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STAINLESS STEEL IN CONTACT WITH FOOD AND BEVARAGE

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Abstract
Stainless steels are probably the most important materials in the food and beverage industries. The main reason for such broad implementation of stainless steel in contact with food are excellent properties which they possess such as corrosion resistance, resistance to high and low temperatures, very good mechanical and physical properties, aesthetic appeal, inertness of surface, durability, easy cleaning and recycling. Low thermal conductivity of these steels produces steeper temperature coefficient provoking an increased distortion, shrinkage and stresses compared with carbon steel.
Key words: stainless steel, food and bevarage, corrosion resistance, properties, recycling

Introduction

Stainless steels were introduced in the technical world at the beginning of the twentieth century as result of pioneering work of engineers in England and Germany. In the ensuing half of century manufacturers developed a large family of stainless steel. The modern era of stainless steel began in the early 1970s when steel makers began the new refining and casting technologies. There are more than 200 types of stainless steel now, and they all meet minimum chromium requirements [1]. For storage, production, transportation and catering of food and beverages no more than 10 types of stainless steel are used.

Author's basic idea was to devote this paper to the people involved in the field of food and beverage industry, to become more familiar with stainless steels as most important materials for equipment, installation, and vessels they use permanently.

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What are Stainless Steels?

Stainless steel is the term used to describe an extremely versatile family of engineering materials, which are selected primarily for their corrosion and heat resistant properties. Stainless steels are defined as iron based alloys containing at least 10.5 % chromium. At this level, chromium reacts with oxygen and moisture in the environment to form a protective, adherent and coherent, oxide film that envelops the entire surface of the material. This oxide film (the passive layer) is very thin (2-3 nm). The passive layer on stainless steels exhibits a truly remarkable property: when damaged (e.g. abraded), it self-repairs as chromium in the steel reacts rapidly with oxygen and moisture to reform the oxide layer which acts as a barrier between the alloy and the surrounding medium (Fig. 1).

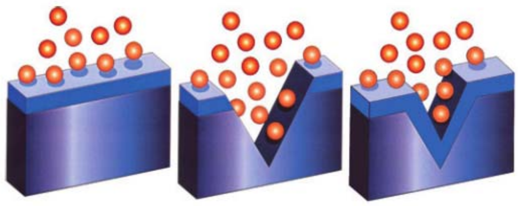


Fig. 1 Formation of passive layer on stainless steel surface (few microns thick, rich in Cr.)

Increasing the chromium content beyond the minimum of 10.5% confers still greater corrosion resistance. Corrosion resistance may be further improved, and a wide range of properties provided, by the addition of 8% or more nickel. Other elements can influence the effectiveness of chromium in forming or maintaining this film [2]. Increasing the chromium content to the 18 % level, typical of the austenitic stainless steels, provides increased stability of the passive film. However, if ordinary or carbon ‘steel’ comes in contact with oxygen its surface become completely covered with rust.

Benefits of Stainless Steel

Benefits which offer stainless steels are the following [3]: corrosion resistance, high and low temperature resistance, ease of fabrication, strength and hardness values, aesthetic appeal, hygienic properties, life cycle characteristics and easy recycling of stainless steel scrap.

Categories of Stainless Steels

The stainless steel family tree has several branches. They can be differentiated in a variety of ways, e.g. in terms of their areas of application, by the alloying elements used in their production, or the most accurate way, by the metallurgical phases present in their microscopic structures: ferritic, martensitic (including precipitation hardening steels), austenitic and duplex stainless steels (Fig. 2). Within each of these groups, there are several “grades” of stainless steel defined according to their compositional ranges.

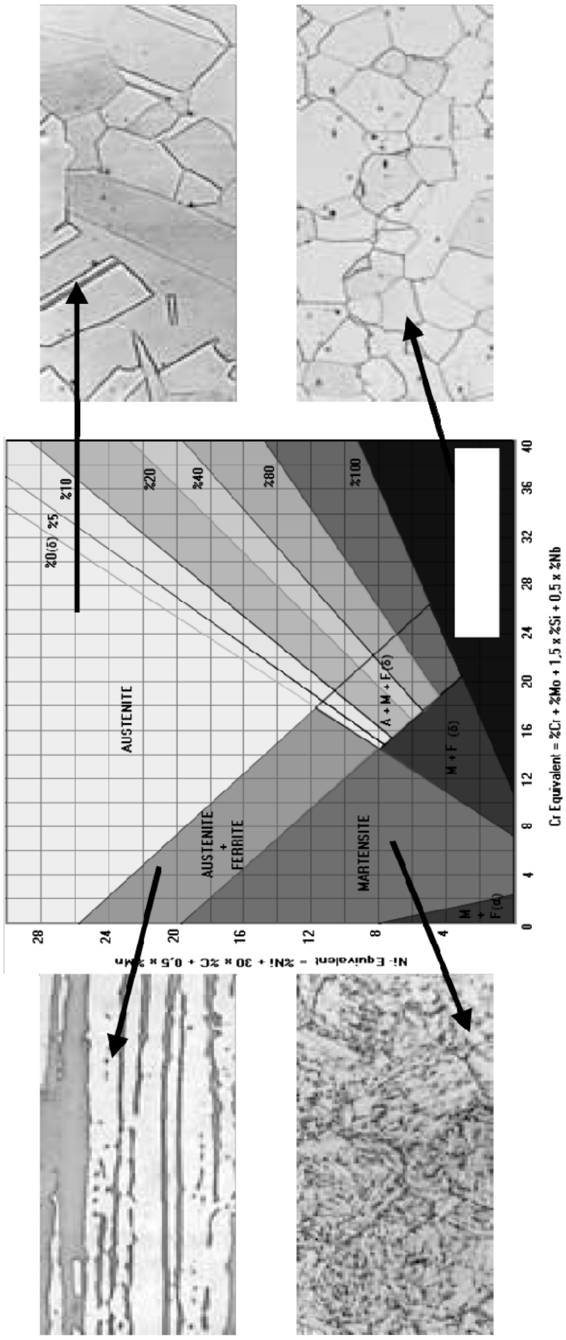


Fig. 2 Classification of stainless steel according chemical composition and microstructure Schaeffler diagram

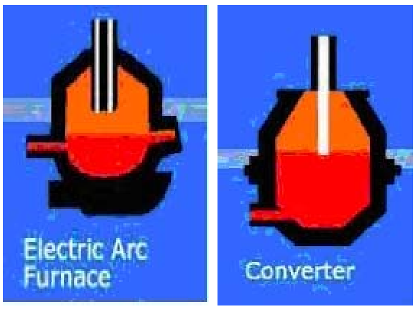
Properties of different types of stainless steel

The „simplest“ stainless steels are the iron carbon-chromium alloys and these fall into two groups. The first group is the *martensitic stainless* steels. These contain only about 13% chromium (least expensive), but they have high levels of carbon. Whilst the high level of carbon in the martensitic stainless steels makes them difficult to form and weld, it also makes them very hard and strong. These types of stainless steels are ideal where the environment is not particularly aggressive. The other iron-carbon-chromium group is known as the *ferritic stainless* steels and these will typically contain about 17% chromium and about 0.05% carbon. Only ferritic stainless steels are magnetic. Ferritic is less easily formed or welded than the austenitic stainless steels. The addition of nickel to stainless steel offers valuable fabrication advantages [4], better formability and weldability as well as improved corrosion resistance. There is no universal composition limits for stainless steels to be used in food contact applications. The strongest legislative requirements are in France and Italy. In France, stainless steels for food contact must contain at least 13% chromium. In Italy, there is a "positive list" of stainless steel grades for food contact.

In Europe, stainless steel types are usually defined by designations given in Euronorm EN 10088. These designations follow the Werkstoff numbering system for steels originally developed in Germany.

Production and properties of stainless steel of stainless steel

Production of stainless steel starts with melting in Electric Arc Furnace (EAF), (Fig. 3a), with typical capacity of 100-150 tones. Scrap account is 60-70% of new melt or cast. The molten steel is transferred to a converter usually AOD vessel (Argon Oxygen Decarburization) as presented in Fig. 3b. The invention of this process in 1954 and its subsequent development led to steep change in the cost of production of stainless steels due to efficient reduction in carbon levels particularly "L"grades. Alloying elements are added to bring the cast into the required composition range [5].



a. *b.*

Fig. 3 Production of stainless steel. a. Electric arc furnace; b. converter.

Stainless steels are strong and are more formable than most other metallic materials (Fig. 4). They can be formed into the necessary shapes for food processing, transportation and storage. They are readily welded too. They resist impact, fatigue, wear, abrasion and erosion. Stainless steel provides excellent toughness, ductility, weldability, and work hardening characteristics. Excellent cryogenic and high temperature oxidation resistance is also provided.

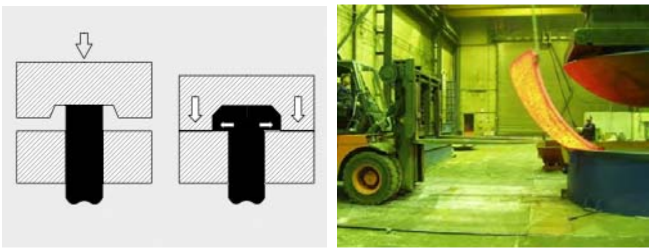


Fig. 4 Cold and hot forming of stainless steel.

The physical properties of carbon and austenitic steels are quite different. Melting point of austenitic steel is lower, so less heat is required to produce fusion. Their electrical resistance is higher than that of mild steels, and they have lower coefficient of thermal conductivity. Austenitic steel have higher coefficient of thermal expansion. Difference in physical properties between stainless steels is well known too.

Why stainless steel in contact with food?

A variety of materials are used in the construction and fabrication for different applications in food equipment. These materials vary in their properties with regard to workability, compatibility, and sanitary design. Depending upon the application, various metals as well as non-metallic materials are used. Some materials are not recommended and should be avoided**,** but stainless steel**s** become credibly the most important material in household and modern food industry [6]. Satin smooth or mirror brightly, easily maintained surface of stainless steel provides a modern and attractive appearance. They can withstand fire for a long time and does not warp or buckle easily. Stainless steel can retain its natural colour for a very long time. Stainless steel is practically impervious to corrosive attack by animal fats, blood, salts, fruit and vegetable and acids. Stainless steel needs no maintenance and can be kept clean, bright and beautiful simply by wiping and washing with water. Having no pores or cracks to harbour dirt, grime or bacteria, stainless steel lets soap and water does all but the toughest cleaning jobs. Stainless steel's clean ability is similar to that of glass and china and far superior to plastics [7].

As to safety considerations, the chemical and biological neutrality of the material in food contact applications has become a focus of interest. Many properties of stainless steels lead to their application throughout the food chain: from food processing and brewing, to distribution, to storage and to serving food [8].

Stainless steels have ability to be readily cleaned and sterilised without deterioration using a wide range of cleaning/sterilising systems, and the fact that they impart neither colour nor flavour to foodstuffs and beverages.

Stainless steel avoids contamination of food and beverage and maintains freshness of the items handled. Stainless steel is basically inert to most of the acids/alkalises released by cooked foods, vegetables, additives etc. Further**,** stainless steel does not break/crack unlike other comparative wares used for foods.

Stainless steels are tolerant of the wide range of temperatures encountered in the production of foods, from cooking to freezing, and they resist thermal shock.

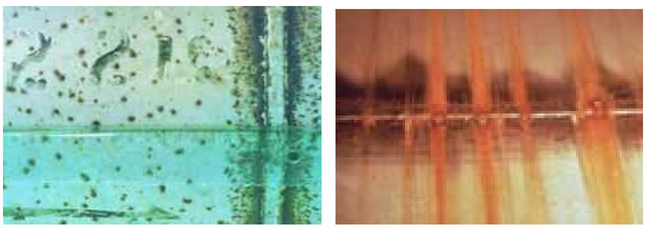
Design and welding of stainless steels

Long time ago, stainless steels established themselves as the crucial material for different food applications: in the households, for the food catering, food production and storage too. If stainless steels are used correctly and maintained in an appropriate way, a long trouble-free service at the minimum life-cycle cost can be ensured. Due to the properties of stainless steels it is relatively easy to design and construct assemblies which can process foods effectively and economically. As a rule, designs in stainless steel convey an impression of elegance, solidity and modern life style.

Joining of stainless steels is mostly often performed by implementation of welding, brazing and soldering processes. All conventional arc welding processes can be used [9]. It is more complicated to join stainless steel compared with carbon steel because the process must maintain besides mechanical and corrosion properties of weldments. Effects of physical properties of stainless steel on welding are quite different from carbon steel. Physical properties of stainless directly influence welding conditions. Low thermal conductivity of austenitic stainless steels produces temperature gradient near the weld inducing an increased distortion, shrinkage and stresses compared with carbon steel.

Defects which can appear during fabrication of stainless steel equipment

Defect which can appear during fabrication of stainless steel may be divided in several categories: surface contamination, embedded iron, mechanical damage or welding related defects. When new stainless steel equipment develops rust spots it is mostly the result of embedded free iron. If the iron is not removed, deep attack in the form of pitting corrosion may take place. Free iron is most often embedded in steel during forming operations (Fig. 5a). Some strict fabrication rules are: do not bring iron or carbon steel surface into intimate contact with stainless steel; use of tools such as abrasive discs previously used on carbon steel is forbidden. Never use brushes with carbon steel wire (Fig. 5b). And the most important: locate stainless steel fabrication away from carbon steel fabrication.



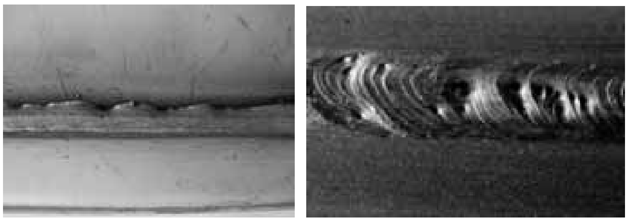
a. *b.*

Fig. 5 a. Embedded iron on the surface of stainless steel; b. corrosion of stainless steel weld (brushing with carbon steel brush).

For best corrosion resistance, the stainless steel surface should be free from surface oxides. The oxides may be in the form of heat tint (Fig. 6).

Fig. 6 Welding heat tint in HAZ and weld metal.

Fig. 7 shows typical welding defects [10, 11] which can cause corrosion of stainless steel equipment because of capturing food or beverage residues which cannot be removed during cleaning.



a. *b.*

Fig. 7 Welding defects. a. Lack of fusion; b. pores.

Types of corrosion of stainless steel

Different types of corrosion could appear due to the wrong grade selection or inappropriate use of equipment in stainless steel. **C**revice and pitting corrosion occur most readily in aqueous chloride-containing solutions. Pitting corrosion (Fig. 8a) is characterised by local deep pits on free surfaces. Examples for crevice corrosion under washers are given in (Fig. 8b).

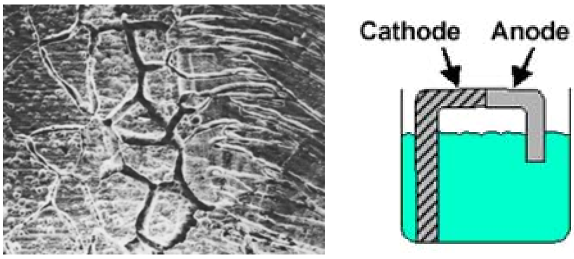
a. *b.*

Fig. 8 a. Pitting corrosion; b. Crevice corrosion.

Stress Corrosion Cracking (SCC) is a localised form of corrosion characterised by the appearance of cracks in materials subjected to both stress and a corrosive environment. It usually occurs in the presence of chlorides at temperatures generally above 50^0C. Stress corrosion cracking in stainless steel piping and tanks (Fig. 9) is a problem in water lines in brewery applications.

Fig. 9 Stress corrosion cracking.

Intergranular Corrosion (IGC) is the result of localised attack, generally in a narrow band around heat affected zones of welds (Fig. 10a). It is more likely to occur in the “standard“ carbon austenitics. The risk of IGC attack is virtually eliminated if steel contains low carbon (max 0.030%C).



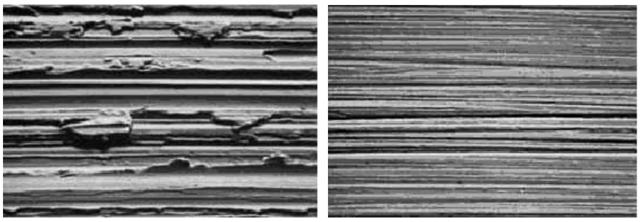
a. *b.*

Fig. 10 a. Intergranular corrosion; b. galvanic corrosion.

Galvanic corrosion is an accelerated attack between two dissimilar metals coupled in electrical contact and exposed to an electrolyte. For example, in hydrostatic sterilizers, the flight bars are made of aluminum or stainless steel, the transport chain is made of carbon steel, and both are exposed to hot water and steam. In this assembly the less noble metal is susceptible to galvanic corrosion.

Finishing treatment of stainless steel equipment

If surface is ground, polished, or textured in any way, it must be done so the final surface is smooth, durable, and free of cracks and crevices, meeting sanitary design requirements. Surface finish and condition are very important to the successful application of stainless steels. Smooth surfaces not only promote good cleanability but also reduce the risk of corrosion. Sanitary standards has recently adopted an industry recognized method for determining an acceptable food contact surface termed roughness average or Ra value. Fig. 11 presents typical Ra values, i.e. difference in the surface quality. A wide range of decorative finishes is available [12].



a. *b.*

Fig. 11. Different Ra values i.e. quality of surface of stainless steel
a. Ra=1μm; b. Ra=0.2μm.

“Grinding”and “polishing” are a forms of machining, involving the removal of a layer of metal from the surface by abrading action. This involves the use of hard particles. The surface finish created is dependent on a number of factors, including the coarseness of the abrasive used. As a starting point, using finer grit size abrasives produces smoother finishes. In contrast to grinding and polishing, buffing is not intended to deliberately remove any of the stainless steel surface. It is instead a smoothing process, making the surface brighter and more reflective.

a. *b.*

Fig. 12 a.Grinding; b. buffing.

Some application of stainless steel for food necessity

They have different fields of application. For instance: beverage transportation, milk processing equipment, the dairy and chocolate industry, fruit processing industry, containers such as wine tanks, brew kettles and beer kegs, processing of dry food, for utensils (blenders and bread dough mixers), slaughter-houses, processing of fish, all of the equipment in big kitchens, such as in restaurants, hospitals, etc

Typical applications of different types of stainless steel for different allocation are presented below. Martensitic steel 420 is used for professional knives and spatulas. Ferritic 430 steels are implemented for components requiring little formability or weldability. They are used for moderately corrosive environments. Austenitic 304 stainless steel is used for components requiring some formability and weldability. Components used with more corrosive components are made of 316 austenitic steel. Duplex steel are implemented with corrosive foods.

Cleaning of stainless steel equipment after welding and application

Welding of all stainless steel grades must be followed by an effective "post-weld clean-up" (Fig. 13). The heat of welding ("heat tint") near to the weldment will have a significantly reduced resistance to corrosion. "Pickling" is the controlled corrosion of the surface and will remove undesirable oxidation. The usual pickling medium is 10% nitric and 3% hydrofluoric acid at about 50°C.

Cleanability is also important in relation to taste, colour and contamination of edible products. Wiping action to the washing treatment enhances the bacterial clean ability. No flavours or discoloration are imparted to foods and beverages in contact with stainless steels. Cleaning methods suitable for stainless steel equipment are: water, steam, mechanical scrubbing, scouring powder, detergents and organic solvents**.**

a. *b.*

Fig. 13 Welded joint after welding (a) and pickling treatment (b)

Hygiene is of utmost importance in sanitation or in the preparation or processing of food or beverages. Stainless steel has a proven record of success in these areas where sanitation and ease of cleaning are so important. The easy cleaning ability of stainless steel makes it the first choice for strict hygienic conditions [13]. As soon as chlorides are present, however, special care must be taken in selecting a suitable stainless steel grade to avoid corrosion problems. Stainless steel equipment often contains gaskets or other components that can absorb cleaning liquids. When these liquids dry, harmful concentrations can arise resulting in corrosion attack.

Summary

Product quality, health, and sanitation issues are major concerns in the food-processing industry. The industry cannot tolerate corrosion deposits in the manufactured product. The food industry, therefore, needs to account for corrosion control before production starts and during working period.

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