Stainless steel in the food industry
– an introduction

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Introduction

This guideline gives an introduction to the aspects that should be clarified in connection with the choice of stainless steel materials for process equipment for the food industry.

Key words

Corrosion, surface, finish, documentation, approval, certificate, strength, statics, life, production environment, foods, process equipment, norms, alloy, welding, tool steel, dimension, food contact.

Definition and use of guidelines

This guideline is not an encyclopedia that will answer all questions. Rather, it should be a guide to which information is needed to complete a task satisfactorily. It helps the reader ask informed questions.

For further help, follow the various references and links.

This guideline is prepared by a task group under the competence centre of the Danish stainless steel industry and is one in a collection of guidelines. The others are:

Guideline no. 1: Cabling and electrical cabinets
Guideline no. 2: Check list for purchase/sale of production equipment
Guideline no. 3: Conveyors
Guideline no. 4: Stainless steel in the food industry
Guideline no. 5: Design of piping systems for the food processing industry
Guideline no. 6: Installation of components in closed processing plants for the food processing industry

Contents

1. Domain

This guideline gives an introduction to the aspects that should be clarified in connection with the choice of stainless steel materials for process equipment for the food industry.

As it will appear, it is necessary to know the requirements and wishes for, among other things, corrosion resistance, documentation, approvals, together with certificates, strength and statics, character of surface, flexibility, lifetime, seals, cleaning, production environment etc.

1.1. Limitations

This guide is limited to materials that are used in the food industry – mainly stainless steel.

1.2. Definition and use of guidelines

The guide can be used by constructing engineers in connection with getting the correct material for processing equipment and tools.

It can also be used by purchasing officers as a tool for specifying components for manufacturing equipment.

Finally, the guideline can be used as a communication tool between purchasing officers and suppliers.

It is not the purpose of the guide to recommend certain types of solutions or suppliers.

2. Introduction

When faced with the task of selecting materials for construction of equipment – e.g. for the food processing sector or pharmaceutical industry – one might easily feel out of one's depth. Although groups of experts or experienced staff often gather in an attempt to write general guidelines, they rarely succeed due to the huge variation of materials and uses.

In Europe and the US, the situation is the same. There is an abundance of information on various materials and processes. Tempting sales pitches do not provide a clearer picture. So what should you do?

Choose your sources of information carefully, and make sure they are valid. Some of the supervisory bodies, like the Food and Drug Administration in the US (www.fda.gov) and national and European food regulations, offer reliable documentation.

One should always make sure that the collected information can be applied to the intended purpose. This means that when aiming to comply with national regulations in Europe, you should always keep informed of any new regulations that might be in preparation or have been passed recently in replacement of current legislation, and which requires changes in the work process. It is useful to establish which regulations are being prepared.

EUR-Lex offers direct access to EU legislation[1]. The EU has furthermore collected all legal aspects concerning materials relating to materials with food contact[2].

One of the reasons for the evident lack of information on material selection is that most national and European legislation only comprises the standards that should be observed and leaves it to the individual company to arrive at these standards.

The knowledge portal www.staalcentrum.dk offers a clear picture of the guidelines, standards, legislation etc. that is available for specific fields/types of equipment and geographical regions. It is easy to search the material and read a short description of the actual contents. The relevant links lets you order material from the source.

The European Hygienic Engineering & Design Group (EHEDG) has prepared a number of guidelines (see www.ehedg.org) on different subjects, including material selection. These documents will help you find various contacts, necessary material or organisations.

We further refer you to CODEX ALIMENTARIUS, who develop food standards, guidelines and codes of practice (see http://www.codexalimentarius.net). The site offers i.a. documents relating to process water in food processing companies, and you can find outlines of the guidelines that are observed in the food industry.

It is recommended to study the initiatives of others prior to defining your own hygiene strategy. This is usually task of the person in charge of material selection.

An illustrative case history for a comprehensive strategy outlining the certification steps in relation to sterile and pharmaceutical pumps can be found at www.hilge.de.

If you are not familiar with the Hazard Analysis and Critical Control Point method (HACCP), we recommend that you study it, as it is the basis of many decisions within the food industry.

3. Norms and standards for stainless steel

All well-known steel materials are specified. The individual steel manufacturers/steel works have described the production methods and processes for the available steel materials.

[1] Go to http://europa.eu.int/eur-lex/lex/da/index.htm (replace language code – e.g. EN with DA – to view the page in your own language). The system lets you consult the Official Journal of the European Union and contains, among other things, the treaties, legislation, legal usage and preliminary legal instruments. It comprises advanced search functions. Any questions in relation to the status of legislation can be directed at tel. 00 800 6789 10 11. The number is toll-free.

[2] Go to http://europa.eu.int/comm/food/food/resources/publications_en.htm

To facilitate the selection of steel materials, commonly used steel materials have been grouped according to standards which can be national and/or international, such as the common European standards, which Denmark has adopted. In Denmark, these standards are designated DS/EN, followed by a number. The international designation for common steel materials is 1.XXXX (e.g. 1.4301).

Steel is often documented by a certificate describing the chemical composition and the mechanical properties, and other specifications according to the agreement. There are various types of certificates.

In other words, you are left with the ”simple” task of picking the most suitable steel material for the job at hand. However, a certain knowledge and understanding is required when selecting a suitable quality of steel by means of standards and works of reference. *Therefore, when in doubt of the selection, we recommend that you seek the advice and guidance of steel wholesalers and manufacturers and consultant engineers.*

Several different works of reference are available to help you find a steel material for a given job. The most famous, the Stahlschlüssel, uses the previously mentioned designation of steel materials. The Stahlschlüssel can be bought through technical bookstores and Dansk Standard (DS), which is the body that collects and maintains norms and standards that apply in Denmark. DS will be able to supply you with all common national and international norms and standards etc.

Norms and standards are legal instruments that compare with e.g. the acts, regulations and guidelines of the Working Environment Authority, and with by-laws or police regulations. This is one of the reasons why it is paramount to classify technical projects correctly in accordance with the law and to establish which norms and standards apply, prior to the project. Danish norms and standards are subject to Danish law. The manufacturer is legally responsible for the technical design and functionality of his product.

Special steel is not necessarily listed in a norm. Consequently, you may have to seek the necessary information at steel wholesalers/manufacturers. Such information can be used to evaluate corrosion-resistant properties under given conditions. If the material is to be tooled, joined (e.g. by welding) or exposed to repetitive, mechanical and/or thermal impact, it is important to know the resistance of the material to the current impact.

The necessary technical information may include:

- Chemical composition
- Mechanical properties
- Thermal properties

Within certain technical fields, a selection of steel materials have been pre-approved. This applies to e.g. pressure-bearing plants and equipment, pursuant to the common European EN13445 standard. Other steel materials than those pre-approved in EN13445, may be used, but that will require a PED (Pressure Equipment Directive) approval of the steel works as well as of the materials, which is both time-consuming and costly. Steel materials pre-approved according to PED are found e.g. in EN13445 Part 2 (55 pages).

Table 1 contains various applications of stainless steel and some of the governing standards and norms for the equipment.

Table 1. List of the different applications of stainless steel, and some of the current standards and norms

Stainless steel is used for the manufacture of:

- **Machines, machinery and quipment.** (The Machine Directive is a safety directive that applies to the field. Note: The Machine Directive may also apply to other fields.)

- **Pipes and piping systems.** (Pressurised pipes and piping systems with a pressure above 0.5 bar (g) and a dimension larger than DN25[3] are usually subject to the Danish Working Environment Authority's (DWEA) Order No. 743 of 23 September 1999. Executive order on the design of pressurised equipment. See application and definitions etc. in the order. For pressurised pipes and piping systems with a pressure of less than 0.5 bar (g) and a size of DN25 or less, see the same directive Article 3(3) – technical requirements. Note: Pipes and piping systems described in Article 3(3) should not be CE-marked, any other pipes and piping systems subjected to the DWEA's Executive Order No. 743, must be CE-marked.)

- **Processing plants and equipment.** (Pressurised process plants and equipment with a pressure above 0.5 bar (g) and a size larger than DN25 are usually subjected to the Danish Working Environment Authority's (DWEA) Order No. 743 of 23 September 1999. Executive order on the design of pressurised equipment. See application and definitions etc. in the order. For pressurised processing plants and equipment with a pressure of less than 0.5 bar (g) and a size of DN25 or less, see the same directive Article 3(3) on technical requirements.Note: Processing plants and equipment described in Article 3(3) should not be CE-marked, any other processing plants or equipment subjected to the DWEA's Executive Order No. 743, must be CE-marked.)

- **Containers and tankinstallations.** (Pressurised containers and individual tank installations with a pressure above 0.5 bar (g) and pipe connections with a size larger than DN25 are usually subjected to the DWEA's Order No. 743 of 23 September 1999.Executive order on the design of pressurised equipment. See application and definitions etc. in the order. For pressurised containers and individual tank installations with a pressure of less than 0.5 bar (g) and pipe connections with a size of DN25 or less, see the same directive Article 3(3) on technical requirements.Note: Containers and tank installations described in Article 3(3) should not be CE-marked, any other containers or tank installations subjected to the DWEA's Executive Order No. 743, must be CE-marked.)

Please note that there is an ongoing research in new steel materials with improved properties. Therefore, you should consult your steel wholesaler about new materials for specific purposes.

4. Documentation requirements

The requirements that documentation must meet have grown dramatically in recent years with regard to products for i.a. the food, pharmaceutical and chemical industries. The requirements are typically related to certificates on materials, declarations in relation to the Machine Directive, observance of hygiene standards and cleaning issues.

[3] DN designates the nominal diameter of a workpiece and is used e.g. when indicating the size of pipes and fittings. Please note that the material thickness may vary.

Why all this approval with documentation, when a third party is often appointed to perform the evaluation of a newly built and installed plant?

It can basically be summed up in the principle of wanting to ensure the best possible plant in terms of effective life and price. Another issue could be that some court cases in the US have resulted in huge claims for damages. So we safeguard ourselves as best we can.

In many cases, manufacturing rooms, processing lines, equipment and machines will be subject to requirements from authorities, manufacturers or customers. You will be able to find several documents describing such demands. In general, we distinguish between statutory requirements, certification standards and guidelines or best practice/common practice.

4.1. Statutory requirements

Statutory requirements are laid down by the authorities, and as such they *must* be observed. They are described in acts (national or EU).

In Denmark, these acts tend to be implemented through circulars, executive orders and guidelines that explain how these laws are to be interpreted. You can find the statutory requirements that apply to Denmark at www.retsinfo.dk, where they have been divided into the following hierarchy: *Passed acts (*Act No. xxx). These have a number of *executive orders* attached to them (Executive Order No. xxx), which constitute a further description of these acts, and the executive orders are in turn implemented into *guidelines* (Guideline No. xxx) and *circulars* (Circular No. xxx).

Materials that come into contact with food are regulated by law in practically all countries.

EU legislation can be found at www.europa.EU.int/eur-lex. A list of "all" legislative aspects in the individual EU member states concerning food contact materials can be found at http://europa.eu.int/comm/food/food/chemicalsafety/foodcontact/eu_nat_laws_en.pdf.

In the US, legislation on meat, poultry and eggs is prepared by the US Department of Agriculture (USDA) (see www.usda.gov). The USDA is the governing body for the approval of, among other things, machines. The USDA has transferred control of lubricants and disinfectants etc. to the National Sanitation Foundation (NSF) (see the NSF White Book Listing of Non-food Compounds at http://www.nsf.org/business/nonfood_compounds/index.asp?program=NonFoodComReg).

Legislation on dairy products and other foodstuffs (not meat/eggs) is prepared by the U.S. Food and Drug Administration (**FDA**) www.fda.gov. The FDA is also in charge of the approval of engineering materials

Canada operates with a food inspection programme that governs the approval of factories, including the materials allowed for use. See http://www.inspection.gc.ca/english/toce.shtml.

4.2. Standards

Standards are solutions that are described in a document called a "standard". By following the directions, one might achieve certification – i.e. an independent party/certifying body will perform an audit (inspection) to establish whether the directions of the particular standard have been followed and subsequently issue a document/certificate stating that the audited company is in compliance with the standard. ISO 9000 and DS 3027 are examples of standards.

The International Organization for Standardization (ISO) is an international body whose task it is to inform of, measure, handle and eliminate hazards in connection with manufacturing (see www.iso.com). The ISO 14159 standard applies to the food processing, biotechnological and pharmaceutical industries and includes hygiene, risk assessment and safety.

Danish standards have a nomenclature beginning with the letters DS-XXX. These are standards decided by the Danish Standards Association (see www.ds.dk).

EN standards apply to the entire EU. Many can be acquired through Danish Standard at www.ds.dk.
ICH standards (applying particularly to pharmaceuticals) can be found at www.ich.org.

3A Sanitary Standard/3A Accepted Practices often apply specifically to one type of machines. Learn more at www.3-a.org.

The American Society of Mechanical Engineers (ASME) covers fields within pressure-bearing equipment, which in Europe is governed by EN 13445. See also *www.ASME.org*.

4.3. Guidelines and best practice

Guidelines are a collection of good pieces of advice or a best practice, describing the most expedient way to operate. Many guidelines are so widely recognised that they, like standards, may serve as sales and safety parameters in a marketing context.

FDA guidances and guidelines can be found on the Internet.

Center for Drug Evaluation and Research (CDER):
http://www.fda.gov/cder/guidance/index.htm

Center for Biologics Evaluation and Research (CBER):
http://www.fda.gov/cber/guidelines.htm

European guidelines can be bought at www.EHEDG.ORG. The European Hygienic Engineering & Design Group (EHEDG) works diligently towards introducing hygiene standards as early as the preparatory phase of a building project, with regard to the buildings as well as the machines that are to be installed. EHEDG have prepared a number of guidelines for the manufacture of safe foods.

The Campden and Chorleywood Food Research Association Group is part of an institute in England. They have issued quite a number of guidances/guidelines for specific machines, descriptions of requirements for hygienic walls, ceilings, floors etc. Learn more at http://www.campden.co.uk.

4.4. Issue of certificates

A certificate is a document issued by a manufacturer of for example stainless steel.

The certificates may have different names depending on the current demands of an end user.
Please refer to DS/EN 10204 (10.91) for a complete list of the various types that are relevant to the steel industry.

Within the plastic industry, demands have also increased in recent years. The FDA 177.2600 standard, which is widely used in e.g. the food and pharmaceutical industries, now also applies to this industry.

The EHEDG and others also issue certificates to companies who have proven that they can meet and document the design standards required.

Likewise, a certificate is issued to welders who have verified that they meet the requirements in, among others, EN287-1 and the procedural requirements in EN288-3.

In addition, a wide range of more or less relevant standards and requirements for certificates are being defined in various places of the world, but thanks to the ever increasing globalisation, countries that buy Danish exports tend to use the same requirements.

5. Selection of stainless steel

5.1. What is stainless steel?

Stainless steel is an alloy of iron containing at least 12 per cent chromium. Chromium combines with oxygen in the surroundings to form an adherent chromium oxide film on the surface. This oxide film, also referred to as the passive layer, offers resistance to corrosion and will spontaneously self-repair when damaged in air or water. So the corrosion resistance is in the metal surface, and the stability of the passive layer is therefore decisive to the corrosion resistance of the stainless steel.

5.2. Can stainless steel corrode?

Yes it can, although we often believe it cannot.

If the passive layer is damaged and not restored, the stainless steel will corrode. This may be case when metal gets into contact with aggressive liquids (like chlorine or chlorine-containing liquids) where the passive layer is not stable.

The stability of the passive layer is not only dependent on the chemical composition (content of alloy constituents like chromium, nickel and molybdenum) and on the liquid to which it is exposed. The processes that stainless steel may undergo from raw material to finished product are also of importance.

The processes that stainless steel may undergo from raw material to finished product are of great importance to the corrosion resistance. Welding, shaping, honing and handling in production may damage the passive layer and make the stainless steel more sensitive to corrosion attacks. Therefore, it is important to estimate the result of a certain manufacturing process on the corrosion resistance of the finished product, and whether a subsequent surface finishing (pickling, electropolishing) may be required to restore the properties of the passive layer. Often, damage as a result of corrosion occurs because this step is overlooked.

5.3. Factors that are important to corrosion resistance

5.3.1. Which alloy is used?

Stainless steel comprises a whole family of alloys that are divided into the following four main groups, all of which refer to the microstructure of the metal (see also table 2):

- Ferritic
- Martensitic
- Austenitic
- Austenitic-ferritic (duplex)

Each of these main groups contains a number of alloys that are defined according to the chemical composition and specified in European and international standards. Apart from chromium, the alloy constituents molybdenum, nickel and nitrogen are of great importance to the corrosion resistance. Carbon will always be present to a certain degree, and it is important to the welding properties. In addition, copper, manganese, sulphur, titanium and niobium are used as alloy constituents to obtain certain properties.

Below, you will find a short introduction to the main groups, including examples of frequently used alloys with their international names. The indication as to whether the metal is magnetic is only for the sake of information.

Ferritic stainless steel (magnetic):
Apart from chromium, it contains only small quantities of nickel. Is moderately corrosion-resistant and cannot be hardened through heat treatment. The impact resistance is reduced considerably at low temperatures. Typical applications are cutlery, kitchen sinks and drums for washing machines.
Examples: EN 1.4016/AISI 430

Martensitic stainless steel (magnetic):
Apart from chromium, it contains sufficient quantities of carbon to enable hardening through heat treatment. This will ensure a high strength that makes it suitable for knives, motors and pump shafts.

Is moderately corrosion-resistant.
Examples: EN 1.4057/AISI 431

Austenitic stainless steel (nonmagnetic):
Comprises by far the majority of the total stainless steel production. Of this, EN 1.4301(AISI 304) and EN 1.4401 (AISI 316) constitute the greatest part. Apart from chromium, austenitic stainless steel typically contains 8 to 30 per cent nickel and varying quantities of molybdenum. It has a low carbon content, and cannot be hardened through heat treatment. However, a certain work hardening may result from cold deformation. The popularity of austenitic stainless steel is due to its corrosion resistance, weldability and shaping properties. Likewise, their high-temperature and low-temperature properties tend to be good.
Examples: EN 1.4301/AISI 304, EN 1.4401/AISI 316, EN 1.4547/254SMO

Duplex stainles steel (ferritic/austenitic) (magnetic):
The microstructure of these stainless steels is a compound of ferrite and austenite. This makes them stronger than austenitic stainless steels. The corrosion resistance is comparable to that of austenitic steels, but their resistance to stress corrosion is far greater than with EN 1.4301(AISI 304) and EN 1.4401 (AISI 316). Due to the two-phase structure, special precautions are necessary in connection with welding (the heat input must be monitored closely, and the use of nitrogenous gas protection is recommended).
Examples: EN 1.4462/SAF 2205, EN 1.4410/SAF 2507

Stainless steel can be attacked by localised corrosion (pitting and crevice corrosion) in chlorine-containing environments. This form of corrosion is particularly problematic due to its unpredictable development, and because it may rapidly lead to material failure. The most important alloy constituents that may serve to improve resistance to local corrosion are chromium, molybdenum and nitrogen. The corrosion resistance of a steel in a specific application depends on several other parameters than just chlorine content and alloy composition (e.g. operating conditions and cleaning procedures).

The Pitting Resistance Equivalent number (PRE number) has proven a good indication of the resistance of stainless steel to pitting. The higher the PRE number, the higher the resistance to local corrosion. It is important to note that the PRE number can only be used to rank the various types of stainless steel.

Likewise, it should be noted that the machining-friendly qualities with a high sulphur content cannot be categorised according to the PRE number. For example, EN 1.4305/AISI 303 will have the same PRE number as EN 1.4301/AISI 304, but because of the high sulphur content of EN 1.4305/AISI 303, for this type is much lower. Therefore, machining-friendly steels with a corrosion resistance that matches that of the standard qualities have been developed.

The calculation of the PRE number is based on the following empirical formula:

$$PRE = \%Cr + 3.3 \times \%Mo + 16 \times \%N$$

The below table shows the PRE numbers for some stainless steels.

Stainless steel grade	PRE
EN 1.4016/AISI 430	17
EN 1.4057/AISI 431	17
EN 1.4301/AISI 304	18
EN 1.4401/AISI 316	24
EN 1.4547/254SMO	43
EN 1.4462/SAF 2205	34
EN 1.4410/SAF 2507	43

5.3.2. Forms of corrosion

Depending on the content of the alloy constituents, the metal may have different properties when it comes to machining, shaping, welding, corrosion resistance etc. Therefore, the requirements for the design/application (comprising the production as well as the cleaning environment) should be carefully evaluated, when the type of alloy is selected.

In the event of tension in the workpiece, austenitic stainless steels like EN 1.4301 and EN 1.4401 are sensitive to stress corrosion in media with chlorine contents as well as high pH values and temperatures. The tension can be both internal and external. Internal stress may be residual stress from welding or shaping, and external stress may occur when workpieces are mechanically joined or mounted.

Internal stress can be partly removed by stress-relieving annealing, but to remove it completely heat treatment at temperatures over 1,000° C often proves necessary. Heat treatment may, however, cause problems with workpiece run-out and therefore often prove unsuited.

Examples of corrosion:

1. General corrosion: In this case, the passive layer on the metal surface is broken down completely, and corrosion is therefore characterised by being uniform on the entire metal surface. General corrosion is frequent in reducing acids.

2. Pitting (cavitation erosion, pinpoint corrosion): Local corrosion that manifests itself in often quite deep pinpoint corrosion attacks. Occur in neutral or moderately acidic – predominantly chlorine-containing (Cl^-) – solutions, or for instance in sea water. Attacks occur where the oxice film is weakened, due to e.g. inclusions or surface defects.

3. Crevice corrosion (deposit corrosion): Occur in narrow crevices and cavities. The more narrow the crevice (although down to a minimum), the greater the risk of corrosion. Most frequent in chlorine-containing solutions like sea water. A rule of thumb is that steels with high resistance to cavitation corrosion also tend to have high crevice corrosion resistance.

4. Stress corrosion: Characterised by producing cracks and caused by simultaneous tensile stress and corrosion. Particularly frequent with austenitic stainless steels in chlorine-containing liquids and in alkaline liquids (high pH) at high temperatures.

5. Intercrystalline corrosion (intergranular corrosion) A classic example is liberation of chromium carbides at the grain boundaries. Thus, chromium content is reduced in the adjacent area, resulting in reduced corrosion resistance. This often occurs in connection with wrong heat treatment and welding procedures.

5.3.3. Welding precautions

The austenitic stainless steels (like EN 1.4301 and EN 1.4401) are very suitable for welding. They are followed by duplex stainless steels (like SAF 2205), and the least suitable are ferritic steels (like EN 1.4016) and martensitic steels (like EN 1.4057).

In addition to the general suitability of the various steel grades, the focus is on carbon content. The recommended maximum carbon content is 0.03 per cent. There are, however, special stainless grades with good weldability in which the carbon content exceeds 0.03 per cent – the so-called stabilised stainless steels. These have been added small quantities of titanium or niobium, which are carbon-binding. Thus, the risk of precipitating chromium carbides is reduced. However, stabilised steel is becoming increasingly infrequent, as the difficulties of producing low carbon stainless steels have been more or less solved.

<u>Gas protection:</u>
Insufficient gas protection will lead to oxidation of the metal surface. This will change the properties of the passive layer. The effect will be a visual change in stainless steel surface – from invisible to stained. From being thin and tight, the passive layer increases in thickness and chromium content, but unfortunately also becomes more porous, thus reducing corrosion resistance. In the case of heavy staining, the stainless steel just underneath the passive layer will contain less chromium, and even if the oxidised passive layer is removed, corrosion resistance will still have been reduced.

<u>Filler wire:</u>
Some alloys require the use of filler wire (e.g. the duplex steels like SAF 2205), whereas austenitic alloys like EN 1.4301 and EN 1.4401 can be welded without. Still, the use of filler wire will always contribute to ensuring that corrosion resistance is not reduced.

<u>Surface quality:</u>
If the surface is stained due to welding, it should be subsequently pickled. Furthermore, a subsequent electropolishing may prove necessary in connection with food applications. Both methods – of which electropolishing gives the best results – will removed the oxidised layer as well as the low-chromium layer immediately underneath the film. This will recreate the passive layer in its original state.

5.3.4. Construction design

Crevices and areas with potential deposits represent a risk of crevice corrosion. Use in the food industry puts special demands on the construction, such as high cleanability. This in turn leads to demands that the construction is free of crevices and “dead ends”.

Learn more about stainless steel at www.nickelinstitute.org/goodpractices/ and in ”Håndbog – Rustfrit Stål” (Handbook – Stainless Steels), Sandvik Materials Technology, Referencenummer S-003-DAN (260 pages) and the text book ”Korrosionsbestandigt Rustfrit Stål, Hvordan?” (corrosion-resistant stainless steel: how?) by Ebbe Rislund et al., FORCE Technology, ISBN 87-600-0079-1 (358 pages).

6. Receiving inspection

Receiving inspection should, among other things, ensure:

- That the delivered material contains no visible defects and impurities. This might later on cause problems in the processing equipment where these impurities might accumulate.
- That the material has been delivered in the agreed quality, and that the material comes with certificates verifying this.
- That surfaces which come in contact with the product are free of scratches, holes, porosity and other defects that appear as cavities in the surface.

The following techniques can be used for inspection of received material and documentation of surface treatment and finish.

- Optical emission spectral analyses (OES analyses) to examine the chemical composition stated in the accompanying delivery certificates according to EN 10204/3.1B (identical to prEN 10204/3.1a).
- Light Optical Microscopy (LOM) to inspect the microstructure.
- Scanning Electron Microscopy (SEM) for the inspection and photographic documentation of the surface finish (topography).
- Roughness measurements for the documentation of Ra and Rz values and the recording of surface profiles, cf. ISO 4288, ISO 4287 and ISO 3274.

7. Names of stainless steels

The below table shows stainless steels in various standards, grouped according to quality with a 2004 price index. As prices of stainless steel are very dependent on the alloy constituents, the price index will fluctuate over time.

Table 2. Stainless steels in various standards, grouped according to quality with a 2004 price index. As prices of stainless steel are very dependent on the alloy constituents, the price index will fluctuate over time.

	Steel grade		C %	Cr %	NI %	Mo %	P %	S %	N %	Price index (relative scale)
Common stainless steel	AISI 304	min.		18.0	8.0	-				100
		max.	0.08	20.0	10.5	-	0.045	0.030		
	AISI 304 L	min.		18.0	8.0	-				
	EN 1.4306	max.	0.03	20.0	10.5	-	0.045	0.030		
	SS 2333	min.		17.0	8.0	-				
		max.	0.05	19.0	11.0	-	0.045	0.030		
	EN 1.4301	min.		17.0	8.5	-				
		max.	0.07	19.0	10.5	-	0.045	0.030		
Acid-resistant stainless steel (austenitic steel containing molybdenum)	AISI 316	min.		16.0	10.0	2.0				130
		max.	0.08	18.0	14.0	3.0	0.045	0.030		
	AISI 316 L	min.		16.0	10.0	2.0				
	EN 1.4404	max.	0.03	18.0	14.0	3.0	0.045	0.030		
	SS 2347	min.		16.5	10.5	2.0				
		max.	0.05	18.5	14.0	2.5	0.045	0.030		
	SS 2343	min.		16.5	10.5	2.5				
		max.	0.05	18.5	14.0	3.0	0.045	0.030		
	EN 1.4401	min.		16.5	10.5	2.0				
		max.	0.07	18.5	13.5	2.5	0.045	0.030		
	EN 1.4436	min.		16.5	11.0	2.5				
		max.	0.07	18.5	14.0	3.0	0.045	0.030		
	AISI 904 L		0.01	20.0	25.0	4.5	-	-		300
	AV 254 SMO		0.01	20.0	18.0	6.1				400
Duplex steel (austenitic-ferritic steel)	SAF 2304	min.		22.0	4.0				0.10	170
		max.	0.03	23.5	5.5					
	SAF 2205	min.		21.0	4.5	2.5			0.14	190
	(EN 1.4462)	max.	0.03	23.0	6.5	3.5				
	SAF 2507	min.		24.0	6.0	3.0			0.30	400
		max.	0.03	26.0	8.0	5.0				

AISI 304 and EN 1.4301 are frequently regarded as identical. Nevertheless, they are slightly different.

8. Surface condition

When using stainless steel, there are typically three reasons for inspecting the condition of the surface:

Cosmetics This means that the surface condition/topography has been selected to provide a certain visual appearance of the surface. An example is rose cutting of tanks. Scratches are made in the surface with a rotating brush, which provides the surface with a dull pattern to hide e.g. welded seams and various surface defects.

Hygiene The surface should be easy to clean. Usually, this will entail the demand for an *Ra* value below a certain level.

In connection with hygienic surfaces, please note that there is not necessarily a connection between what looks clean and what is actually hygienically clean. Thus, a rose-cut surface, because of the shade and the reduced reflection, will be much more likely to appear clean, whereas all lime stains etc. will be clearly visible on an electropolished surface. Despite this visual difference, there should be no doubt that a deliberately scratched surface is less hygienic than an electropolished one.

Corrosion To increase corrosion resistance, a chemical or manual treatment which removes any contaminants, oxides or the like, can be applied to the surface.

When choosing surface and surface finishing, it is important to consider which parameters will be important. Often, the best and most uniform-looking surfaces are not necessarily the most corrosion resistant and hygienic.

8.1. Pickling

Pickling is a chemical treatment of the surface in a usually 20 per cent nitric acid and 5 per cent hydrofluoric acid with the purpose of removing contamination, oxide layers from welding and the like in order to restore the passivating and corrosion-resistant properties of the surface. In connection with pickling, the properties of the surface are more important than the appearance.

8.2. Electropolishing

Likewise, correctly performed electropolishing leaves a surface that is completely decontaminated of manganese sulphides and without roughness that might harbour for instance bacteria. The surface is highly corrosion resistant and at the same time very hygienic. Due to the shining surface, electropolishing is also often used for reasons of appearance. However, the finish tends to reveal all the different materials that have been used. Different alloys will appear differently after electropolishing.

8.3. Glass-bead blasting and shot blasting

Glass-bead blasting and shot blasting are two other frequently used surface treatments. Glass-bead blasting is performed with sharp-edged glass beads which remove the top particles of the surface during blasting. Therefore, glass-bead blasting can in some cases be used instead of pickling, it leaves a rough surface and is not very hygienic. Shot blasting is performed using round steel shots with a diameter of 10 to 15 µm. Shot blasting does not remove material, but leaves a uniform, semi-dull surface. Shot blasting may easily lead to a reduced corrosion resistance as impurities accumlate on the shots and are transferred to the stainless surfaces. Therefore, the cleanness of the steel shots should be monitored closely.

8.4. Manual polishing

As is the case with electropolishing, manual polishing leaves very smooth and shining surfaces. Despite the shining surface, manual polishing will not enhance corrosion resistance and level of hygiene to the same degree as electropolishing. The reason for this is that while electropolishing removes the free iron particles on the surface, and thus reduces the roughness, manual polishing tends to just "lay down" the particles. This leaves a shining surface with a low Ra value, but one which can still be full of tiny crevices and cavities. With manual polishing, the "quality" of the surface relies heavily on the person doing the polishing.
The following is a list of recommended titles for further reading within the various fields:

Bejdsning og passivering af rustfrit stål (pickling and passivation of stainless steel). Cleanodan a/s, 1999.
Passivation of stainless steel. Dairy, Food and Environmental Sanitation, vol. 18, May 1998.
Korrosionsbestandigt rustfrit stål (corrosion-resistant stainless steel), ISBN 87-600-0079-1, Industriens forlag 1996.
Surface Modification and Passivation of Stainless Steel. ISBN 91-554-3375-8, C. Olsson 1994.
ASTM A967-01. Standard Specification fro Chemical Passivation Treatments for Stainless Steel Parts.
ASTM A380-99. Standard Practice for Cleaning, Descaling, and Passivation of Stainless Steel Parts, Equipment, and Systems.

9. Tool steel

Tool steel is a niche product for solving problems, and not a product from which to build an entire production plant.

Tool steel is part of concepts, together with knowledge and consultancy. Even the qualities of the best product will yield nothing, unless they are used at the right location or is given the proper heat treatment.

The term "tool steel" is actually misleading, as a lot of people tend to connect this steel grade with tools used in the manufacture of punched, bent, stamped or cast workpieces.

But the qualities of these steels can be used for solving a wide range problems, e.g. knives for chopped meat, wearing parts and machine components. All it takes is an analysis of the problem and finding the relevant quality profile. Uddeholm A/S has developed certain general concepts like the Stainless Concept for corrosion-resistant workpieces, but often the solution for a problem is designed in cooperation with the specific customer.

Tool steel is a type name for a steel that is an alloy containing carbon, silicon, manganese, chromium, nickel, molybdenum, tungsten, vanadium and cobalt to mention the most important constituents. Through a combination of these alloys, you get a quality profile that covers three main steel grades (see below).

Tool steel must be heat treated, i.e. hardened and tempered, to achieve its qualities. To facilitate things, Uddeholm A/S, and others, have developed a code system that makes it quick and easy to decide on the right heat treatment. See Table 3.

Table 3. Code system for tool steel. The example shows six of the approx. 25 steel grades available and their respective heat treatment codes 1 and 2. The grades shown belong to the first main group of steel (see below).

Codes → ↓		1		2	3	4	5
	Steel grades	Stress relieving	Hardening tempera-ture	Tempering min. 2x	Tempering min. 2x	Tempering min. 2x	Tempering min. 3x
		ºC	ºC	ºC / HRC*	ºC / HRC*	ºC / HRC*	ºC / HRC*
ARN	Arne	650	820	200 / 60			
ARN-B	Arne	650	820	Austempering at 250° C to 56 HRC			
CAM	Calmax	650	960	250 / 57			
RIG	Rigor	650	960	250 / 58			
SV3	Sverker 3	650	960	250 / 62			
SV21-A	Sverker 21	650	1030	180 / 61			

9.1. Three main steel groups

The first group focuses primarily on wear and compression strength. By creating alloys with a high carbon content, you achieve hardnesses of up to 68 HRC (Hardness Rockwell). Within this group it is possible to combine wear and compression strength and ductility/tenacity. This group offers longer life on machine components and equipment that would otherwise wear quickly.

The second group comprises the tenacious steels which can be subdivided into two groups: the hardened and tempered steels with a hardness of approx. 30 HRC, and the steels which come as soft-annealed, and are then hardened to 40-58 HRC. In this group, you will also find the corrosion-resistant steels. These steels are mainly designed for tasks that demand high ductility/tenacity. This could be shafts or machine components that require a corrosion resistance and compression strength that is somewhat higher than with stainless steel, e.g. knives etc.

<u>The third group</u> also comprise tenacious steels, but with high ductility. At the same time, these steels do not get soft at high temperatures. At a thermal impact of 500° C for more than 100 hours, steel like Orvar Supreme will not lose its hardness. The hardness range is 38 to 58 HRC.

9.1.1. Concepts

To all these steels we can attach words like: Abrasive wear, adhesive wear, ductility, tenacity, corrosion resistance and compression strength; words that require a definition.

- Abrasive wear is the type of wear that stems from abrasive items in the workpiece material, such as glass that has been mixed in a plastic, in hard steel grades or similar abrasive media.

- Adhesive wear occurs during processing of soft materials, when the workpiece material adheres to the tool steel. To prevent this type of wear, the steel must have high ductility.

- Ductility means that the steel is not prone to cracking due to stress.

- Tenacity is the speed at which a crack develops. The slower the development, the higher the tenacity.

- Corrosion resistance for tool steel is generally lower than for the AISI 316 grade, but you can find tool steel that is on level with AISI 304. Moreover, you can increase corrosion resistance through surface coatings.

- Compression strength is a measure for the hardness of the material. Greater hardness means greater compression strength.

10. Strength of materials and statics

The primary purpose of calculations is to document that a given construction can resist the impact and the environment to which it is exposed for a given period of time. Statics and strength of materials are tools that are applied in connection with technical documentation/calculations.

We will not go into the actual statics calculations in this guideline. That would be beyond the scope of this text and only be relevant to a small group of people. Statics calculations are used for e.g. sizing mechanical equipment, steel constructions, pressure-bearing plants and equipment etc.

Technical statics and strength of materials is a specialty. Statics calculations should be left to persons with documented expertise in the field. Great experience is required to assess the consequences of a possible construction failure, and the costs can be incalculable.

10.1. Sizing

Knowledge of the physical, chemichal and thermal properties of the materials is a necessary prerequisite for being able to perform sizing. Sizing is carried out by means of statics and strength of materials.

Strength requirements and resistance to deformation mean that the components we use in our constructions resist the impact we expose them to. To be able to solve this task, we need help from statics, which contains the science of the equilibrium of bodies and enables us to find the most loaded point of a structural component. Once we have found the most loaded point, the theory of strength of materials takes us further and helps us find the proper and necessary sizes.

10.2. Making statics calculations

Statics calculations should be clear and logical so that they can:

- be checked at an internal audit
- be checked at an external audit, e.g. by the authorities

Systematic clarity is a great help to the person(s) making the calculations, particularly in connection with more complicated and/or extensive projects.

It is of course vital that the person(s) in charge of the calculations always have a clear picture. For large projects involving several stress analysts, it is necessary to break down the calculations into manageable partial calculations.

In addition to the primary objectives, there will be other matters that require calculations. For instance, in connection with the building phase (purchasing, manufacturing and installation), project changes might occur or be desired. Here it is important that the calculations are clear and easy to grasp, so as to facilitate a quick response/basis for decision, particularly in cases that require further analyses by another person than the one who made the initial calculations. In the event of a later rebuilding, the people in charge, who may not have participated in the original planning, may need to use the calculations again.

Below, we give an example of the making/handling of statics calculations, showing how they may be handled when sent to a third party, including the authorities, in order to be checked, or how they can be filed. A theoretical example could be an outdoor steel structure according to the DS 412 Code of Practice for the structural use of steel, or the DS446 Code of Practice for thin-plate steel structures.

Table 4. An example of how to handle statics calculations

0 Contents
Make sure you have a detailed table of contents This will give everyone involved a clear picture and facilitate subsequent searches for calculations. Remember references ("page xx").

1 Introduction
The introduction should give an account of the task and a short description of the project, its application and any special circumstances.

2 Basis of calculation
2.1 Norms (references to current norms regulating the particular field)
List all norms, specifications, acts, by-laws etc.
2.2 Literature
List any special literature
2.3 Other
List other specific references, such as research reports, IT software etc.

3 Materials (refer to current norms for the specific materials)
List all the engineering materials used in the construction. List the permissible values for strength.
List material class, security class, seam class for welding, certificate requirements, control class etc.

4 Loads (DS 409 Code of Practice for The Safety of Structures, DS 410 Code of Practice for loads for the design of structures)
4.1 Proper load
List the proper load for the individual structural members.
4.2 Useful load
List the useful loads used in the calculations, e.g access roads with personnel load.
4.3 Natural load
4.3.1 Wind load
4.3.2 Snow load (ice)
4.3.3 Accidental load
4.3.4 Thermal load
4.3.5 Other load
E.g horizontal mass load which will often affect stability accross a structure.
The horizontal mass loads usually amount to 1.5 per cent of the permissible vertical load.

5 Load combinations (DS 410 Code of Practice for loads for the design of structures in Denmark)
- The safety of the structure against breakage is checked in load combination 2.1 of the code.
- The safety of the structure against lifting and overturning (stability) is checked in load combination 2.2 of the code.
- Structures in which the proper load make up most of the load is checked in load combination 2.3 of the code.

Particularly exposed structures are studied in the serviceability state.

- Structures where there is a risk of fall load, are checked for load combination 3.1 of the code.
- Structures where there is e.g. a high explosion risk or which belong in a high security class are checked for load combination 3.2 of the code.
- Structures where there is a risk of fire and structures that are frequented by a personnel are checked for the fire load combination 3.3 of the code

6 The supporting system
This section describes the supporting system. In connection with complex structures, only the general statics system is described, as details can be described under the individual calculations.
The reader should get a general understanding of how forces are led through the structure. Use drawings to illustrate.

7 The reinforcing system (including robustness)
This section describes the reinforcing system. Use drawings to illustrate.

8 Static calculations (refer to text books within the individual fields/specialties)
This is where the actual calculations come in. Start from the top and follow the loads down through the construction.
Specify the source of the figures, i.e. refer to the pages where values on which the calculations are based are calculated. Use drawings that help to illustrate the subject.

9 Signature
Calculated by: Yy yyyy
Checked by: Xx xxxx

The calculations must be signed by the person who made the calculations and by the person who checked them. State date and location.

10 Appendix
As appendices you may add calculations by persons involved, including suppliers, together with print-outs and other relevant documentation.

11. Related guidelines and links

EHEDG Doc. 8, 2004: Hygienic equipment design criteria.
This document describes design criteria that must be met before equipment used for food is regarded hygienic and sterile. A number of general directions for the design and manufacture of equipment have been issued to ensure microbial safety and product quality. They deal with, among other things, cleaning, validation of hygienic quality, surfaces, geometry, design and materials.
The guideline can be bought at EHEDG: http://www.ehedg.org.

EHEDG Doc. 9, 1993: Welding stainless steel to meet hygienic requirements.
This guideline describes techniques that ensure that welds remain hygienic. The descriptions are for stainless steels thinner than 3 mm. The guidline mentions both manual and automatic welding techniques. Furthermore, it describes typical errors and methods for quality control.
The guideline can be bought at EHEDG: http://www.ehedg.org.

The knowledge portal www.staalcentrum.dk offers a clear picture of the guidelines, standards, legislation etc. available for specific fields/types of equipment and locations. It is easy to search the material and read a short description of the actual contents. The relevant links lets you order material from the source. Furthermore, it contains a wide range of relevant links to authorities and organisations etc.

The Stahlschlüssel contains a list of steel qualities from more than 20 countries. You can search information about any steel grade, alloy or brand, and find cross references between the different national standards. Stahlschlüssel is issued both as a spiral-bound book and on CD-ROM (see http://www.stahlschluessel.de/).

Steel suppliers

Sandvik:	http://www.sandvik.com/
Outokumpo:	http://www.outokumpu.com/
British Stainless Steel Association:	http://www.bssa.org.uk/index.htm
Dockweiler:	http://www.dockweiler.com/ie/index.html
Edelstahl Rostfrei:	http://www.edelstahl-rostfrei.de/
Olympic Steel:	http://www.olysteel.com/
Special Metals:	http://www.specialmetals.com/

Welding:

American Welding Society:	http://www.aws.org/pr/jul10-99.html
Huntingdon:	http://huntingdonfusion.com/HFT/
Böhler Thyssen:	http://www.boehler-thyssen.com/
ESAB:	http://www.esab.com/

Organisations etc.

Danish Standard Association:	www.ds.dk
ASSDA:	http://www.assda.asn.au/asp/index.asp
KCI Publishing BV:	http://home.pi.net/~kci/
NIDI:	http://www.nickel-institute.org

SSIC: http://www.ssina.com
3A Sanitary Standards: http://www.3-a.org/
EHEDG: http://www.ehedg.org/
Corrosion Doctors: http://www.corrosion-doctors.org/
Food and Drug Administration in the US: http://www.fda.gov
Nickel Institute: www.nickelinstitute.org/goodpractices/

Literature
”Håndbog – Rustfrit Stål” (handbook: stainless steel), Sandvik Materials Technology, Referencenummer S-003-DAN (260 pages).
Bejdsning og passivering af rustfrit stål (pickling and passivation of stainless steel). Cleanodan a/s, 1999.
Passivation of stainless steel. Dairy, Food and Environmental Sanitation, vol. 18, May 1998.
Korrosionsbestandigt rustfrit stål (corrosion-resistant stainless steel), ISBN 87-600-0079-1, Industriens forlag 1996
Surface Modification and Passivation of Stainless Steel. ISBN 91-554-3375-8, C. Olsson 1994
ASTM A967-01. Standard Specification fro Chemical Passivation Treatments for Stainless Steel Parts.
ASTM A380-99. Standard Practice for Cleaning, Descaling and Passivation of Stainless Steel Parts, Equipment, and Systems.
”Korrosionsbestandigt Rustfrit Stål, Hvordan? (corrosion-resistant stainless steel: how?) by Ebbe Rislund and others, FORCE Technology, ISBN 87-600-0079-1 (358 pages).

12. Applied methods

The experience and knowledge of the group members was collected and structured from 2003 to 2005.

13. Concepts/terminology

Please see the EHEDG Glossary (http://www.ehedg.org). Go to Guidelines > Library > Glossary.

EHEDG	European Hygienic Engineering & Design Group
DS/EN	Danish Standard/European Norm
AISI	American Iron and Steel Institute
USDA	United States Department of Agriculture
FDA	U.S. Food and Drug Administration
PED	Pressure Equipment Directive
ASME	American Society of Mechanical Engineers
GMP	Good Manufacturing Practice
Ra value	Rougness Average
HRC	Hardness Rockwell
OES	Optical Emission Spectral analyses
LOM	Light Optical Microscopy
SEM	Scanning Electron Microscopy
ISO	International Organization for Standardization

14. Change protocol

This is the first edition. Future changes will be listed here.