \frac{5{,}2}{(1-0{,}81\beta)} / \gamma_{M5}$$

$$M_{ip,1,Rd} = 4{,}85 \frac{f_{y0} t_0^2 d_1}{\sin\theta_1} \sqrt{\gamma} \beta k_p / \gamma_{M5}$$

$$M_{op,1,Rd} = \frac{f_{y0} t_0^2 d_1}{\sin\theta_1} \frac{2{,}7}{1-0{,}81\beta} k_p / \gamma_{M5}$$

Failure mode : Chord punching shear
when $d_i \leq d_0 - 2t_0$

$$N_{i,Rd} = \frac{f_{y0}}{\sqrt{3}} t_0 \pi d_i \frac{1+\sin\theta_i}{2\sin^2\theta_i} / \gamma_{M5}$$

$$M_{ip,1,Rd} = \frac{f_{y0} t_0 d_1^2}{\sqrt{3}} \frac{1+3\sin\theta_1}{4\sin^2\theta_1} / \gamma_{M5}$$

$$M_{op,1,Rd} = \frac{f_{y0} t_0 d_1^2}{\sqrt{3}} \frac{3+\sin\theta_1}{4\sin^2\theta_1} / \gamma_{M5}$$

Parameters:

$$\beta = \frac{d_1}{d_0}, \quad \gamma = \frac{d_0}{2t_0},$$

$n_p > 0$ (compression) : $k_p = 1 - 0{,}3 n_p (1+n_p)$, but $k_p \leq 1{,}0$

$n_p \leq 0$ (tension) : $k_p = 1{,}0$

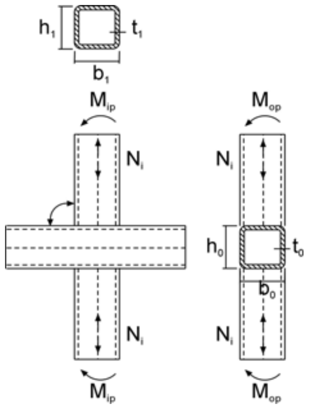
$$n_p = \left(\frac{\sigma_{p,Ed}}{f_{y0}}\right) \cdot \frac{1}{\gamma_{M5}}$$

Table 7.2.10.5.

<table>
<tr><td rowspan="3">Joint type</td><td colspan="6">Joint parameter (i = 1 or 2, j = overlapped brace)</td></tr>
<tr><td rowspan="2">b_i/b_0 or d_i/d_0</td><td colspan="2">b_i/t_i and h_i/t_i or d_i/t_i</td><td rowspan="2">h_0/b_0 and h_i/b_i</td><td rowspan="2">b_0/t_0 and h_0/t_0</td><td rowspan="2">Gap or overlap b_i/b_j</td></tr>
<tr><td>Compression</td><td>Tension</td></tr>
<tr><td>T, Y or X</td><td>$b_i/b_0 \geq 0{,}25$</td><td rowspan="2">$b_i/t_i \leq 35$ and $h_i/t_i \leq 35$ and Class 2 (min)</td><td rowspan="3">$b_i/t_i \leq 35$ and $h_i/t_i \leq 35$</td><td rowspan="3">≥0,5 but $h_i/t_i \leq 2{,}0$</td><td>≤35 and class 1 or class 2</td><td></td></tr>
<tr><td>K and N gap</td><td>$b_i/b_0 \geq 0{,}35$ and $\geq 0{,}1+0{,}01 b_0/t_0$</td><td>≤35 and class 1 or class 2</td><td>$g/b_0 \geq 0{,}5(1-\beta)$, but $\leq 1{,}5(1-\beta)$[1] $g \geq t_1+t_2$</td></tr>
<tr><td>K and N overlapped</td><td>$b_i/b_0 \geq 0{,}25$</td><td>Class 1</td><td>Class 1 or class 2</td><td>$\lambda_{ov} \geq 25\%$, but $\lambda_{ov} \leq 100\%$[2]</td></tr>
<tr><td>Circular hollow section brace member</td><td>$d_i/b_0 \geq 0{,}4$ but $\leq 0{,}8$</td><td>Class 1</td><td>$d_i/t_i \leq 50$</td><td colspan="3">as above but d_i replacing b_i and d_j replacing b_j</td></tr>
</table>

[1] If $g/b_0 > 1{,}5(1-\beta)$ and $g/b_0 > t_1+t_2$ joint is treated as two separate T or Y joints.

Table 7.2.10.6. X-joint



$\beta < 0{,}85$ Failure mode : Chord face failure

$$N_{i,Rd} = \frac{k_n f_{y0} t_0^2}{(1-\beta)\sin\theta_1}\left(\frac{2\eta}{\sin\theta_1} + 4\sqrt{1-\beta}\right)/\gamma_{M5}$$

$$M_{ip,1,Rd} = k_n f_{y0} t_0^2 h_1 \left(\frac{1}{2\eta} + \frac{2}{\sqrt{1-\beta}} + \frac{\eta}{1-\beta}\right)/\gamma_{M5}$$

$$M_{op,1,Rd} = k_n f_{y0} t_0^2 \left(\frac{h_1(1+\beta)}{2(1-\beta)} + \sqrt{\frac{2b_0 b_1 (1+\beta)}{1-\beta}}\right)/\gamma_{M5}$$

$0{,}85 \le \beta$ • 1,0 Failure mode : Brace failure

$$N_{i,Rd} = f_{yi} t_i (2h_i - 4t_i + 2b_{eff})/\gamma_{M5}$$

$$M_{ip,1,Rd} = f_{y1}\left(W_{pl,1} - (1 - b_{eff}/b_1) b_1 h_1 t_1\right)/\gamma_{M5}$$

$$M_{op,1,Rd} = f_{y1}\left(W_{pl,1} - 0{,}5(1 - b_{eff}/b_1)^2 b_1^{\,2} t_1\right)/\gamma_{M5}$$

Failure mode : Chord side wall crushing

$$M_{ip,1,Rd} = 0{,}5 \cdot 0{,}8 \cdot f_{y0} t_0 (h_1 + 5t_0)^2 /\gamma_{M5}$$

$$M_{op,1,Rd} = 0{,}8 \cdot f_{y0} t_0 (b_0 - t_0)(h_1 + 5t_0)/\gamma_{M5}$$

$\beta = 1{,}0$ Failure mode : Chord side wall buckling

$$N_{i,Rd} = \frac{f_b t_0}{\sin\theta_i}\left(\frac{2h_i}{\sin\theta_1} + 10t_0\right)/\gamma_{M5}$$

$0{,}85 \le \beta \le (1 - 1/\gamma)$ Failure mode : Chord punching shear

$$N_{i,Rd} = \frac{f_{y0} t_0}{\sqrt{3}\sin\theta_1}\left(\frac{2h_i}{\sin\theta_1} + 2b_{e,p}\right)/\gamma_{M5}$$

Parameters:

$$\beta = \frac{b_1}{b_0} \;,\quad \eta = \frac{h_i}{b_0} \;,\quad n = \left(\frac{\sigma_{0,Ed}}{f_{y0}} \right) \cdot \frac{1}{\gamma_{M5}}$$

$n > 0$ (compression) : $k_n = 1{,}3 - \dfrac{0{,}4n}{\beta}$, but $k_n \leq 1{,}0$

$n \leq 0$ (tension) : $k_n = 1{,}0$

$$b_{eff} = \frac{10}{b_o / t_0} \frac{f_{y0} t_0}{f_{yi} t_i} b_i \text{ , but } b_{eff} \leq b_i \;,\quad b_{e,p} = \frac{10}{b_o / t_0} b_i \text{ , but } b_{e,p} \leq b_i$$

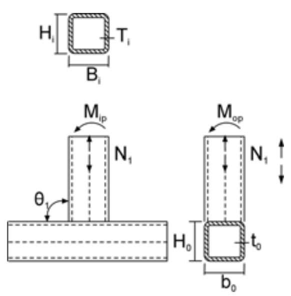
Tension : $f_b = f_{y0}$

Compression : $f_b = 0{,}8 \chi f_{y0} \sin\theta_i$, where reduction factor for flexural buckling χ

is calculated according to EN 1993-1-1 using the relevant buckling curve and normalised slenderness,

$$\bar{\lambda} = 3{,}46 \frac{\left(\dfrac{h_0}{t_0} - 2 \right) \sqrt{\dfrac{1}{\sin\theta_i}}}{\pi \sqrt{\dfrac{E}{f_{y0}}}}$$

Table 7.2.10.7. T and Y –joint



β<0,85 Failure mode : Chord face failure

$$N_{i,Rd} = \frac{k_n f_{y0} t_0^2}{(1-\beta)\sin\theta_1}\left(\frac{2\eta}{\sin\theta_1} + 4\sqrt{1-\beta}\right)/\gamma_{M5}$$

$$M_{ip,1,Rd} = k_n f_{y0} t_0^2 h_1 \left(\frac{1}{2\eta} + \frac{2}{\sqrt{1-\beta}} + \frac{\eta}{1-\beta}\right)/\gamma_{M5}$$

$$M_{op,1,Rd} = k_n f_{y0} t_0^2 \left(\frac{h_1(1+\beta)}{2(1-\beta)} + \sqrt{\frac{2b_0 b_1 (1+\beta)}{1-\beta}}\right)/\gamma_{M5}$$

β>0,85 Failure mode : Brace failure

$$N_{i,Rd} = f_{yi} t_i (2h_i - 4t_i + 2b_{eff})/\gamma_{M5}$$

$$M_{ip,1,Rd} = f_{y1}\left(W_{pl,1} - (1 - b_{eff}/b_1) b_1 h_1 t_1\right)/\gamma_{M5}$$

$$M_{op,1,Rd} = f_{y1}\left(W_{pl,1} - 0{,}5(1 - b_{eff}/b_1)^2 b_1^{\,2} t_1\right)/\gamma_{M5}$$

Failure mode : Chord side wall crushing

$$M_{ip,1,Rd} = 0{,}5 \cdot f_{y0} t_0 (h_1 + 5t_0)^2 /\gamma_{M5}$$

$$M_{op,1,Rd} = f_{y0} t_0 (b_0 - t_0)(h_1 + 5t_0)/\gamma_{M5}$$

β=1,0 Failure mode : Chord side wall buckling

$$N_{i,Rd} = \frac{f_b t_0}{\sin\theta_i}\left(\frac{2h_i}{\sin\theta_1} + 10t_0\right)/\gamma_{M5}$$

0,85 ≤ β ≤ (1 - 1/γ) Failure mode : Chord punching shear

$$N_{i,Rd} = \frac{f_{y0} t_0}{\sqrt{3}\sin\theta_1}\left(\frac{2h_i}{\sin\theta_1} + 2b_{e,p}\right)/\gamma_{M5}$$

Failure mode : Chord distortional failure

$$M_{op,1,Rd} = 2f_{y0} t_0 (h_1 t_0 + \sqrt{b_0 h_0 t_0 (b_0 + h_0)})/\gamma_{M5}$$

Parameters:

$$\beta = \frac{b_1}{b_0} \ , \quad \eta = \frac{h_i}{b_0} \ , \quad n = \left(\frac{\sigma_{0,Ed}}{f_{y0}} \right) \cdot \frac{1}{\gamma_{M5}}$$

$n \ > 0$ (compression) : $k_n 1{,}3 - \frac{0{,}4n}{\beta}$, but $k_n \le 1{,}0$

$n \le 0$ (tension) : $k_n = 1{,}0$

$$b_{eff} = \frac{10}{b_o / t_0} \frac{f_{y0} t_0}{f_{yi} t_i} b_i \text{ , but } b_{eff} \le b_i \ , \quad b_{e,p} = \frac{10}{b_o / t_0} b_i \text{ , but } b_{e,p} \le b_i$$

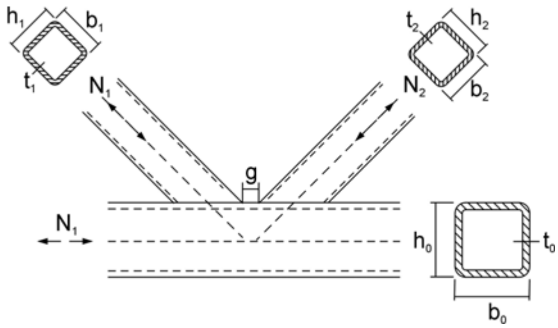
Tension : $f_b = f_{y0}$

Compression : $f_b = \chi f_{y0} \sin\theta_i$, where reduction factor for flexural buckling χ is calculated according

to EN 1993-1-1 using the relevant buckling curve and normalised slenderness,

$$\bar{\lambda} = 3{,}46 \frac{\left(\frac{h_0}{t_0} - 2 \right) \sqrt{\frac{1}{\sin\theta_i}}}{\pi \sqrt{E / f_{y0}}}$$

Table 7.2.10.8. K and N –joint



Failure mode : Chord face failure

$$N_{i,Rd} = \frac{8{,}9 k_n f_{y0} t_0^2 \sqrt{\gamma}}{\sin\theta_1} \left(\frac{b_1 + b_2 + h_1 + h_2}{4b_0} \right) / \gamma_{M5}$$

Failure mode : Brace failure

$$N_{i,Rd} = f_{yi} t_i (2h_i - 4t_i + b_i + b_{eff}) / \gamma_{M5}$$

Failure mode : Chord shear

$$N_{i,Rd} = \frac{f_{y0} A_v}{\sqrt{3} \sin\theta_i} / \gamma_{M5}$$

β ≤ (1 – 1/γ) Failure mode : Chord punching shear

$$N_{i,Rd} = \frac{f_{y0} t_0}{\sqrt{3} \sin\theta_1} \left(\frac{2h_i}{\sin\theta_1} + b_i + b_{e,p} \right) / \gamma_{M5}$$

Parameters:

$$n = \left(\frac{\sigma_{0,Ed}}{f_{y0}} \right) \cdot \frac{1}{\gamma_{M5}}$$

$n > 0$ (compression) : $k_n = 1{,}3 - \frac{0{,}4n}{\beta}$, but $k_p \leq 1{,}0$

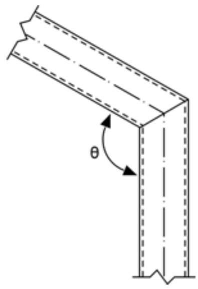
$n \leq 0$ (tension) : $k_p = 1{,}0$

$b_{eff} = \frac{10}{b_o / t_0} \frac{f_{y0} t_0}{f_{yi} t_i} b_i$, but $b_{eff} \leq b_i$, $b_{e,p} = \frac{10}{b_o / t_0} b_i$, but $b_{e,p} \leq b_i$

$A_v = (2h_0 + \alpha b_0) t_0$; $\alpha = \sqrt{\frac{1}{1 + \frac{4g^2}{3t_0^2}}}$

Table 7.2.10.9. Welded knee joint

No reinforcement between the hollow sections



Cross section shall be of class 1

$$N_{Ed} \leq 0{,}2 N_{pl,Rd} \text{ and } \frac{N_{Ed}}{N_{pl,Rd}} + \frac{M_{Ed}}{M_{pl,Rd}} \leq \kappa$$

If $\theta \leq 90^0$:

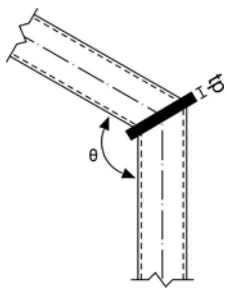
$$\kappa = \frac{3\sqrt{b_0 / h_0}}{(b_0 / t_0)^{0,8}} + \frac{1}{1 + 2b_0 / h_0}$$

If $90^0 < \theta \leq 180^0$:

$$\kappa = 1 - (\sqrt{2}\cos(\theta/2))(1 - \kappa_{90}),$$

where $\kappa_{90} = \kappa(\theta = 90^0)$

Reinforcing plate welded to connect the hollow sections



$t_p \geq 1{,}5t$ and $\geq 10mm$

$$\frac{N_{Ed}}{N_{pl,Rd}} + \frac{M_{Ed}}{M_{pl,Rd}} \leq 1{,}0$$

7.2.11 Calculation of deflection

The non-linear shape of the stress-strain curve of stainless steels must be taken into consideration when determining the deflection of a member. In the serviceability limit state, the deflection of a single member is calculated using the value of the secant modulus E_s corresponding to the appropriate load level. The secant modulus value for the stress corresponding to the serviceability limit state $E_{s,ser}$ can be determined from:

$$E_{s,ser} = \frac{(E_{s,1} + E_{s,2})}{2} \qquad (7.2.11.1)$$

where:
$E_{s,1}$ is the secant modulus corresponding to the stress in the tension flange σ_1;
$E_{s,2}$ is the secant modulus corresponding to the stress in the compression flange σ_2.

The values of secant moduli $E_{s,1}$ and $E_{s,2}$ for the serviceability limit state stress $\sigma_{i,Ed,ser}$ are calculated using the equation below:

$$E_{s,i} = \frac{E}{1 + 0.002 \dfrac{E}{\sigma_{i,\mathrm{Ed,ser}}} \left(\dfrac{\sigma_{\mathrm{i,Ed,ser}}}{\mathrm{f_y}} \right)^{\mathrm{n}}} \qquad (7.2.11.2)$$

When the stress $\sigma_{i,Ed,ser}$ values are chosen to correspond to the maximum stress in the serviceability limit state, the value of secant modulus $E_{s,i}$ will reach its minimum. The stress values $\sigma_{i,Ed,ser}$ can be defined as effective stresses for rectangular and circular profiles /11th Int. Specialty conference on cold-formed steel structures 1992/. Effective stress is determined using the following equation (7.1.9.3):

$$\sigma_e = k_\sigma \frac{M_{\max}}{W_e} \qquad (7.2.11.3)$$

where:
M_{max} is the maximum bending moment determined at serviceability limit state
W_e is the elastic section modulus
k_σ is a factor chosen on the basis of the structure and the profile of the cross-section
For single-span structures with a point load
k_σ = 2/3 rectangular stainless steel hollow sections
k_σ = ¾ circular stainless steel hollow sections
For a continuous structure
k_σ = ½ for rectangular and square profiles

7.3 Resistance of structures made of stainless steel hollow steel at fire temperatures

The basis of fire design of stainless steel structures is presented in standard EN 1993-1-2 and in Euro Inox "Design Manual for Structural Stainless Steel" (2006). When utilising standard EN 1993-1-4, fire design parameters and instructions defined in standard EN 1993-1-2 must be used. This summary presents the procedure in compliance with EN 1993-1-2. Considering the strength class and design strength the differences between the approaches of these two sources are:

According to the Euro Inox Design Manual, the enhanced yield strength and tensile strength values of cold-worked austenitic stainless steels can be used as a basis for design up to strength class CP 500.
According to the Euro Inox Design Manual, the design strength for members loaded in axial compression and members subject to combined axial compression and bending is the 0,2 % proof strength, depending on the temperature of the material.

The behaviour of stainless steel differs from that of other metals at fire temperatures in that its mechanical properties (mainly modulus of elasticity and yield strength) maintain their values comparatively well up to temperatures corresponding to a 30-minute standard fire. The stability of the yield strength of stainless steel depends on the alloy of the material i.e. the chosen stainless steel grade.

It must be noted that the yield strength relevant to the fire design of stainless steel structures is yield strength $f_{y,\theta}$ instead of strength $f_{0,2p,\theta}$ corresponding to a permanent elongation of 0,2 %.

The rise in temperature has been described with a model in compliance with the standard fire curve given in EN 1363-1 (ISO 834).

7.3.1 Material properties and calculation of steel temperature during fire in compliance with EN 1993-1-2

The following sections present the mechanical properties of most common stainless steels grades used in construction, a method for defining the design resistance of a structure and the calculation of steel temperature during fire and the required parameter values.

7.3.1.1 Mechanical properties: yield strength and tensile strength

The yield strength and tensile strength value of stainless steels decrease as temperature rises. Tables 7.3.1.1–7.3.1.3. present the temperature-dependent reduction factor ($k_{0,2p,\theta}$ and $k_{u,\theta}$) values for the 0,2 % strength and tensile strength of most common stainless steel grades. In addition, the Table presents the temperature-dependent values of factor $k_{2\%,\theta}$. Factor $k_{2\%,\theta}$ is used when determining the temperature related effective yield strength $f_{y,\theta}$ for stainless steel in fire situation (section 7.3.1.3)

Table 7.3.1.1. Reduction factors for austenitic steel grades EN 1.4301, EN 1.4401, EN 1.4404 and EN 1.4571 at elevated temperatures.

Steel grade 1.4301			
Steel temperature θ_a	$k_{0,2p,\theta}$	$k_{u,\theta}$	$k_{2\%,\theta}$
20	1	1	0,26
100	0,82	0,87	0,24
200	0,68	0,77	0,19
300	0,64	0,73	0,19
400	0,6	0,72	0,19
500	0,54	0,67	0,19
600	0,49	0,58	0,22
700	0,4	0,43	0,26
800	0,27	0,27	0,35
900	0,14	0,15	0,38
1000	0,06	0,07	0,4
1000	0,03	0,03	0,4
1200	0	0	0,4

Steel grade 1.4401 ja 1.4404			
Steel temperature θ_a	$k_{0,2p,\theta}$	$k_{u,\theta}$	$k_{2\%,\theta}$
20	1	1	0,24
100	0,88	0,93	0,24
200	0,76	0,87	0,24
300	0,71	0,84	0,24
400	0,66	0,83	0,21
500	0,63	0,79	0,2
600	0,61	0,72	0,19
700	0,51	0,55	0,24
800	0,4	0,34	0,35
900	0,19	0,18	0,38
1000	0,1	0,09	0,4
1000	0,05	0,04	0,4
1200	0	0	0,4

Steel grade 1.4571			
Steel temperature θ_a	$k_{0,2p,\theta}$	$k_{u,\theta}$	$k_{2\%,\theta}$
20	1	1	0,25
100	0,89	0,88	0,25
200	0,83	0,81	0,25
300	0,77	0,8	0,24
400	0,72	0,8	0,22
500	0,69	0,77	0,21
600	0,66	0,71	0,21
700	0,59	0,57	0,25
800	0,5	0,38	0,35
900	0,28	0,22	0,38
1000	0,15	0,11	0,4
1000	0,075	0,055	0,4
1200	0	0	0,4

Table 7.3.1.2. Reduction factors for duplex 1.4462 steel at elevated temperatures.

Steel grade 1.4462			
Steel temperature θ_a	$k_{0,2p,\theta}$	$k_{u,\theta}$	$k_{2\%,\theta}$
20	1	1	0,35
100	0,91	0,93	0,35
200	0,8	0,85	0,32
300	0,75	0,83	0,3
400	0,72	0,82	0,28
500	0,65	0,71	0,3
600	0,56	0,57	0,33
700	0,37	0,38	0,4
800	0,26	0,29	0,41
900	0,1	0,12	0,45
1000	0,03	0,04	0,47
1000	0,015	0,02	0,47
1200	0	0	0,47

Table 7.3.1.3. Reduction factors for ferritic steel grade 1.4003 at elevated temperatures.

Steel grade 1.4003			
Steel temperature θ_a	$k_{0,2p,\theta}$	$k_{u,\theta}$	$k_{2\%,\theta}$
20	1	1	0,37
100	1	0,94	0,37
200	1	0,88	0,37
300	0,98	0,86	0,37
400	0,91	0,83	0,42
500	0,8	0,81	0,4
600	0,45	0,42	0,45
700	0,19	0,21	0,46
800	0,13	0,12	0,47
900	0,1	0,11	0,47
1000	0,07	0,09	0,47
1000	0,035	0,045	0,47
1200	0	0	0,47

7.3.1.2 Modulus of elasticity

The value of modulus of elasticity of all stainless steel grades decreases when temperature rises.

The modulus of elasticity at a selected temperature can be calculated by multiplying the room temperature value of the modulus of elasticity with a reduction factor $k_{E,\theta}$ corresponding to the specified temperature. Reduction factors are given below in Table 7.3.1.4.

Value of modulus of elasticity at room temperature:

- EN 1.4301, EN 1.4401, EN 1.4404, EN 1.4571 and EN 1.4462 materials: 200 000 N/mm^2.
- EN 1.4003 material: 220 000 N/mm^2.

Table 7.3.1.4. Reduction factor $k_{E,\theta}$ at elevated temperatures.

Steel temperature θ_a	$k_{E,\theta}$
20	1
100	0,96
200	0,92
300	0,88
400	0,84
500	0,8
600	0,76
700	0,71
800	0,63
900	0,45
1000	0,2
1000	0,1
1200	0

7.3.1.3 Design strength of material (effective yield strength)

The effective yield strength $f_{y,\theta}$ of stainless steel at the elevated temperatures is determined as follows:

$$f_{y,\theta} = f_{0,2p,\theta} + k_{2\%,\theta}(f_{u,\theta} - f_{0,2p,\theta}) \quad (7.3.1.1)$$

where:
$f_{0,2p,\theta}$ is the 0,2 % strength of the material at the specified temperature. The value is calculated by multiplying the room temperature value for 0,2 % strength with the 0,2 % strength reduction factor $k_{0,2p,\theta}$ presented in Tables 7.3.1.1-7.3.1.3.
$k_{2\%,\theta}$ is the correction factor for determining yield strength at the specified temperature. The value is given in Tables 7.3.1.1-7.3.1.3.
$f_{u,\theta}$ is the tensile strength at the specified temperature. The value is calculated by multiplying the room temperature tensile strength value by the tensile strength reduction factor $k_{u,\theta}$ presented in Tables 7.3.1.1-7.3.1.3.

Table 7.3.1.5 shows the design strength values of materials and the value of modulus of elasticity as a function of temperature. The room temperature values used for the materials are as follows:

EN 1.4301: f_y =230 N/mm², f_u=540 N/mm², E=200 000 N/mm².
EN 1.4401 and 1.4404: f_y =240 N/mm², f_u=530 N/mm², E=200 000 N/mm².
EN 1.4571: f_y =240 N/mm², f_u=540 N/mm², E=200 000 N/mm².
EN 1.4462: f_y =480 N/mm², f_u=660 N/mm², E=200 000 N/mm².
EN 1.4003: f_y =280 N/mm², f_u=450 N/mm², E=220 000 N/mm².

Table 7.3.1.5. The values of design strength (effective yield strength) f_y and modulus of elasticity E at fire temperatures.

Strength value θ_a	EN1.4301	EN1.4401 EN1.4404	EN1.4571	EN1.4003	EN1.4462	EN1.4003	Other
	$f_{y,\theta}$	$f_{y,\theta}$	$f_{y,\theta}$	$f_{y,\theta}$	$f_{y,\theta}$	E [N/mm²]	E[N/mm²]
20	311	310	315	343	543	220000	200000
100	256	279	279	333	499	211200	192000
200	206	249	259	323	441	202400	184000
300	194	236	244	316	416	193600	176000
400	186	218	230	305	400	184800	168000
500	169	205	218	280	359	176000	160000
600	157	191	206	154	304	167200	152000
700	128	163	183	72	207	156200	142000
800	91	125	150	45	152	138600	126000
900	51	65	87	38	62	99000	90000
1000	23	33	45	29	20	44000	40000
1100	11	16	23	15	10	22000	20000
1200	0	0	0	0	0	0	0

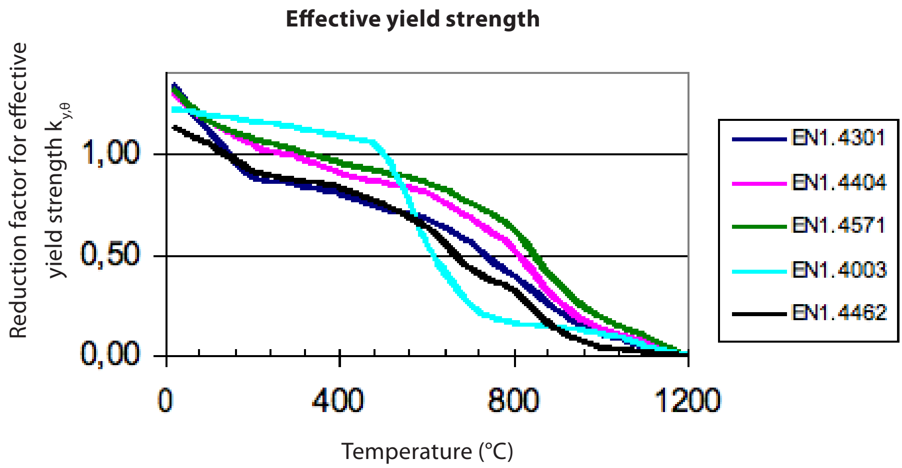


Figure 7.3.1.1. The ratio between design strength of materials and room temperature yield strength (0,2 % strength) as a function of temperature. The design strength (effective yield strength) reduction factor $k_{y,\theta}$ is calculated using Table 7.3.1.5 and the values of mechanical properties given at room temperature at the beginning of this section.

Table 7.3.1.6. The values of steel design strength (effective yield strength) reduction factor ky,θ and elasticity module reduction factor $k_{E,\theta}$ for steel grades.

Steel temperature θ_a	$k_{y,\theta}$ EN1.4301	EN1.4401 EN1.4404	EN1.4571	EN1.4003	EN1.4462	$k_{E,\theta}$ All stainless steels
20	1,34	1,29	1,31	1,22	1,13	1
100	1,10	1,16	1,16	1,19	1,04	0,96
200	0,89	1,04	1,08	1,15	0,92	0,92
300	0,84	0,98	1,02	1,13	0,87	0,88
400	0,80	0,91	0,96	1,09	0,83	0,84
500	0,73	0,85	0,91	1,00	0,75	0,8
600	0,68	0,80	0,86	0,55	0,63	0,76
700	0,55	0,68	0,76	0,26	0,43	0,71
800	0,39	0,52	0,62	0,16	0,32	0,63
900	0,22	0,27	0,36	0,14	0,13	0,45
1000	0,10	0,14	0,19	0,11	0,04	0,2
1100	0,05	0,07	0,09	0,05	0,02	0,1
1200	0,00	0,00	0,00	0,00	0,00	0

7.3.2 Thermal properties of the material

7.3.2.1 Density ρ_a

Steel density ρ_a when calculating the temperature increase in fire is

ρ_a= 7850 kg/m^3

7.3.2.2 Specific heat capacity c_a

The specific heat capacity c_a for steel is calculated as follows:

$$c_a = 450 + 0{,}280 \times \theta_a - 2{,}91 \times 10^{-4} \times \theta_a^2 + 1{,}34 \times 10^{-7} \times \theta_a^3 J / kgK \qquad (7.3.2.1)$$

7.3.3. Increase of steel temperature during fire

7.3.3.1 Steel temperature rise during fire

The increase of the temperature of unprotected indoor steel structures is calculated in compliance with standard EN 1993-1-2 (equation 4.25):

$$\Delta\theta_{a,t} = K_{sh} \times \frac{A_m / V}{c_a \rho_a} \times \dot{h}_{net} \times \Delta t \qquad (7.3.2.2)$$

where:
K_{sh} is a shielding effect correction factor whose value for circular and rectangular hollow sections is 1,0.
A_m/V is the cross-section factor of an unprotected steel member
$\dot{h}_{net}$ is the net heat flux per surface unit [W/m^2]
Δt is the interval between time steps in the calculation [s].

Net heat flux $\dot{h}_{net}$ is calculated using the equation (EN 1991-1-2, equation 7.3.2.3) :

$$\dot{h}_{net} = \dot{h}_{net,c} + \dot{h}_{net,r}$$

where:
the convective heat flux component

$$\dot{h}_{net,c} = \alpha_c \times (\theta_g - \theta_a) [W / m^2 K]$$

and the radiative heat flux component as

$$\dot{h}_{net,r} = \varphi \times \varepsilon_m \times \varepsilon_f \times \sigma \times [(\theta_g + 273)^4 - (\theta_a + 273)^4] [W / m^2 K]$$

where:

$α_c$ is the coefficient of heat transfer by convection. When the standard temperature-time curve of standard fire is used, $α_c$ = 25 W/m^{2}K

φ is the configuration factor, the value of 1,0 is used

ε_m is the surface emissivity factor of the structure

- for stainless steel ε_m = 0,4 (EN 1993-1-2)

ε_f is the emissivity of the flame, 1,0.

θ_g is the gas temperature of environment of the member in fire exposure (^{0}C), given by the nominal temperature-time curve.

θ_a is the temperature of the steel section (^{0}C) which assumed to be uniform at time t.

σ is the Stefan Boltzmann constant [5,67 × 10^{-8} W/m^{2}K^4]

7.3.3.2 Steel temperature calculation at fire situation in compliance with EN 1363-1

Table 7.3.7 presents the heating up of a material of a thickness of 3 mm, 4 mm, 5 mm, 6 mm, 8 mm, 10 mm and 12 mm using the emissivity coefficient values 0,2 and 0,4 for material surface after exposure to a fire for 10, 15 and 30-minutes when the fire temperature is determined in compliance with the EN 1363-1 (ISO 834) standard fire curve.

Table 7.3.3.1. Increase in steel temperature as a function of material thickness, time and surface emissivity. The material surface emissivity ε_m = 0,4 corresponds to EN 1993-1-2. The value ε_m = 0,2 has been determined on the basis of laboratory tests /VTT, TTY/

T [°C]	10 min		15min		30 min	
t / ε_m	0,2	0,4	0,2	0,4	0,2	0,4
3mm	526	595	674	713	833	840
4mm	458	538	625	688	823	834
5mm	403	485	574	657	811	830
6mm	359	437	527	621	795	825
8mm	296	365	450	549	753	811
10mm	251	312	390	485	704	789
12mm	219	278	345	433	655	761
14,2mm	193	239	304	386	602	723

7.3.4. Resistance of stainless steel structures in the fire situation

The variables are defined in sections 7.3.3.1–7.3.3.4:

$k_{y,\theta}$ is the effective yield strength reduction factor, Table 7.3.6 and Figure 7.3.1.

γ_{M0} is the partial factor of the material for room temperature design, the rec ommended value is 1,1.

$\gamma_{M,fi}$ is the partial factor of the material for fire design, the recommended value 1,0

It is recommended that the cross-section class is determined at room temperature, ie. the cross-section is the same both in the fire situation and at room temperature. / Euro Inox Design Manual, 2006/. The justification for this is given below:

For stainless steel grades the term ε for the determination cross-section class at room temperature is defined (section 7.2.2) as:

$$\varepsilon = \sqrt{\frac{235}{f_y}\frac{E}{210000}}$$

The value of term ε_θ is calculated by substituting the values of 0,2 % proof strength and modulus of elasticity at the fire temperature into the formula above as follows:

$$\varepsilon_\theta = \sqrt{\frac{k_{E,\theta}}{k_{y,\theta}}}\sqrt{\frac{235}{f_y}\frac{E}{210000}} = \sqrt{\frac{k_{E,\theta}}{k_{y,\theta}}}\varepsilon_{20^0C}$$

For carbon steels the value of expression $\sqrt{\frac{k_{E,\theta}}{k_{y,\theta}}}$ can be conservatively taken as

0,85 / EN 1993-1-2/. When substituting the temperature related values of factors $k_{E,\theta}$ and $k_{0,2p,\theta}$ (austenitic and duplex stainless steel grades) into this expression the value of ε_θ is higher compared to ε /J. Kouhi, 2008/. Based on this, the value for the square root expression is recommended to be taken as 1,0 which means that the cross-sectional class is determined at the fire situation the same way as at room temperature.

7.3.4.1 Members subject to axial tension

The design resistance of a tension member at a uniform cross-section temperature distribution θ_a is determined from:

$$N_{fi,\theta,Rd} = k_{y,\theta} N_{Rd} \left[\gamma_{M,0} / \gamma_{M,fi} \right] \tag{7.3.4.1}$$

where:
N_{Rd} is cross-section design resistance at room temperature in compliance with EN 1993-1-4.

7.3.4.2 Members loaded in bending

$$M_{fi,\theta,Rd} = k_{y,\theta} M_{Rd} \left[\gamma_{M,0} / \gamma_{M,fi} \right] \tag{7.3.4.2}$$

where:
<u>For cross section class 1 and 2 flexural members:</u>
M_{Rd} is the plastic moment resistance of cross-section $M_{pl,Rd}$ at room temperature in compliance with EN 1993-1-4.
<u>For cross section class 3 flexural members:</u>
M_{Rd} is the elastic moment resistance of cross-section $M_{el,Rd}$ at room temperature in compliance with EN 1993-1-4.
<u>For cross section class 4 flexural members:</u>
M_{Rd} is the effective moment resistance of cross-section $M_{eff,Rd}$ at room temperature in compliance with EN 1993-1-4. Instead of $k_{y,\theta}$, the value of $k_{0,2p,\theta}$ from Tables 7.3.1.1-7.3.1.3 is used.

7.3.4.3 Members subject to axial compression, class 1, 2 and 3 cross-sections.

The buckling resistance of a compression member at the point of time t is calculated as follows:

$$N_{b,fi,t,Rd} = \chi_{fi} A k_{y,\theta} f_y / \gamma_{M,fi} \tag{7.3.4.3}$$

where
χ_{fi} is the flexural buckling reduction factor in fire temperature design.
The value is calculated as follows:

$$\chi_{fi} = \frac{1}{{}_{\theta} + \sqrt{{}_{\theta}^{2} - \bar{\lambda}_{\theta}^{2}}} \text{ but } \chi_{fi} \leq 1 \tag{7.3.4.4}$$

$$\varphi_\theta = 0,5 \cdot \left(1 + \alpha \cdot \bar{\lambda}_\theta + \bar{\lambda}_\theta^2\right)$$

in which $\alpha = 0.65\sqrt{235/f_y}$

Modified slenderness in the specified temperature is calculated as follows:

$$\bar{\lambda}_\theta = \bar{\lambda}\sqrt{k_{y,\theta}/k_{E,\theta}} \qquad (7.3.4.5)$$

The values for $k_{y,\theta}$ and $k_{E,\theta}$ are presented in Tables 7.3.1.4 and 7.3.1.6. The values for the term under the square root is gieven in Table 7.3.4.1

where:
the modified slenderness at room temperature is

$$\bar{\lambda} = \sqrt{\frac{A_{eff} \cdot f_y}{N_{cr}}} = \frac{L_{cr}}{i} \cdot \frac{1}{\pi} \cdot \sqrt{\frac{f_y}{E}}$$

Instructions on selecting the buckling length of a column in fire situation can be found in EN 1993-1-2, section 4.2.3.2.

Equation (7.3.4.3) differs from that in the Euro Inox Design Manual (2006) where the design strength in fire temperature is the 0,2 % strength. In the equation presented in Euro Inox Design Manual 2006 the term φ_θ is defined in the same was as for room temperature conditions.

Table 7.3.4.1. The calculated values of the auxiliary variable $\sqrt{k_{y,\theta}/k_{E,\theta}}$ required in the calculation of equation (7.3.4.5) for stainless steel presented as a function of temperature.

		EN1.4401			
Steel temperature θ_a	EN1.4301	EN1.4404	EN1.4571	EN1.4003	EN1.4462
20	1,16	1,14	1,15	1,11	1,06
100	1,07	1,10	1,10	1,11	1,04
200	0,98	1,06	1,08	1,12	1,00
300	0,98	1,06	1,08	1,13	0,99
400	0,98	1,04	1,07	1,14	1,00
500	0,96	1,03	1,07	1,12	0,97
600	0,94	1,02	1,06	0,85	0,91
700	0,88	0,98	1,04	0,60	0,78
800	0,79	0,91	1,00	0,50	0,71
900	0,70	0,77	0,90	0,55	0,54
1000	0,71	0,84	0,97	0,72	0,46
1100	0,68	0,81	0,97	0,72	0,46

7.3.4.4 Members subject to combined axial compression and bending moment

Class 1 and 2 cross-section members:

$$\frac{N_{fi,Ed}}{\chi_{\min} \cdot A \cdot k_{y,\theta} \cdot \frac{f_y}{\gamma_{M,fi}}} + \frac{k_y \cdot M_{y,fi,Ed}}{W_{pl,y} \cdot k_{y,\theta} \cdot \frac{f_y}{\gamma_{M,fi}}} + \frac{k_z \cdot M_{z,fi,Ed}}{W_{pl,z} \cdot k_{z,\theta} \cdot \frac{f_y}{\gamma_{M,fi}}} \leq 1 \qquad (7.3.4.6)$$

Class 3 cross-section members:

$$\frac{N_{fi,Ed}}{\chi_{\min} \cdot A \cdot k_{y,\theta} \cdot \frac{f_y}{\gamma_{M,fi}}} + \frac{k_y \cdot M_{y,fi,Ed}}{W_{el,y} \cdot k_{y,\theta} \cdot \frac{f_y}{\gamma_{M,fi}}} + \frac{k_z \cdot M_{z,fi,Ed}}{W_{el,z} \cdot k_{z,\theta} \cdot \frac{f_y}{\gamma_{M,fi}}} \leq 1 \qquad (7.3.4.7)$$

where the terms k_y and k_z are determined as follows:

$$k_y = 1.0 - \frac{\mu_y \cdot N_{fi,Ed}}{\chi_{y,fi} \cdot A \cdot k_{y,\theta} \cdot \frac{f_y}{\gamma_{M,fi}}} \leq 3$$

$$\mu_y = (2 \cdot \beta_{M,y} - 5) \cdot \bar{\lambda}_{y,\theta} + 0.44\beta_{M,y} + 0.29 \leq 0.8 \quad \text{and} \quad \bar{\lambda}_{y,20°C} \leq 1.1$$

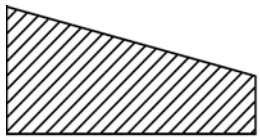
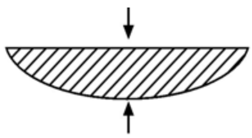
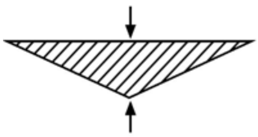
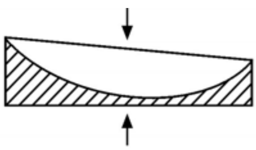
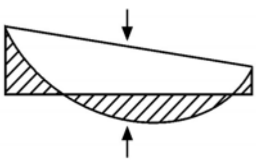
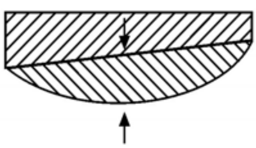
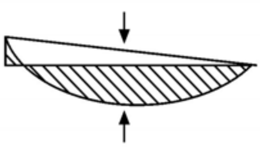
and

$$k_z = 1.0 - \frac{\mu_z \cdot N_{fi,Ed}}{\chi_{z,fi} \cdot A \cdot k_{y,\theta} \cdot \frac{f_y}{\gamma_{M,fi}}} \leq 3$$

$$\mu_z = (1.2 \cdot \beta_{M,z} - 3) \cdot \bar{\lambda}_{z,\theta} + 0.71\beta_{M,z} - 0.29 \leq 0.8$$

terms $\beta_{M,y}$ and $\beta_{M,z}$ depend on the moments affecting the member ends as well as the distribution of moment between the ends. The determination of the term in different cases is given in EN 1993-1-2.

Table 7.3.4.2. Equivalent uniform moment factors.

Moment diagram	Equivalent uniform moment factor β_w
End moment  M_1 $-1 \le \psi \le 1$ ψM_1	$\beta_{M,w} = 1{,}8 - 0{,}7\psi$
Moment due to in-plane lateral loads 	$\beta_{M,Q} = 1{,}3$
 M_Q	$\beta_{M,Q} = 1{,}4$
Moments due to in-plane lateral loads plus end moments 	$\beta_M = \beta_{M,\psi} + \frac{M_Q}{\Delta M}\left(\beta_{M,Q} - \beta_{M,\psi}\right)$
	$M_Q = \lvert \max M \rvert$ due to lateral loads only
	For moment diagram without change of sing $\Delta M = \lvert \max M \rvert$
	For moment diagram with change of sign: $\Delta M = \lvert \max M \rvert + \lvert \min M \rvert$

8. Examples

The design example 13 ‘Stainless steel lattice girder made of hollow sections’ of the ‘Euro Inox – Design Manual for Structural Stainless Steel’ has been utilised when preparing the examples 8.2 and 8.3 in this section.

The minimum material thickness in the examples is limited to 3 mm which meets the minimum thickness requirement for designing lattice girder joints /EN 1993-1-8/.

8.1 Example 1: Definition of temperature and mechanical strength of stainless steel structure when temperature rise during a fire situation follows the EN 1363-1 model.

Basic data:

Hollow section	200x200x8 mm
A_m/V	≈1/t = 1000/8 = 125
Surface finish	Hot rolled, ε_m = 0,4
Density	7,850 kg/m^3
Convective heat transfer coefficient	25 W/m^{2}K

Calculation of steel temperature in compliance with section 7.3.3

$$\Delta\theta_{a,t} = K_{sh} \times \frac{A_m/V}{c_a\rho_a} \times \dot{h}_{net} \times \Delta t \qquad (7.3.3.1)$$

Time	Steel temperature
10 min	365 °C
15 min	549 °C
30 min	811 °C
45 min	891 °C
60 min	938 °C

Values for yield strength (equation 7.3.3.1) and modulus of elasticity for profile 200x200x8mm as a function of time for the most commonly used stainless steels are calculated:

	1.4301		1.4404		1.4571		1.4003		1.4462	
Aika [min]	$f_{y,\theta}$ [N/mm^2]	E [N/mm^2]	$f_{y,\theta}$ [N/mm^2]	E [N/mm^2]	$f_{y,\theta}$ [N/mm^2]	E [N/mm^2]	$f_{y,\theta}$ [N/mm^2]	E [N/mm^2]	$f_{y,\theta}$ [N/mm^2]	E [N/mm^2]
10	187	170800	224	170800	235	170800	309	187880	406	170800
15	162	156080	198	156080	212	156080	219	171688	332	156080
30	86	122040	119	122040	143	122040	44	134244	142	122040
45	51	91080	66	91080	89	91080	38	100188	65	91080
60	26	45000	37	45000	50	45000	30	49500	24	45000

8.2 Example 2: Resistance of tension member

The fire resistance requirement of the structure is 30 minutes. A circular and rectangular hollow section is selected for profiles to carry the tension load. Steel grades 1.4301 and 1.4571 are compared.

Axial tension of the member at room temperature	$N_{t,Ed}$ = 142 kN
Axial tension of the member at the fire temperature	$N_{t,fi,Ed}$ = 47 kN

Room temperature design:

$$N_{pl} = Af_y / \gamma_{M0} > N_{t,Ed}$$

Required cross-section area:
$A = N_{t,Ed}\gamma_{M0} / f_y$ = 142 000 Nx1,1 / 230 N/mm^2 = 680 mm^2

- 50x50x4 mm, A = 695 mm^2, weight/metre 5,95 kg/m,
  N_{pl} = 145,31 kN , for grade 1.4301
  N_{pl} = 151,63 kN , for grade 1.4571
- 76,1x3 mm, A = 689 mm^2, metre weight 5,49 kg/m,
  N_{pl} = 144,06 kN , material 1.4301
  N_{pl} = 150,32 kN , material 1.4571

Fire temperature design:
Steel temperatures after 30 minutes fire exposure defined using the equation (7.3.3.1) are as follows

- 50x50x4 mm	Steel temperature 834 °C
- 76,1x3 mm	Steel temperature 840 °C

Effective yield strength at the selected temperature, equation (7.3.1.1) and Table (7.3.1.5)

	Temperature	
Material	834 °C	840 °C
1.4301	77 N/mm^2	74 N/mm^2
1.4571	128 N/mm^2	125 N/mm^2

Member resistance , equation (7.3.3.2): $N_{fi,\theta,Rd} = k_{y,\theta} N_{Rd} \left[\gamma_{M0} / \gamma_{M,fi} \right]$

Effective yield strength reduction factor $k_{y,\theta}$ is defined using Table 7.2.6 or calculated as follows

	Temperature	
Material	834 °C	840 °C
1.4301	77/230=0,33	74/230=0,32
1.4571	128/240=0,53	125/240=0,52

Profile resistance after 30 minutes fire exposure is

	1.4301	1.4571
50x50x4	52,75 kN	88,40 kN
76,1x3,0	50,71 kN	85,98 kN

The profiles made of steel grade 1.4301 have an adequate resistance. The degree of utilisation in fire is about 90 % for stainless steel grade 1.4301 and about 53 % for stainless steel grade 1.4571. The degree of utilisation at room temperature is over 95 % for both steel grades.

8.3 Example 3: Resistance of axially compression loaded member

The fire resistance after 15 minutes fire exposure is calculated for an axially compressed diagonal brace member in a stainless steel lattice girder. The brace member can be made of stainless steel grades 1.4301, 1.4571 and 1.4003. The compression member length is 1,253 mm, which is also taken as the buckling length.

Compression force at room temperature $N_{c,Ed} = -66$ kN
Compression force in fire $N_{c,fi,Ed} = -22$ kN

Profiles are selected on the basis of room temperature design:

Square profile:
1.4301, 50x50x3 mm, A=541 mm^2, i=19,0 mm
1.4571, 50x50x3 mm, A=541 mm^2, i=19,0 mm
1.4003, 50x50x3 mm, A=541 mm^2, i=19,0 mm

Circular profile
1.4301, 48,3x3,2 mm, A=453 mm^2 , i=16,0 mm
1.4571, 48,3x3,2 mm, A=453 mm^2 , i=16,0 mm

Buckling resistance (equation 7.2.5.4):

$$N_{b,Rd} = \chi \cdot A \cdot f_y / 1{,}1$$

Profile	$\bar{\lambda}$	φ	χ	$N_{b,Rd}$ [kN]
50x50x3 1.4301	0,711	0,829	0,796	90,0
50x50x3 1.4571	0,727	0,844	0,784	92,6
50x50x3 1.4003	0,748	0,866	0,769	105,9
48,3x3,2 1.4301	0,845	0,966	0,696	66,1
48,3x3,2 1.4571	0,863	0,986	0,683	67,5

Resistance at fire situation:

After 15 min in a fire, the steel temperature is 713 °C (Table 7.3.3.1 and equation (7.3.3.1)).

The parameters used at the temperature of 713 °C are given in the table below.

Material	$\sqrt{k_{y,\theta} / k_{E,\theta}}$	α	$k_{y,\theta}$	$k_{E,\theta}$
1.4301	0,87	0,657	0,53	0,699
1.4571	1,03	0,643	0,74	0,699
1.4003	0,59	0,595	0,25	0,699

The buckling resistance of the member $N_{b,fi,t,Rd}$ is calculated using equation (7.3.4.3).

Profile	$\bar{\lambda}_{\theta}$	φ_{θ}	χ_{fi}	$N_{b,fi,t,Rd}$
50x50x3 1.4301	0,619	0,895	0,648	42,7
50x50x3 1.4571	0,748	1,021	0,582	55,9
50x50x3 1.4003	0,442	0,729	0,764	28,9
48,3x3,2 1.4301	0,735	1,012	0,585	32,3
48,3x3,2 1.4571	0,889	1,181	0,510	41,0

All chosen profiles have an resistance. The low yield strength of austenitic steel grades 1.4301 and 1.4571 at room temperature means a larger profile should be selected. The profiles were over-dimensioned for a 15-minute fire. The 0,2 % strength of 350N/mm^2 can be used for austenitic steel grades, which affects the selection of room temperature profile design significantly. If the higher yield strength is used, the size of the profile can be reduced, which results in an estimated saving in materials of almost 30 %. The critical situation for ferritic profiles is that of the fire. A smaller-sized profile would be adequate for room temperature, but the mechanical strength of the material decreases faster during fire which means that a larger profile must be selected.

The utilisation ratios of the profiles examined in room and fire temperature are as follows.

Profile	Room temperature	Fire design 15 min
50x50x3 1.4301	66 kN / 90 kN = 0,73	22 kN / 42,7 kN = 0,52
50x50x3 1.4571	66 kN / 92,6 kN = 0,71	22 kN / 55,9 kN = 0,39
50x50x3 1.4003	66 kN / 105,9 kN = 0,62	22 kN / 28,9 kN = 0,76
48,3x3,2 1.4301	66 kN / 66,1 kN = 0,99	22 kN / 32,2 kN = 0,68
48,3x3,2 1.4571	66 kN / 67,5 kN = 0,97	22 kN / 41,1 kN = 0,54

8.4 Example 4: Resistance to bending loaded member

A beam is designed for a fire of 30 minutes with an moment E_d = 55 kNm at room temperature and $E_{fi,d}$ = 27,5 kNm at the fire temperature.

Profiles are selected on the basis of room temperature design.
The following profiles are examined:

1.4301 200x100x8 mm, W_{pl} = 267,26x1,000 mm^3, f_y = 230 N/mm^2
1.4301 193,7x8 mm, W_{pl} = 276,05x1,000 mm^3, f_y = 240 N/mm^2
1.44571 200x100x8 mm, W_{pl} = 267,26x1,000 mm^3, f_y = 230 N/mm^2
1.4571 193,7x8 mm, W_{pl} = 276,05x1,000 mm^3, f_y = 240 N/mm^2

Profiles are of class 1 cross-section.

$$M_{c,Rd} = W_{pl} f_y / \gamma_{M0}$$

1.4301 200x100x8 mm, $M_{c,Rd}$ = 267,26x1,000 mm^3 x 230 N/mm^2 /1,1= 55,9 kNm
1.4301 193,7x8 mm, $M_{c,Rd}$ = 276,05x1,000 mm^3 x 230 N/mm^2 /1,1= 57,7 kNm
1.4571 200x100x8 mm, $M_{c,Rd}$ = 267,26x1,000 mm^3 x 240 N/mm^2 /1,1= 58,3 kNm
1.4571 193,7x8 mm, $M_{c,Rd}$ = 276,05x1,000 mm^3 x 240 N/mm^2 /1,1= 60,2 kNm

Profiles OK.

In a fire, a material of thickness 8 mm reaches a temperature of 811 °C after a 30- minute fire. Effective yield strength reduction factor $k_{y,\theta}$ is defined (Table 7.3.1.6)

1.4301 $k_{y,\theta} = 0,37$
1.4571 $k_{y,\theta} = 0,59$

The bending resistance of the profiles is calculated in fire is calculated as follows:

$$M_{fi,\theta,Rd} = k_{y,\theta} [\gamma_{M0} / \gamma_{M,fi}] M_{Rd} \tag{7.3.4.2}$$

1.4301 200x100x8 mm, $M_{fi,\theta,Rd}$ = 22,7 kNm
1.4301 193,7x8 mm, $M_{fi,\theta,Rd}$ = 23,5 kNm
1.4571 200x100x8 mm, $M_{fi,\theta,Rd}$ = 37,8 kNm
1.4571 193,7x8 mm, $M_{fi,\theta,Rd}$ = 39,0 kNm

The beams made of CrNiMo “acid proof” steel grade 1.4571 meet the requirement set. The dimensions of beams made of CrNi “stainless” steel grade 1.4301 must be increased in order to enhance bending resistance . The dimensions of profiles made of 1.4301 are increased.

A material of thickness 10 mm reaches a temperature of 789 °C after a 30-minute fire, in which case the effective yield strength reduction factor $k_{y,\theta}$ = 0,41:

1.4301 200x100x10 mm, $M_{c,Rd}$ = 318,08 x 1,000 mm^3 x 230/1,1= 66,5 kNm
$M_{fi,\theta,Rd}$ = 0,41 x 66,5 x 1,1 = 29,9 kNm

EN1.4301 193,7x10 mm, $M_{c,Rd}$ = 337,79 x 1,000 mm^3 x 230/1,1= 70,6 kNm
$M_{fi,\theta,Rd}$ = 0,41 x 70,6 x 1,1= 31,8 kNm

Both profiles OK.

8.5 Example 5: Resistance of member subject to combined axial compression and bending

The loading on the compression chord member of the lattice girder is as follows:

At room temperature
$N_{c,Ed}$ = -149,1 kN
$M_{\max,Ed}$ = 2,15 kNm

In fire
$N_{c,fi,Ed}$ = -49,2 kN
$M_{\max,fi,Ed}$ = 0,73 kNm

The moment load includes the bending moment caused by eccentricity of the joint of the lattice.

The fire resistance requirement of the structure is 30 minutes.

Room temperature design:

The combined effect of axial compression and bending moment on the resistance of the member is examined using the equation below (EN 1993-1-4):

$$\frac{N_{Ed}}{(N_{b,Rd})_{\min}} + k_y \left(\frac{M_{y,Ed} + N_{Ed} e_{Ny}}{\beta_{W,y} W_{pl,y} f_y / \gamma_{M1}} \right) \leq 1.0$$

Profiles of 80x80x5 mm made of steel grades 1.4301 and 1.4571 are examined.

Cross-section factors:
A = 1436 mm^2
i = 30,3mm
W_{pl} = 39,74 x 1000 mm^3
L_{cr} = 1536 mm

Buckling resistance:

Profile	$\bar{\lambda}$	φ	χ	$N_{b,Rd}$
80x80x5 1.4301	0,545	0,684	0,910	273 kN
80x80x5 1.4571	0,557	0,694	0,903	283 kN

Bending resistance:

80x80x5 1.4301 $M_{pl,Rd}$ = 8,30 kNm

80x80x5 1.4571 $M_{pl,Rd}$ = 8,67 kNm

Joint effect:

Moment enhancement factor:

$k_y = 1.0 + 2\left(\bar{\lambda}_y - 0.5\right)\frac{N_{Ed}}{N_{b,Rd,y}}$, but $1.2 \le k_y \le 1.2 + 2\frac{N_{Ed}}{N_{b,Rd,y}}$

k_y = 1,0+2 (0,545-0,5) x 149,1 kN / 273 kN = 1,049 for material 1.4301

k_y = 1,0+2 (0,557-0,5) x 149,1 kN / 283 kN = 1,060 for material 1.4571

Because k_y < 1,2, the value of k_y = 1,2 is given for both materials.

$\frac{149.1}{273} + 1.2\left(\frac{2.15}{8.30}\right)$ = 0,86 < 1,0 80x80x5mm 1.4301 OK.

$\frac{149.1}{283} + 1.2\left(\frac{2.15}{8.67}\right)$ = 0,82 < 1,0 80x80x5mm 1.4571 OK.

Design in fire:

The temperature of 5 mm thick material after a 30-minute fire is 830 °C.

$$\frac{N_{fi,Ed}}{\chi_{\min,fi} A_g k_{y,\theta} \frac{f_y}{\gamma_{M,fi}}} + \frac{k_y M_{y,fi,Ed}}{M_{y,fi,\theta,Rd}} \le 1.0$$

Buckling resistance:

Material	$\sqrt{k_{y,\theta} / k_{E,\theta}}$	α	$k_{y,\theta}$	$k_{E,\theta}$
1.4301	0,768	0,657	0,34	0,576
1.4571	0,977	0,643	0,55	0,576

Profile	$\bar{\lambda}_\theta$	φ_θ	χ_{fi}	$N_{b,fi,t,Rd}$
80x80x5 1.4301	0,418	0,724	0,760	85,3
80x80x5 1.4571	0,544	0,822	0,692	131,1

Bending resistance:

$$M_{fi,\theta,Rd} = k_{y,\theta}\left[\gamma_{M0} / \gamma_{M,fi}\right]M_{Rd}$$

1.4301 80x80x5 mm: 0,34 x [1,1/1,0] x 39,74 x 1,000 mm^3 x 230 N/mm^2 = 3,41 kNm

1.4571 80x80x5 mm: 0,55 x [1,1/1,0] x 39,74 x 1,000 mm^3 x 240 N/mm^2 = 5,77 kNm

Combined effect:

Bending moment factor :

$$k_y = 1 - \frac{\mu_y N_{fi,Ed}}{\chi_{y,fi} A_g k_{y,\theta} f_y / \gamma_{M,fi}} \leq 3$$

$$\mu_y = (2\beta_{M,y} - 5)\bar{\lambda}_{y,\theta} + 0.44\bar{\beta}_{M,y} + 0.29 \leq 0.8$$

ψ = -0,66

$\beta_{M,y}$ = 1,8 – 0,7x ψ = 2,466

for material 1.4301: μ_y = 1,35, use of value $\mu_y = 0{,}8$

for material 1.4571: μ_y = 1,34, use of value $\mu_y = 0{,}8$

k_y = 0,539 for 1.4301 80x80x5 mm

k_y = 0,699 for 1.4571 80x80x5 mm

Checking the member resistance:

$$\frac{49.2}{85.3} + 0.539 \cdot \frac{0.73}{3.41} = 0{,}69 < 1{,}0 \qquad \text{EN1.4301 80x80x5mm}$$

$$\frac{49.2}{131.1} + 0.699 \cdot \frac{0.73}{5.77} = 0{,}46 < 1{,}0 \qquad \text{EN1.4571 80x80x5mm}$$

At the fire temperature, steel grade 1.4301 has adequate resistance. A profile made of 1.4571 is over-dimensioned for the fire.

8.6. Example 6

The “bending loaded member” of example 8.4 is calculated again using stainless steel hollow section of strength class CP350. The 0,2 % strength of 350 N/mm^2 can be used in design.

Tested profile: 200x100x5 mm

A = 2,391 mm^2
$W_{pl,y}$ = 181,37x1,000 mm^3
$f_{0,2}$ = 350 N/mm^2

At room temperature:

$M_{pl,y}$ = 181,37 x 1,000 mm^3 x 350 N/mm^2/1,1 /1,000/1,000= 57,75 kNm OK.

At the fire temperature:

Steel temperature 830 °C

Material 1.4301: $k_{y,\theta} = 0,34$
Material 1.4571: $k_{y,\theta} = 0,55$

Material 1.4301: $M_{pl,\theta}$ = 0,34 x 57,75 x [1,1/1,0] kNm = 21,6 kNm, not sufficient
Material 1.4571: $M_{pl,\theta}$ = 0,55 x 57,75 x [1,1/1,0] kNm = 34,3 kNm, ok

9. Costing

9.1 Price development

The price of alloying elements, in particular nickel and molybdenum, significantly affects the price of stainless steel. The market price consists of the basic price and alloy surcharge (Figure 9.1). The market price has fluctuated considerably between 1994 and 2007, the most intensive fluctuations being at the end of the said period of time.

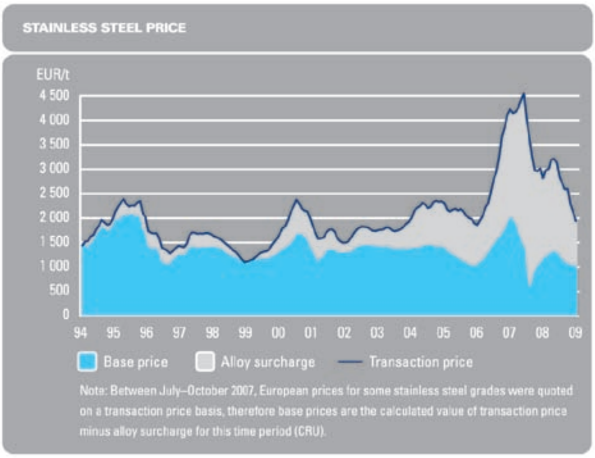


Figure 9.1. Price development of stainless steel grade 1.4301 (AISI 304, cold-rolled) in the German markets (source: Outokumpu/CRU, www.outokumpu.com / Annual Report 2008).

Fluctuations in prices are based on changes in the demand for raw material and end products in the global economy. The price level of hollow sections compared to that of original material depends on the form of hollow section, dimension and the time period of purchasing. The price level has been varied approximately from 1,4 to 1,8 times higher than that of the original material.

9.2 Life cycle costing

The life cycle of a product begins with the design of the structure and ends when the product is disposed of. Most of life cycle costs are generated during the design stage. Choices of material made during the design stage significantly affect the life cycle costs of a product.

During the life cycle, costs primarily arise from use and maintenance. Therefore life cycle costs greatly depend on the design life of the product. The life of many consumables is less than five years, whereas the design life of more valuable products, such as household appliances and private cars, is often 5–15 years. The design life of longer-term products, such as commercial vehicles, can be 15–25 years. The design life of buildings and investments that are important to society is usually 50–100 years, sometimes even more than 100 years (Table 9.2). The service life of building components that can be easily replaced or feasibly repaired, such as roofs, facades, doors and windows, is usually shorter e.g. 25 years. The design life of load bearing structures of bridges is usually 100 years, decks 20–40 years, and railings and lamp posts 30–50 years. The typical design life of piers and shoreline walls is 50 years, but in the case of socially important special sites, the design life can be over 100 years (RIL 2006). The design life used in a life cycle approach is based on the goals set by the owner, user or manufacturer of the product.

Age group	Design service life	Building types within the class	Building components typical to the class	Typical justification for service life
Group 1	1–5 years	Temporary buildings (very rare)	IT systems of buildings and IT system components, short-lived coatings.	Becoming outdated Becoming damaged
Group 2	25 years	More permanent temporary buildings, huts, temporary storage units	HVAC, water, waste water, information and waste systems and their components. Sheeting. Windows. Doors. Supplement structures (occasionally). Long-term coating.	Buildings: becoming outdated Building parts: Becoming damaged or outdated
Group 3	50 years	Ordinary buildings	Foundations. Framework structures. Exterior walls. Roof structures. Supplement structures.	Buildings: becoming outdated or damaged Building parts: Becoming damaged
Group 4	100 years	Buildings with more demanding performance criteria or other need for increased calculation accuracy	Foundations. Framework structures. Exterior walls. Roof structures. Supplement structures.	Buildings: becoming outdated or damaged Building parts: Becoming damaged
Group 5	over 100 (150, 200, 300, 500) years	Special buildings (e.g. historical buildings). Defined on a case-by-case basis	Foundations. Framework structures. Exterior walls. Roof structures. Supplement structures.	Buildings: becoming outdated or damaged Building parts: Becoming damaged

Table 9.2. Design life of different building types and their components in different age groups (RIL 2001).

The service life is governed either by the product becoming outdated or getting damaged. A product can become outdated due to reasons attributed to technology, functioning, finance or ecology. A product is financially outdated when the product can be used in terms of technology and functioning, but its use and service costs are more expensive than a new corresponding product, which makes a new investment feasible. A product is ecologically outdated when its environmental impacts no longer meet the demands of society, the user or owner.

The calculation of life cycle costs is fundamentally an investment profitability calculation which, in addition to purchase cost, includes use and service costs as well as costs related to owning, using, dismantling and disposing of the dismantled waste of a product or system. Labour costs are an increasingly important part of use and service costs in developed countries. Residual value and disposal of the product are usually insignificant in products with long service life, but they may be highly important in short-term investments.

The main items of a life cycle cost calculation are

- Definition of evaluation criteria and limitations
- Recognition of cost-generating factors
- Calculation of costs
- Discounting the costs to current value
- Comparison of different alternatives.

When defining the evaluation criteria for life cycle costs, cost-generating factors can, if required, be limited in compliance with the selected approach. For example, when designing route structures, the life cycle cost assessment can be made from the perspective of the road administrator, user or the society. If the assessment is made from the society's perspective, indirect costs for road users (petrol for a longer trip, longer travelling time due to speed limits and accident costs) and environmental costs must be taken into account, in addition to building and maintenance costs.

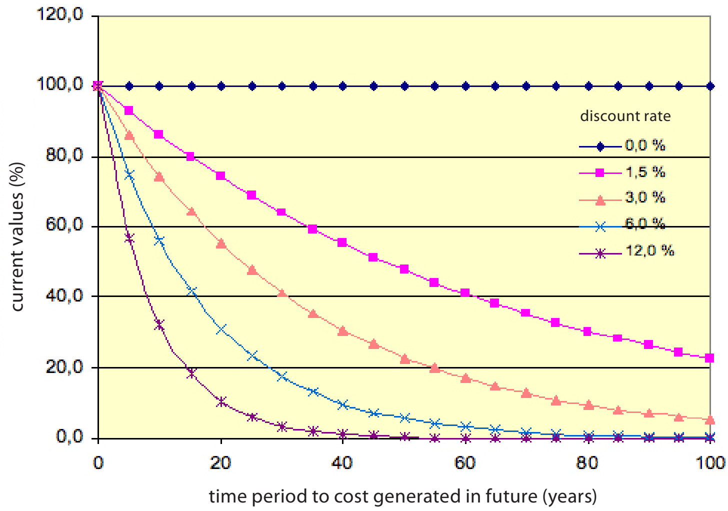
The profitability of the investment is usually evaluated by discounting all future costs to the current value. The discount rate is used in calculation. Discount rate in a purely financial assessment describes an evaluation of the real interest that can be gained on the invested capital when making a long-term investment. The selected interest level significantly affects the results of the life cycle cost calculation. A high discount rate favours repairs made in the future whereas a low interest rate favours investments aiming to increase the service life of the building, e.g. in terms of the selection of materials (Figure 9.2). The discount rate can be selected from the chosen viewpoint e.g. as follows (Tupamäki 2004, Tiehallinto 2004):

- Environmental impacts approach, discount rate 0 %
- National economy approach, discount rate 3 %
- State economy approach, discount rate 6 %
- Business economy approach, discount rate 9 %.

The discount rate applied is usually determined by the relevant authorities or profit target set for the capital invested. Depending on the product, the discount rate based on profit for the invested capital is defined by the owner, user or manufacturer.

Figure 9.2. Current value of cost generated in the future using different discount rate values (Talja et al. 2006).

In the business economy approach, discount rate depends on the market rate, which in



turn is affected by fluctuations in the economic situation. For example, Euro Inox (2005) used the rate of 7,4 % in its life cycle cost calculation of a coach frame. In that case, the use of stainless steel grades 1.4301 and 1.4016 (stainless steel hollow sections and plates of the body) were justified if the design service life of the body is 20 years, and full repair of the body in 12 years can be avoided by selecting a new material.

The discount rate level is usually 3–6 % in the case of socially important investments based on the approaches of national and State economy. In Finland, the Ministry of Transport and Communications' instruction for route projects is 5 % (LVM 2003). Decisions are often based on calculations made using different discount rates, because the rate used significantly affects life cycle costs. For example, Talja et al. (2006) examine the use of stainless steel as an enclosure for a concrete column of a bridge using the discount rates of 0, 3 and 6 %. The results indicated that using steel grade 1.4404 as an enclosure is justified at all discount rate levels, if it avoids repairing the concrete column and the related direct and indirect costs two times (at 30-year intervals) during the design service life of 100 years. Lower discount rate levels further emphasise the feasibility of stainless steel. In general, an advantage in life cycle costs is obtained by using stainless steel for applications where direct or indirect costs attributed to maintenance are high, in addition to the other benefits of using stainless steel. The benefits are obvious if life cycle assessment is based on the approach of the national economy, which is typically used in the building of infrastructure. Such uses in house construction are, for example, support structures for glass facades and railings.

10. Handling and maintenance

Stainless steel should be handled carefully in the workshop. The following topics give general guidance on the handling and maintenance of stainless steel and stainless steel structures. It is recommended that specific guidance is prepared in a target-specific manner for workshops and sites in order to ensure that the properties assumed in design are present in the assembled structure throughout its entire service life. In some cases it is recommended that a specialist is consulted when preparing this guidance.

10.1 Storing

- Stainless steel hollow sections should be stored in such a way that they can be clearly distinguished from other material to avoid the risk of mix-up

- Stainless steel hollow sections marked by the warehouse/user, pens that do not impact on the corrosion resistance of the material or the surface finish must be used, in addition to which the marking of the pen must be easily removable from the assembled structure.

- The contact surfaces of warehouse racks should be protected with wood or plastic. Contact surfaces and possible plastic or millboard strips between the hollow sections or bundles must be kept clean and dry in order to prevent the hollow section surfaces from getting stained or scratched.

- The evaporation of moisture collecting on the surface of hollow sections stored horizontally may cause concentration of impurities and, later on, pitting. It is recommended to store stainless steel hollow sections in dry premises or ensure sufficient ventilation in order to prevent the collection of moisture.

- The storage area must be protected against increased air pollution or heavy sand dust. Unprotected storage, for example in industrial areas, close to the sea or sea transport exposed to splashing causes changes in surface finish in terms of staining.

10.2 Transportation

- Lifting gear must be made of material which does not transfer impurities or iron particles to the surface of stainless steel hollow sections. Impurities, together with moisture, may later cause staining.

- When transferring separate stainless steel hollow sections or whole bundles, care must be taken not to damage hollow sections against the warehouse supporting structures and cause visual damage such as dents in the stainless steel surface.

- Transferring stainless steel hollow sections on working tables must be made by lifting or using rolls. Sliding on the table will scratch the surface and cause visual damage.

- Particular care must also be taken in workshops of the cleanness of tools processing carbon steels or separate tools must be used for stainless steel.

10.3 Machining

- The surfaces of working tables must be made of wood or non-metallic material in order to minimise the adhesion of extraneous rust on the surfaces of stainless steel hollow sections and also to prevent scratching of the surface

- It is recommended to keep the protective plastic on the stainless steel hollow section surface during machining whenever possible. If the film must be removed and reinstalled on the surface of the material, separate instructions must be given for this. When machining close to stainless steel, it must be ensured that sparks or loose material do not hit the stainless steel.

- Special care must be taken when machining carbon steel in order to prevent carbon steel dust and particles collecting on the stainless steel surface.

- When welding, spattering of the surface must be avoided. Spatter must be removed and the corrosion resistance of the critical spot restored by pickling. Ignition of the welding arc must be made in the area of the groove or to a separate secondary piece

- The processing area for stainless steel can be separated from other processing areas, for example by using movable walls.

10.4 Handling of component

- Before a component can be delivered from the workshop to site, it must be finished and cleansed in order to achieve a surface finish that is in compliance with the instructions. After installation, it must be ensured that the structure is cleansed and the material is in a passive state ready for the intended usage.

- Special care must be taken when transferring components to prevent denting and scratching.

- Components can be protected using tarpaulins in the workshop and during transportation to prevent impurities from collecting on the surface of the material.

- Care must also be taken on the site that no impurities or spatter flying around during the finishing work of the adjacent structures remain in assembled structures. If impurities or spatter are found, the surface must be restored to the original state by washing, polishing or pickling.

10.5 Maintenance of the surface

In terms of the visual properties of the surface, surface treatment and material alloying are the critical factors. If it is possible to inspect and maintain the surface of a component in situ, then it may be possible to use a lower-alloyed (and consequently cheaper) grade. This will decrease investment costs and transfer them partly to future maintenance costs. Possible neglect in maintenance will result in deteriorating visual properties and, depending on the corrosion attack, in damaging the entire structure.

If the long term appearance of the structure is important and corrosion attack from the environment is likely to cause staining or if the surrounding air is impure, it is recommended that simple maintenance instructions for the structure are developed. In addition, if structures can be visually inspected on a regular basis, instructions can be made for treating critical areas where the surface has deteriorated before actual maintenance measures are taken. Swimming pool secondary structures serve as an example of typical visually critical targets whose continuous maintenance can be arranged. Another example is the support structures of double facades where the outer skin is glass, in which case steel structures are placed in a tight space between the wall and the glass and they can be easily visually inspected from the inside of the building.

- It is important to follow the instructions given on surface maintenance. It is recommended to draw up a maintenance schedule on a case-by-case basis for structures with a particular visual function. Rinsing outdoor structures with hot water 1 to 2 times a year is usually enough.

- Grime can be washed with a detergent solution, rinsed with abundant water, after which it must be ensured that the surface dries properly. Neutral or slightly alkaline detergents can be used for washing stainless steel.

- Stains can be removed using detergent containing nitric acid, but spotting must be removed by pickling.

- Minor scratches on the surface can be polished to correspond to the original surface by using sufficiently fine paper and polishing in the original polishing direction.

- When washing surrounding structures, components, windows or other similar elements, removal of detergent from stainless steel surfaces must be taken into account.

- It is recommended to rinse secondary structures in swimming pool buildings daily with fresh water and dry them after rinsing.

- If the surface is damaged and it is not known how to repair the damage, a specialist should be consulted.

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Table 1. Sectional properties of rectangular hollow sections.

h	b	t	r	A	I_y	$W_{el,y}$	$W_{pl,y}$	i_y	I_z	$W_{el,z}$	$W_{pl,z}$	i_z	I_v	W_v	F/V
[mm]	[mm]	[mm]	[mm]	[mm²]	[mm⁴]	[mm³]	[mm³]	[mm]	[mm⁴]	[mm³]	[mm³]	[mm]	[mm⁴]	[mm³]	[1/m]
				x10²	x10⁴	x10³	x10³	x10	x10⁴	x10³	x10³	x10	x10⁴	x10³	
30	20	1,2	2,4	1,11	1,34	0,89	1,09	1,1	0,71	0,71	0,83	0,8	1,52	1,18	867
30	20	1,5	3	1,35	1,59	1,06	1,32	1,08	0,84	0,84	0,99	0,79	1,83	1,4	702
30	20	2	4	1,74	1,94	1,29	1,65	1,06	1,02	1,02	1,24	0,77	2,29	1,71	536
40	10	1,5	3	1,35	2,15	1,08	1,49	1,26	0,21	0,43	0,52	0,4	0,7	0,81	702
40	10	2	4	1,74	2,6	1,3	1,85	1,22	0,25	0,49	0,63	0,38	0,83	0,94	536
40	20	1,2	2,4	1,35	2,73	1,36	1,71	1,42	0,92	0,92	1,05	0,83	2,27	1,6	861
40	20	1,5	3	1,65	3,27	1,63	2,07	1,41	1,1	1,1	1,27	0,81	2,74	1,91	695
40	20	2	4	2,14	4,05	2,02	2,61	1,38	1,34	1,34	1,6	0,79	3,45	2,36	529
40	30	1,2	2,4	1,59	3,63	1,81	2,17	1,51	2,33	1,55	1,78	1,21	4,52	2,5	857
40	30	1,5	3	1,95	4,38	2,19	2,64	1,5	2,81	1,87	2,17	1,2	5,52	3,02	691
40	30	2	4	2,54	5,49	2,75	3,37	1,47	3,51	2,34	2,77	1,18	7,07	3,79	525
40	30	3	6	3,61	7,27	3,63	4,61	1,42	4,6	3,07	3,77	1,13	9,72	5,03	359
45	35	2	4	2,94	8,27	3,68	4,46	1,68	5,6	3,2	3,75	1,38	10,89	5,13	521
50	10	2	4	2,14	4,93	1,97	2,82	1,52	0,31	0,62	0,79	0,38	1,09	1,2	529
50	12	3	6	3,13	6,86	2,74	4,03	1,48	0,57	0,96	1,28	0,43	1,99	1,84	363
50	20	1,5	3	1,95	5,77	2,31	2,97	1,72	1,35	1,35	1,55	0,83	3,69	2,42	691
50	20	2	4	2,54	7,23	2,89	3,78	1,69	1,67	1,67	1,96	0,81	4,66	3	525
50	25	1,2	2,4	1,71	5,5	2,2	2,73	1,8	1,88	1,5	1,69	1,05	4,54	2,59	855
50	25	1,5	3	2,1	6,65	2,66	3,33	1,78	2,25	1,8	2,05	1,04	5,54	3,13	689
50	25	2	4	2,74	8,38	3,35	4,26	1,75	2,81	2,25	2,62	1,01	7,06	3,92	523
50	25	3	6	3,91	11,17	4,47	5,86	1,69	3,67	2,93	3,56	0,97	9,64	5,18	357
50	30	1,2	2,4	1,83	6,22	2,49	3,02	1,85	2,83	1,89	2,13	1,25	6,22	3,17	854
50	30	1,5	3	2,25	7,54	3,01	3,7	1,83	3,42	2,28	2,6	1,23	7,6	3,83	688
50	30	2	4	2,94	9,54	3,81	4,74	1,8	4,29	2,86	3,33	1,21	9,77	4,84	521
50	30	3	6	4,21	12,83	5,13	6,57	1,75	5,7	3,8	4,58	1,16	13,53	6,49	356
50	30	4	8	5,35	15,25	6,1	8,05	1,69	6,69	4,46	5,58	1,12	16,53	7,71	273
50	40	1,5	3	2,55	9,3	3,72	4,42	1,91	6,6	3,3	3,8	1,61	12,26	5,24	685
50	40	2	4	3,34	11,84	4,74	5,7	1,88	8,39	4,19	4,89	1,59	15,86	6,67	519
50	40	3	6	4,81	16,15	6,46	7,98	1,83	11,38	5,69	6,83	1,54	22,34	9,12	353
60	10	1,5	3	1,95	6,69	2,23	3,14	1,85	0,32	0,65	0,77	0,41	1,13	1,25	691
60	10	2	4	2,54	8,32	2,77	3,99	1,81	0,38	0,76	0,95	0,39	1,35	1,46	525
60	20	1,2	2,4	1,83	7,64	2,55	3,29	2,05	1,35	1,35	1,5	0,86	3,85	2,45	854
60	20	1,5	3	2,25	9,25	3,08	4,02	2,03	1,61	1,61	1,83	0,85	4,66	2,94	688
60	20	2	4	2,94	11,68	3,89	5,15	1,99	1,99	1,99	2,32	0,82	5,89	3,65	521
60	30	1,5	3	2,55	11,82	3,94	4,9	2,15	4,03	2,68	3,03	1,26	9,77	4,64	685
60	30	2	4	3,34	15,05	5,02	6,31	2,12	5,08	3,39	3,89	1,23	12,57	5,88	519
60	30	3	6	4,81	20,5	6,83	8,82	2,06	6,8	4,53	5,39	1,19	17,48	7,95	353
60	30	4	8	6,15	24,7	8,23	10,92	2	8,06	5,37	6,62	1,14	21,47	9,52	270
60	40	1,5	3	2,85	14,39	4,8	5,77	2,25	7,71	3,86	4,38	1,64	15,97	6,35	683
60	40	2	4	3,74	18,41	6,14	7,47	2,22	9,83	4,92	5,65	1,62	20,7	8,12	517
60	40	3	6	5,41	25,38	8,46	10,53	2,17	13,44	6,72	7,94	1,58	29,28	11,17	351
60	40	4	8	6,95	30,99	10,33	13,16	2,11	16,28	8,14	9,89	1,53	36,67	13,65	268
70	20	2	4	3,34	17,6	5,03	6,72	2,3	2,32	2,32	2,68	0,83	7,14	4,31	519
70	40	2	4	4,14	26,85	7,67	9,44	2,55	11,28	5,64	6,41	1,65	25,72	9,56	515
70	40	3	6	6,01	37,31	10,66	13,39	2,49	15,5	7,75	9,05	1,61	36,49	13,23	349
70	40	4	8	7,75	45,95	13,13	16,84	2,44	18,88	9,44	11,33	1,56	45,84	16,25	266
70	50	2	4	4,54	31,48	8,99	10,8	2,63	18,76	7,5	8,58	2,03	37,45	12,2	514
70	50	3	6	6,61	44,05	12,59	15,4	2,58	26,1	10,44	12,21	1,99	53,62	17,06	348
80	10	2	4	3,34	19,1	4,78	6,93	2,39	0,51	1,02	1,27	0,39	1,87	1,99	519
80	20	1,5	3	2,85	19,74	4,94	6,57	2,63	2,13	2,13	2,38	0,86	6,64	3,97	683
80	20	2	4	3,74	25,19	6,3	8,49	2,6	2,64	2,64	3,04	0,84	8,4	4,96	517
80	40	1,5	3	3,45	28,99	7,25	8,93	2,9	9,94	4,97	5,53	1,7	23,77	8,57	680
80	40	2	4	4,54	37,36	9,34	11,61	2,87	12,72	6,36	7,17	1,67	30,88	11	514
80	40	3	6	6,61	52,25	13,06	16,54	2,81	17,56	8,78	10,16	1,63	43,88	15,28	348
80	40	4	8	8,55	64,79	16,2	20,91	2,75	21,49	10,74	12,77	1,59	55,24	18,84	265
80	40	5	10	10,36	75,11	18,78	24,74	2,69	24,59	12,3	15,02	1,54	64,97	21,74	215
80	50	1,5	3	3,75	33,61	8,4	10,1	2,99	16,36	6,54	7,33	2,09	34,72	10,88	679
80	50	2	4	4,94	43,44	10,86	13,17	2,97	21,06	8,43	9,54	2,07	45,31	14,04	513
80	50	3	6	7,21	61,15	15,29	18,85	2,91	29,42	11,77	13,62	2,02	65	19,71	346
80	50	4	8	9,35	76,36	19,09	23,95	2,86	36,46	14,59	17,25	1,98	82,7	24,57	263
80	50	5	10	11,36	89,19	22,3	28,49	2,8	42,29	16,92	20,45	1,93	98,4	28,69	214
80	60	2	4	5,34	49,53	12,38	14,73	3,05	31,87	10,62	12,11	2,44	61,22	17,08	512
80	60	3	6	7,81	70,05	17,51	21,16	3	44,89	14,96	17,37	2,4	88,35	24,14	345
80	60	4	8	10,15	87,92	21,98	26,99	2,94	56,12	18,71	22,12	2,35	113,12	30,32	262

h [mm]	**b** [mm]	**t** [mm]	**r** [mm]	**A** [mm²] x10²	**I_y** [mm⁴] x10⁴	**$W_{el,y}$** [mm³] x10³	**$W_{pl,y}$** [mm³] x10³	**i_y** [mm] x10	**I_z** [mm⁴] x10⁴	**$W_{el,z}$** [mm³] x10³	**$W_{pl,z}$** [mm³] x10³	**i_z** [mm] x10	**I_v** [mm⁴] x10⁴	**W_v** [mm³] x10³	**F/V** [1/m]
80	60	5	10	12,36	103,28	25,82	32,24	2,89	65,66	21,89	26,38	2,31	135,53	35,67	213
100	40	2	4	5,34	65,38	13,08	16,54	3,5	15,61	7,81	8,69	1,71	41,47	13,89	512
100	40	3	6	7,81	92,34	18,47	23,75	3,44	21,67	10,84	12,38	1,67	59,05	19,39	345
100	40	4	8	10,15	115,7	23,14	30,26	3,38	26,69	13,35	15,65	1,62	74,53	24,04	262
100	40	5	10	12,36	135,6	27,12	36,09	3,31	30,76	15,38	18,52	1,58	87,92	27,9	213
100	50	2	4	5,74	74,98	15	18,5	3,62	25,67	10,27	11,46	2,12	61,59	17,73	511
100	50	3	6	8,41	106,46	21,29	26,66	3,56	36,06	14,42	16,44	2,07	88,56	25,01	345
100	50	4	8	10,95	134,14	26,83	34,1	3,5	44,95	17,98	20,93	2,03	112,99	31,35	261
100	50	5	10	13,36	158,19	31,64	40,84	3,44	52,45	20,98	24,95	1,98	134,87	36,8	212
100	50	6	12	15,63	178,75	35,75	46,9	3,38	58,67	23,47	28,52	1,94	154,2	41,43	179
100	60	2	4	6,14	84,59	16,92	20,46	3,71	38,6	12,87	14,43	2,51	84,08	21,56	510
100	60	3	6	9,01	120,57	24,11	29,57	3,66	54,65	18,22	20,79	2,46	121,67	30,64	344
100	60	4	8	11,75	152,58	30,52	37,94	3,6	68,68	22,89	26,6	2,42	156,27	38,68	261
100	60	5	10	14,36	180,77	36,15	45,59	3,55	80,83	26,94	31,88	2,37	187,86	45,75	211
100	60	6	12	16,83	205,3	41,06	52,54	3,49	91,2	30,4	36,64	2,33	216,44	51,92	178
100	80	2	4	6,94	103,8	20,76	24,38	3,87	73,87	18,47	20,97	3,26	134,59	29,24	509
100	80	3	6	10,21	148,81	29,76	35,39	3,82	105,64	26,41	30,4	3,22	196,12	41,91	343
100	80	4	8	13,35	189,47	37,89	45,62	3,77	134,17	33,54	39,15	3,17	253,79	53,38	259
100	80	5	10	16,36	225,94	45,19	55,09	3,72	159,61	39,9	47,24	3,12	307,55	63,72	210
100	80	6	12	19,23	258,39	51,68	63,82	3,67	182,1	45,53	54,67	3,08	357,38	72,98	176
120	40	2	4	6,14	104,07	17,34	22,28	4,12	18,5	9,25	10,21	1,74	52,32	16,78	510
120	40	3	6	9,01	148,04	24,67	32,16	4,05	25,79	12,89	14,6	1,69	74,56	23,51	344
120	40	4	8	11,75	186,89	31,15	41,21	3,99	31,9	15,95	18,53	1,65	94,23	29,24	261
120	40	5	10	14,36	220,81	36,8	49,45	3,92	36,93	18,46	22,02	1,6	111,35	34,05	211
120	60	2	4	6,94	131,92	21,99	27	4,36	45,33	15,11	16,75	2,56	107,88	26,05	509
120	60	3	6	10,21	189,12	31,52	39,18	4,3	64,4	21,47	24,21	2,51	156,34	37,14	343
120	60	4	8	13,35	240,74	40,12	50,49	4,25	81,25	27,08	31,08	2,47	201,12	47,05	259
120	60	5	10	16,36	286,97	47,83	60,95	4,19	95,99	32	37,38	2,42	242,23	55,85	210
120	60	6	12	19,23	328,01	54,67	70,57	4,13	108,77	36,26	43,12	2,38	279,67	63,6	176
120	80	2	4	7,74	159,77	26,63	31,72	4,54	86,04	21,51	24,09	3,33	175	35,32	508
120	80	3	6	11,41	230,2	38,37	46,2	4,49	123,43	30,86	35,02	3,29	255,47	50,8	342
120	80	4	8	14,95	294,59	49,1	59,77	4,44	157,29	39,32	45,23	3,24	331,24	64,93	258
120	80	5	10	18,36	353,14	58,86	72,45	4,39	187,78	46,94	54,74	3,2	402,27	77,77	209
120	80	6	12	21,63	406,06	67,68	84,25	4,33	215,03	53,76	63,55	3,15	468,54	89,4	175
150	50	5	10	18,36	456,29	60,84	80,48	4,99	77,87	31,15	36,2	2,06	230,05	57,11	209
150	100	3	6	14,41	460,64	61,42	73,48	5,65	247,64	49,53	55,76	4,15	507,2	81,4	340
150	100	4	8	18,95	594,6	79,28	95,67	5,6	318,57	63,71	72,5	4,1	661,63	104,94	257
150	100	5	10	23,36	719,2	95,89	116,73	5,55	384,02	76,8	88,34	4,05	808,68	126,81	207
150	100	6	12	27,63	834,69	111,29	136,68	5,5	444,19	88,84	103,3	4,01	948,34	147,07	173
150	100	8	16	35,79	1039,29	138,57	173,31	5,39	549,48	109,9	130,63	3,92	1205,34	183,05	132
150	100	10	20	43,42	1210,38	161,38	205,67	5,28	635,94	127,19	154,61	3,83	1432,38	213,34	107
200	100	3	6	17,41	924,33	92,43	113,25	7,29	318,23	63,65	70,31	4,28	754,28	109,63	339
200	100	4	8	22,95	1199,71	119,97	148,04	7,23	410,78	82,16	91,7	4,23	985,38	141,81	255
200	100	5	10	28,36	1459,25	145,93	181,37	7,17	496,94	99,39	112,09	4,19	1206,29	171,94	206
200	100	6	12	33,63	1703,31	170,33	213,27	7,12	576,91	115,38	131,5	4,14	1417,03	200,1	172
200	100	8	16	43,24	2090,48	209,08	267,26	6,95	705,36	141,07	164,65	4,04	1810,72	249,1	
250	150	4	8	30,95	2696,87	215,75	259,61	9,33	1234,24	164,57	183,27	6,32	2664,68	275,38	254
250	150	5	10	38,36	3304,18	264,33	319,76	9,28	1507,95	201,06	225,48	6,27	3284,54	336,9	204
250	150	6	12	45,63	3885,56	310,84	378,05	9,23	1768,35	235,78	266,28	6,23	3885,8	395,65	171
250	150	8	16	59,79	4972,24	397,78	489,07	9,12	2250,41	300,06	343,71	6,13	5032,43	505,13	129
250	150	10	20	73,42	5960,2	476,82	592,79	9,01	2682,88	357,72	415,67	6,04	6104,27	604,41	104
250	150	12,5	25	89,73	7061,28	564,9	712,37	8,87	3157,33	420,98	498,11	5,93	7338,44	714,91	84
300	100	5	10	38,36	4065,22	271,01	348,15	10,29	722,77	144,55	159,59	4,34	2043,8	262,23	204
300	100	6	12	45,63	4776,79	318,45	411,43	10,23	842,35	168,47	187,9	4,3	2403,46	306,21	171
300	100	8	16	59,79	6102,25	406,82	531,75	10,1	1058,6	211,72	241,03	4,21	3074,25	386,43	129
300	100	10	20	73,42	7300,57	486,7	643,86	9,97	1245,94	249,19	289,61	4,12	3680,82	456,86	104
300	200	6	12	57,63	7370,23	491,35	587,83	11,31	3962,19	396,22	446,07	8,29	8115,23	651,24	170
300	200	8	16	75,79	9513,66	634,24	765,35	11,2	5097,04	509,7	579,99	8,2	10586,01	839,54	128
300	200	10	20	93,42	11507,23	767,15	933,86	11,1	6144,3	614,43	706,73	8,11	12938,91	1014,48	103
300	200	12,5	25	114,73	13794,58	919,64	1131,99	10,97	7334,98	733,5	855,24	8	15713,54	1215,19	83
400	200	6	12	69,63	14789,35	739,47	905,99	14,57	5091,63	509,16	562,47	8,55	12068,52	877,05	169
400	200	8	16	91,79	19195,28	959,76	1184,31	14,46	6572,45	657,25	733,59	8,46	15766,03	1134,45	128
400	200	10	20	113,42	23348,08	1167,4	1450,98	14,35	7950,97	795,1	896,73	8,37	19300,7	1375,49	103
400	200	12,5	25	139,73	28191,01	1409,55	1768,13	14,2	9535,5	953,55	1089,61	8,26	23489,86	1654,71	83

Table 2. Sectional properties of square hollow sections.

h [mm]	b [mm]	t [mm]	r [mm]	A [mm^2] x10	I_y [mm^4] x10^4	$W_{el,y}$ [mm^3] x10^3	$W_{pl,y}$ [mm^3] x10^3	i_y [mm] x10	I_v [mm^4] x10^4	W_v [mm^3] x10^3	F/V [1/m]
20	20	1	1,5	0,743	0,442	0,442	0,53	0,77	0,7	0,66	1042
20	20	1,2	1,8	0,878	0,510	0,510	0,61	0,76	0,82	0,76	876
20	20	1,5	2,3	1,071	0,601	0,601	0,73	0,75	0,98	0,89	711
20	20	2	3	1,371	0,725	0,725	0,91	0,73	1,22	1,07	546
25	25	1	1,5	0,943	0,897	0,718	0,84	0,98	1,41	1,07	1033
25	25	1,2	2,4	1,105	1,025	0,820	0,97	0,96	1,66	1,24	867
25	25	1,5	3	1,352	1,217	0,973	1,17	0,95	2,01	1,47	702
25	25	2	4	1,737	1,484	1,187	1,47	0,92	2,53	1,8	536
25	25	3	6	2,408	1,841	1,473	1,91	0,87	3,33	2,27	372
30	30	1,2	2,4	1,345	1,833	1,222	1,44	1,17	2,93	1,84	861
30	30	1,5	3	1,652	2,196	1,464	1,74	1,15	3,57	2,21	695
30	30	2	4	2,137	2,722	1,815	2,21	1,13	4,54	2,75	529
30	30	3	6	3,008	3,504	2,336	2,96	1,08	6,15	3,58	365
32	32	1,2	2,4	1,441	2,249	1,406	1,65	1,25	3,58	2,11	859
32	32	1,5	3	1,772	2,701	1,688	2	1,23	4,37	2,54	693
34	34	1,2	2,4	1,537	2,723	1,602	1,88	1,33	4,32	2,41	858
34	34	1,5	3	1,892	3,278	1,928	2,28	1,32	5,28	2,9	692
35	35	1,2	2,4	1,585	2,982	1,704	1,99	1,37	4,73	2,56	857
35	35	1,5	3	1,952	3,595	2,055	2,43	1,36	5,78	3,09	691
35	35	2	4	2,537	4,508	2,576	3,09	1,33	7,41	3,89	525
35	35	3	6	3,608	5,948	3,399	4,23	1,28	10,22	5,18	359
38	38	1,2	2,4	1,729	3,861	2,032	2,37	1,49	6,09	3,05	855
38	38	1,5	3	2,132	4,668	2,457	2,89	1,48	7,46	3,7	689
38	38	2	4	2,777	5,883	3,096	3,7	1,46	9,6	4,67	523
40	40	1,2	2,4	1,825	4,532	2,266	2,64	1,58	7,13	3,4	854
40	40	1,5	3	2,252	5,490	2,745	3,22	1,56	8,75	4,13	688
40	40	2	4	2,937	6,940	3,470	4,13	1,54	11,28	5,23	521
40	40	3	6	4,208	9,324	4,662	5,72	1,49	15,75	7,07	356
40	40	4	8	5,348	11,075	5,537	7,01	1,44	19,44	8,48	273
50	50	1,2	2,4	2,305	9,075	3,630	4,2	1,98	14,15	5,45	850
50	50	2	4	3,737	14,147	5,659	6,66	1,95	22,63	8,51	517
50	50	3	6	5,408	19,467	7,787	9,39	1,9	32,13	11,76	351
50	50	4	8	6,948	23,736	9,494	11,73	1,85	40,42	14,43	268
50	50	5	10	8,356	27,038	10,815	13,7	1,8	47,46	16,56	219
50	50	6	12	9,633	29,454	11,782	15,32	1,75	53,23	18,2	186
60	60	1,5	3	3,452	19,522	6,507	7,53	2,38	30,48	9,77	680
60	60	2	4	4,537	25,142	8,381	9,79	2,35	39,79	12,59	514
60	60	3	6	6,608	35,135	11,712	13,95	2,31	57,09	17,65	348
60	60	4	8	8,548	43,551	14,517	17,64	2,26	72,64	21,97	265
60	60	5	10	10,356	50,494	16,832	20,88	2,21	86,42	25,61	215
60	60	6	12	12,033	56,066	18,689	23,68	2,16	98,41	28,62	182
70	70	3	6	7,808	57,527	16,436	19,42	2,71	92,42	24,74	345
70	70	4	8	10,148	72,120	20,606	24,76	2,67	118,52	31,11	262
70	70	5	10	12,356	84,629	24,180	29,56	2,62	142,21	36,65	213
76	76	3	6	8,528	74,689	19,655	23,13	2,96	119,35	29,56	344
76	76	4	8	11,108	94,129	24,771	29,6	2,91	153,59	37,36	261
76	76	5	10	13,556	111,068	29,228	35,48	2,86	185,01	44,23	212
80	80	2	4	6,137	61,698	15,425	17,85	3,17	96,34	23,16	510

h	b	t	r	A	I_y	$W_{el,y}$	$W_{pl,y}$	i_y	I_v	W_v	F/V
[mm]	[mm]	[mm]	[mm]	[mm^2]	[mm^4]	[mm^3]	[mm^3]	[mm]	[mm^4]	[mm^3]	[1/m]
				x10	$x10^4$	$x10^3$	$x10^3$	x10	$x10^4$	$x10^3$	
80	80	3	6	9,008	87,843	21,961	25,78	3,12	139,93	33,02	344
80	80	4	8	11,748	111,043	27,761	33,07	3,07	180,44	41,84	261
80	80	5	10	14,356	131,442	32,861	39,74	3,03	217,83	49,68	211
80	80	6	12	16,833	149,177	37,294	45,79	2,98	252,07	56,59	178
90	90	3	6	10,208	127,283	28,285	33,04	3,53	201,42	42,51	343
90	90	4	8	13,348	161,921	35,982	42,58	3,48	260,8	54,17	259
90	90	5	10	16,356	192,933	42,874	51,41	3,43	316,26	64,7	210
100	100	2	4	7,737	123,008	24,602	28,3	3,99	190,54	36,92	508
100	100	3	6	11,408	177,047	35,409	41,21	3,94	278,68	53,19	342
100	100	4	8	14,948	226,352	45,270	53,3	3,89	362,01	68,1	258
100	100	5	10	18,356	271,102	54,220	64,59	3,84	440,52	81,72	209
100	100	6	12	21,633	311,474	62,295	75,1	3,79	514,16	94,12	175
100	100	8	16	27,792	379,774	75,955	93,83	3,7	646,69	115,45	134
100	100	10	20	33,425	432,604	86,521	109,61	3,6	759,31	132,49	109
120	120	3	6	13,808	312,347	52,058	60,24	4,76	487,72	78,15	340
120	120	4	8	18,148	402,276	67,046	78,33	4,71	636,57	100,75	257
120	120	5	10	22,356	485,475	80,912	95,45	4,66	778,5	121,75	207
120	120	6	12	26,433	562,157	93,693	111,61	4,61	913,46	141,22	174
120	120	8	16	34,192	696,817	116,136	141,14	4,51	1162,31	175,79	132
120	120	10	20	41,425	807,911	134,652	167,03	4,42	1382,78	204,9	108
150	150	3	6	17,408	622,729	83,031	95,53	5,98	964,61	124,6	339
150	150	4	8	22,948	807,817	107,709	124,87	5,93	1264,76	161,73	255
150	150	5	10	28,356	982,119	130,949	152,98	5,89	1554,13	196,79	206
150	150	6	12	33,633	1145,905	152,787	179,88	5,84	1832,69	229,84	172
150	150	8	16	43,792	1443,001	192,400	230,11	5,74	2357,13	290,21	131
150	150	10	20	53,425	1701,214	226,829	275,67	5,64	2837,67	343,33	106
150	150	12,5	25	64,726	1972,438	262,992	326,24	5,52	3375,93	400,19	86
200	200	3	6	23,408	1506,515	150,652	172,35	8,02	2314,95	226	337
200	200	4	8	30,948	1968,132	196,813	226,44	7,97	3048,66	295,34	254
200	200	5	10	38,356	2410,088	241,009	278,87	7,93	3763,3	361,82	204
200	200	6	12	45,633	2832,748	283,275	329,67	7,88	4458,81	425,51	171
200	200	8	16	59,792	3621,627	362,163	426,39	7,78	5792,19	544,81	129
200	200	10	20	73,425	4337,633	433,763	516,73	7,69	7048,28	653,79	104
200	200	12,5	25	89,726	5134,455	513,446	620,86	7,56	8508,82	776,26	84
220	220	6	12	50,433	3813,360	346,669	402,18	8,7	5976,18	520,57	170
220	220	8	16	66,192	4894,989	444,999	521,7	8,6	7783,51	669,03	129
220	220	10	20	81,425	5887,188	535,199	634,16	8,5	9497,54	805,92	104
220	220	12,5	25	99,726	7006,429	636,948	764,96	8,38	11507,96	961,56	84
250	250	5	10	48,356	4805,010	384,401	442,26	9,97	7443,01	576,84	203
250	250	6	12	57,633	5672,002	453,760	524,45	9,92	8842,52	681,15	170
250	250	8	16	75,792	7315,651	585,252	682,67	9,82	11551,86	879,34	128
250	250	10	20	93,425	8841,863	707,349	832,79	9,73	14141,09	1064,09	103
250	250	12,5	25	114,726	10589,925	847,194	1009,24	9,61	17207,7	1276,94	83
300	300	5	10	58,356	8416,884	561,126	643,15	12,01	12968,27	841,85	203
300	300	6	12	69,633	9963,668	664,245	764,23	11,96	15433,82	996,78	169
300	300	8	16	91,792	12925,073	861,672	998,95	11,87	20236,13	1293,82	128
300	300	10	20	113,425	15713,901	1047,593	1223,86	11,77	24866,11	1574,29	103
300	300	12,5	25	139,726	18963,847	1264,257	1491,37	11,65	30410,04	1902,41	83

Table 3. Sectional properties of circular hollow section.

d	t	A	I_y	$W_{el,y}$	$W_{pl,y}$	i_y	I_v	W_v	F/V
[mm]	[mm]	[mm^2]	[mm^4]	[mm^3]	[mm^3]	[mm]	[mm^4]	[mm^3]	[1/m]
		x10	$x10^4$	$x10^3$	$x10^3$	x10	$x10^4$	$x10^3$	
33,7	2	1,99	2,51	1,49	2,01	1,12	5,02	2,98	532
42,4	2	2,54	5,19	2,45	3,27	1,43	10,38	4,9	525
42,4	2,5	3,13	6,26	2,95	3,99	1,41	12,52	5,91	425
42,4	2,6	3,25	6,46	3,05	4,12	1,41	12,93	6,1	410
42,4	2,9	3,6	7,06	3,33	4,53	1,4	14,11	6,66	370
42,4	3	3,71	7,25	3,42	4,67	1,4	14,49	6,84	359
48,3	2	2,91	7,81	3,23	4,29	1,64	15,62	6,47	522
48,3	2,5	3,6	9,46	3,92	5,25	1,62	18,92	7,83	422
48,3	2,6	3,73	9,78	4,05	5,44	1,62	19,55	8,1	406
48,3	2,9	4,14	10,7	4,43	5,99	1,61	21,4	8,86	367
48,3	3	4,27	11	4,55	6,17	1,61	22	9,11	355
48,3	3,2	4,53	11,59	4,8	6,52	1,6	23,17	9,59	335
60,3	2	3,66	15,58	5,17	6,8	2,06	31,16	10,34	517
60,3	2,5	4,54	18,99	6,3	8,36	2,05	37,99	12,6	417
60,3	2,6	4,71	19,65	6,52	8,66	2,04	39,31	13,04	402
60,3	2,9	5,23	21,59	7,16	9,56	2,03	43,18	14,32	362
60,3	3	5,4	22,22	7,37	9,86	2,03	44,45	14,74	351
60,3	3,2	5,74	23,47	7,78	10,44	2,02	46,94	15,57	330
76,1	2	4,66	31,98	8,4	10,98	2,62	63,96	16,81	513
76,1	2,5	5,78	39,19	10,3	13,55	2,6	78,37	20,6	414
76,1	2,6	6	40,59	10,67	14,05	2,6	81,18	21,34	398
76,1	2,9	6,67	44,74	11,76	15,55	2,59	89,48	23,52	358
76,1	3	6,89	46,1	12,11	16,04	2,59	92,19	24,23	347
76,1	3,2	7,33	48,78	12,82	17,02	2,58	97,56	25,64	326
76,1	4	9,06	59,06	15,52	20,81	2,55	118,11	31,04	264
76,1	5	11,17	70,92	18,64	25,32	2,52	141,84	37,28	214
88,9	2	5,46	51,57	11,6	15,11	3,07	103,14	23,2	512
88,9	2,5	6,79	63,37	14,26	18,67	3,06	126,75	28,51	412
88,9	2,6	7,05	65,68	14,78	19,37	3,05	131,37	29,55	396
88,9	2,9	7,84	72,52	16,31	21,46	3,04	145,04	32,63	356
88,9	3	8,1	74,76	16,82	22,15	3,04	149,53	33,64	345
88,9	3,2	8,62	79,21	17,82	23,51	3,03	158,41	35,64	324
88,9	4	10,67	96,34	21,67	28,85	3	192,68	43,35	262
88,9	5	13,18	116,37	26,18	35,24	2,97	232,75	52,36	212
101,6	2	6,26	77,63	15,28	19,84	3,52	155,26	30,56	510
101,6	2,5	7,78	95,61	18,82	24,56	3,5	191,22	37,64	410
101,6	2,6	8,09	99,14	19,52	25,49	3,5	198,28	39,03	395
101,6	2,9	8,99	109,59	21,57	28,26	3,49	219,19	43,15	355
101,6	3	9,29	113,04	22,25	29,17	3,49	226,07	44,5	343
114,3	2	7,06	111,27	19,47	25,23	3,97	222,53	38,94	509
114,3	2,5	8,78	137,26	24,02	31,25	3,95	274,52	48,03	409
114,3	2,6	9,12	142,37	24,91	32,45	3,95	284,75	49,82	394
114,3	2,9	10,15	157,55	27,57	36	3,94	315,09	55,13	354
114,3	3	10,49	162,55	28,44	37,17	3,94	325,1	56,88	342
114,3	3,2	11,17	172,47	30,18	39,51	3,93	344,94	60,36	322
114,3	4	13,86	211,07	36,93	48,69	3,9	422,13	73,86	259
114,3	5	17,17	256,92	44,96	59,77	3,87	513,84	89,91	209
114,3	6	20,41	300,21	52,53	70,45	3,83	600,42	105,06	176

d	t	A	I_y	$W_{el,y}$	$W_{pl,y}$	i_y	I_v	W_v	F/V
[mm]	[mm]	[mm^2]	[mm^4]	[mm^3]	[mm^3]	[mm]	[mm^4]	[mm^3]	[1/m]
		x10	x10^4	x10^3	x10^3	x10	x10^4	x10^3	
133	2	8,23	176,61	26,56	34,32	4,63	353,21	53,11	508
133	2,5	10,25	218,27	32,82	42,58	4,61	436,54	65,64	408
133	2,6	10,65	226,48	34,06	44,22	4,61	452,97	68,12	392
133	2,9	11,85	250,9	37,73	49,09	4,6	501,81	75,46	353
133	3	12,25	258,97	38,94	50,71	4,6	517,93	77,88	341
133	3,2	13,05	274,98	41,35	53,92	4,59	549,96	82,7	320
133	4	16,21	337,53	50,76	66,59	4,56	675,05	101,51	258
139,7	2,9	12,46	291,68	41,76	54,28	4,84	583,37	83,52	352
139,7	3	12,88	301,09	43,11	56,07	4,83	602,18	86,21	341
139,7	3,2	13,72	319,78	45,78	59,63	4,83	639,55	91,56	320
139,7	4	17,05	392,86	56,24	73,68	4,8	785,72	112,49	257
159	2,9	14,22	433,33	54,51	70,67	5,52	866,66	109,01	351
159	3	14,7	447,42	56,28	73,02	5,52	894,84	112,56	340
159	3,2	15,66	475,44	59,8	77,69	5,51	950,88	119,61	319
159	4	19,48	585,33	73,63	96,12	5,48	1170,67	147,25	256
168,3	2,9	15,07	515,46	61,26	79,34	5,85	1030,93	122,51	351
168,3	3	15,58	532,28	63,25	81,98	5,85	1064,57	126,51	339
168,3	3,2	16,6	565,74	67,23	87,24	5,84	1131,47	134,46	319
168,3	4	20,65	697,09	82,84	108	5,81	1394,18	165,68	256
168,3	5	25,65	855,85	101,7	133,38	5,78	1711,69	203,41	206
219,1	4	27,03	1563,84	142,75	185,09	7,61	3127,67	285,5	255
219,1	5	33,63	1928,04	176	229,24	7,57	3856,08	351,99	205
219,1	6	40,17	2281,95	208,3	272,54	7,54	4563,89	416,6	171
273	5	42,1	3780,81	276,98	359,16	9,48	7561,63	553,97	204
273	6	50,33	4487,08	328,72	427,81	9,44	8974,17	657,45	170
323,9	5	50,09	6369,42	393,3	508,53	11,28	12738,85	786,59	203
323,9	6	59,92	7572,47	467,58	606,43	11,24	15144,93	935,16	170
355,6	5	55,07	8463,58	476,02	614,64	12,4	16927,15	952,03	203
355,6	6	65,9	10070,55	566,4	733,39	12,36	20141,1	1132,8	170
406,4	6	75,47	15128,32	744,5	961,99	14,16	30256,64	1489,01	169
406,4	8	100,13	19873,89	978,05	1269,95	14,09	39747,78	1956,09	128
457	6	85,01	21618,1	946,09	1220,48	15,95	43236,2	1892,18	169
508	6	94,62	29811,53	1173,68	1512,1	17,75	59623,06	2347,36	169
508	8	125,66	39279,95	1546,45	2000,17	17,68	78559,91	3092,91	127
508	10	156,45	48520,24	1910,25	2480,37	17,61	97040,47	3820,49	102
609,6	8	151,2	68414,8	2244,58	2895,55	21,27	136829,6	4489,16	127
609,6	10	188,37	84677	2778,12	3595,53	21,2	169353,99	5556,23	102
711,2	8	176,73	109255,32	3072,42	3956,09	24,86	218510,63	6144,84	126
711,2	10	220,29	135417,2	3808,13	4917,15	24,79	270834,4	7616,27	101
812,8	8	202,27	163778,39	4029,98	5181,79	28,46	327556,78	8059,96	126
812,8	10	252,21	203211,96	5000,29	6445,21	28,39	406423,92	10000,59	101
914,4	10	284,13	290532,39	6354,6	8179,73	31,98	581064,77	12709,2	101
1016	10	316,04	399849,58	7871,05	10120,69	35,57	799699,17	15742,11	101
1016	12	378,5	476984,45	9389,46	12096,77	35,5	953968,89	18778,92	84
1220	10	380,13	695737,75	11405,54	14641,33	42,78	1391475,5	22811,07	101
1220	12	455,41	830777,45	13619,3	17511,74	42,71	1661554,89	27238,6	84

Descriptions

A = cross sectional area
I = second moment of area
i = radius of gyration
W_{el} = elastic section modulus
W_{pl} = plastic modulus
I_v = torsional inertia constant
W_v =torsional modulus constant
F/V =section factor

Notes:

This **Stainless Steel Hollow Sections Handbook** focuses on the properties and usage in different applications of rectangular, square and circular cross-sections manufactured by Stalatube Oy and Oy Outokumpu Stainless Tubular Products Ab. This manual is the first compilation of information specifically about the materials, properties and structural design of stainless structural hollow sections.

Stainless steel hollow sections - enduring strength & beauty