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Stainless Steel for Dairy and Food Industry: A Review

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Abstract

Stainless steels (SS) were invented to overcome the problem of corrosion which is a major concern of food and many other industries. The alloy of steel containing iron-chromium-nickel is known as stainless steels. Stainless steels typically contain between 9 and 30 percent chromium and varying amounts of nickel, molybdenum, copper, sulfur, titanium, niobium, etc., may be added to obtain the desired mechanical properties and service life. Stainless steel is considered noble metal for use in dairy industry. Stainless steels are classified based on the chemical composition and it provides information to overcome many types of corrosion. Some of the limitations of SS employed in food and dairy industry are attack by lactic and malic acids at elevated temperature and poor thermal conductivity. However, these limitations may be overcome by carefully selection and fabrication, optimized operating condition, care and maintenance of the equipment. Stainless steels of various grades are widely used as engineering material for the fabrication of equipment. Stainless steels are corrosive resistant but under certain conditions the materials can stain and can corrode. Dairy and food industries are concerned with reliability of equipment and product purity. To achieve these, stainless steels are often the economical and practical materials of choice for process equipment. It is necessary to select most suitable grade of SS depending on the requirements for the specific application. The understanding of metallurgy and ways of fabrication are very essential to select right grade of SS. The food and dairy processing industries, corrosion becomes a critical factor directly influencing equipment and indirectly, overall equipment longevity. Key to minimizing corrosion impact needs better understanding of factors affecting corrosion as early as the equipment design phase and throughout subsequent processing operation.

Keywords: Stainless steel; SS; AISI 200/300/400; Dairy; Food equipment's

Introduction

Stainless steels (SS) were invented to overcome the problem of corrosion which is a major concern of food and many other industries. The alloy of steel containing iron-chromium-nickel is known as stainless steels. Stainless steels typically contain between 9 and 30 percent chromium and varying amounts of nickel, molybdenum, copper, sulfur, titanium, niobium, etc., may be added to obtain the desired mechanical properties and service life. Stainless steel is considered noble metal for use in dairy industry. Stainless steels are classified based on the chemical composition and it provides information to overcome many types of corrosion. Some of the limitations of SS employed in food and dairy industry are attack by lactic and malic acids at elevated temperature and poor thermal conductivity. However, these limitations may be overcome by carefully selection and fabrication, optimized operating condition, care and maintenance of the equipment [1].

History

The works on material science at several places around the word lead to the discovery and development of the stainless steels. Stainless steels were invented by Stahl in the year 1912. This invention has helped a lot to improve corrosion resistivity and mechanical behavior of the material as compared to pure steels. These developments in metallurgy were not significantly to fulfill requirements of food industry [2]. English metallurgist early in the year 1913 working on a project to improve rifle barrels accidentally discovered that adding chromium to low carbon steel gives it stain resistance. The first application for these stainless steels was in cutlery manufacturing in which the previously used carbon steel was replaced by the new stainless steels [3]. Among the iron-base alloys investigated were iron-chromium-nickel alloys with high chromium contents. It was found that specimens of alloys with more than 20% Cr did not rust in the laboratory for quite some time. It is subsequently concluded that at least 20% chromium was necessary to achieve resistance to oxidation or scaling. This was the starting point of the development of heat-resistant steels for applicable in chemical, food, dairy, beverage, bio-processing, pharmaceuticals industries [2].

Classification of SS

Stainless steels are basically classified as austenitic, ferritic, martensitic, duplex and super-austenitic grades. Each of these main groups contains a number of alloys that are defined according to the chemical composition and specified in European and American International Standards [4,5]. 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 for the welding properties [6]. In addition, copper, manganese, sulphur, titanium and niobium are used as alloy constituents to impart certain properties. Stainless steel is typical wrought alloy AISI (American Iron and Steel Institution) series designations, includes: 200 (high manganese austenitic), 300 (austenitic), and 400 and 500 (ferritic and martensitic) [7]. Martensitic and ferritic steels are magnetic and martensitic steels are typically hardened by heat treatment and are not easily formable. Austenitic steels harden when cold worked. Duplex grades (austenitic/ferritic) are more resistant to stress corrosion cracking than austenitic and are tougher than ferritic grades [8].

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Desirable properties of SS

The properties of stainless steel play an important role in the design of various equipment. The use of high quality SS in fabrication of processing equipment helps not only to prevent corrosion but also ensures purity of food product handled in that equipment. In addition to this, stainless steels are easy to clean and maintain and a number of different products can be manufactured in the same equipment. If properly utilized, equipment made of stainless steel can be expected to last for many years [9]. On a life-cycle basis, the alloys are often the most cost-effective [2]. Important characteristic to be considered in selecting the proper type of stainless steel for a specific application are listed below [1].

- ➢ Corrosion resistance
- ➢ Resistance to oxidation and sulfidation
- ➢ Strength and ductility at ambient and service temperatures
- ➢ Suitability for intended fabrication techniques
- ➢ Suitability for intended cleaning procedures
- ➢ Stability of properties in service
- ➢ Toughness
- ➢ Resistance to abrasion, erosion, galling, and seizing
- ➢ Surface finish and/or reflectivity
- ➢ Physical property characteristics such as magnetic properties, thermal conductivity and electrical resistivity
- ➢ Total cost, including initial cost, installed cost, and the effective life expectancy of the finished product

Metallurgical properties of SS

Austenitic SS (nonmagnetic): The steel containing high content of both chromium and nickel are called austenitic SS. Most commonly used steel contain 18 percent Cr and 8 percent Ni called as 18/8 steel. Austenitic stainless steel comprises most (70-80%) of the total stainless steel production and is particularly prevalent in food-processing applications [2,5,10]. Austenitic stainless steel (AISI 200 e.g. 201, 202 and AISI 300, e.g. 304, 302 and 316) is non-magnetic, ductile, nothardenable by heat treatment, and easily fabricated [7]. Their major weakness is chloride stress corrosion cracking (SCC), being susceptible at temperatures over 55°C [11]. Apart from chromium, austenitic SS typically contains 8 to 30% nickel and varying quantities of molybdenum.

Austenitic SS having low carbon, 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 good high-temperature and low-temperature stability make it useful for wide range of application [12].

Ferritic SS (magnetic): The steel containing greater amount of Cr (16-18%) and about 0.12 percent carbon are called ferritic stainless steel. Ferrite SS (AISI 400 series e.g., 410, 430) are magnetic and hardenable by heat treatment apart from chromium it contains only small quantities of nickel. It is moderately corrosion-resistant. The impact resistance is reduced considerably at low temperatures [7], possessing inferior fracture toughness but better strength and SCC resistance compared with austenitic SS [13]. Owing to their high strength, they are more difficult to fabricate and weld. Ferritic SS grades are used for strongly oxidizing environments (e.g., nitric acid) [4,7]. They are essentially resistant to chloride SCC [5,10-12], but susceptible to IGA (inert granular attack), pitting, and crevice corrosion [14].

Martensitic SS (magnetic): The first group of stainless steel is the 'martensitic' SS. These contain only about 13% chromium (and so they are the least expensive stainless steels) but they have high levels of carbon (even up to 1%) [7]. 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, and heat treatment can make them even harder. These stainless steels are ideal where the environment is not particularly aggressive, but resistance to wear is important. AISI 440C contains 1% carbon and is extremely hard and so it is used for the wearing parts of pumps. Grade AISI 420 contains a minimum of 0.15% carbon and is ideal for knife blades [4,5,7].

Duplex SS (ferritic/austenitic): Duplex SS possesses both characteristics of austenite and ferrite in their micro structure [2]. They have high strength and good ductility, making them potentially suitable for food-processing [7]. In very corrosive environments such as mustard and vinegar-making, cheese plants or fish-canning plants, it may be necessary to use one of the second groups of iron-carbon-chromium-nickel stainless steels are 'duplex' steels. These have very high levels of chromium 22% in grade AISI 2205 and 23% in grade AISI 2304 and, in the case of AISI 2205, about 3% molybdenum is used [7]. Most duplex steels are also more expensive than the austenitic SS. They have a resistance to general corrosion similar to the austenitic stainless steels but much higher mechanical strength [12]. They also have a much better resistance to stress corrosion cracking than austenitic stainless steels and a resistance to crevice and pitting corrosion superior to the AISI 316 austenitic [4,5,7,10,15].

Super-austenitic SS: The super-austenitic stainless steels are tolerant of extremely aggressive conditions [2]. During the production of soy sauce, for instance, the ingredients ferment in tanks for about six months, during which they produce a sauce rich in organic acids, amino acids and alcohols and with a pH of about 4.7 and a sodium chloride content of around 17% [4]. High levels of chromium, nickel, molybdenum and nitrogen and low carbon content confer to austenitic stainless steels superior corrosion resistance in a wide array of aggressive environments. Typical example sare grade (AISI 904L), which has a molybdenum content of over 4%, and grades (AISI 254 SMO) contain more than 6% molybdenum [5,7,15].

Application of SS in Food and Dairy Industry

Stainless steel exhibits some of the most suitable characteristics of the construction materials used for food equipment. It is the most widely used material in direct contact with food found in the industry [7]. Under special corrosion conditions, such as handling of acidic fluid foods or foods containing SO_2, AISI 316 or 316L stainless steel should be employed with preference over AISI 302 or AISI 304. AISI 302 stainless steel is used to improve the external design appearance of food equipment, but not equipment in contact with food or corrosive agents. AISI 304 stainless steel is the most commonly used for general purposes to provided better strength [16].

It is suggested that there are six major reasons for the widespread use of stainless steel in the food and dairy industry: corrosion resistance; durability; ease of fabrication; heat resistance; flavour and colour protection; and cleanability [7]. Corrosion resistance and cleanability of stainless steel are important in relation to food hygiene. Austenitic stainless steel should be preferred for food and dairy application because it characterized most stable and corrosion resist than other stainless steel. Application of SS in food and dairy includes [16]:

- Processing equipment such as pasteurizer, homogenizer, separator, decanter, metal detector, heat-exchanger, mixing tank and process tank etc.
- Storage tanks and form equipments are consists silo tank, road tanker, milking machine, cans and bulk milk cooler etc.
- Accessories include the fittings, valve, pumps, and lab instruments etc.

Corrosion in SS

Corrosion is the tendency of a metal to return to its most stable thermodynamic state which is the most negative free energy of formation. In straightforward terms, it is the chemical reaction of a metal with an environment to form a stable compound (e.g., oxide, sulfate, and carbonate). Every single metal undergoes corrosion to some degree under certain conditions [17], making material selection appropriate to the process a critical factor influencing equipment longevity [15]. Corrosion can be classified as under.

- **Aqueous corrosion:** It refers to corrosion in liquids or moist environments at temperatures up to 300°C, usually in water-based environments.
- **High temperature corrosion:** It denotes corrosion in hot gases at temperatures up to 1300°C.

Key factors affecting corrosion severity are ineffective plant maintenance, inadequate understanding of corrosion sources, incorrect material specification for operating conditions (e.g., temperature, chemicals), sub-optimal operational practices (e.g., poor rinsing of residues, overall cleanability), and misuse of halogen-releasing sterilants (e.g., sodium hypochlorite) [18]. Stainless steel undergoes five types of aqueous corrosion which is given.

General corrosion: In this case, the passive layer on the metal surface is broken down completely, and corrosion is therefore characterized by being uniform on the entire metal surface. General corrosion is frequent in reducing acids [19].

Inter-crystalline corrosion (inter-granular corrosion): Inter granular attack (IGA), inter granular corrosion (IGC), or inter granular stress corrosion cracking (IGSCC) is commonly associated with welding. It is localized, preferential attack, at and adjacent to grain boundaries with relatively little corrosion within the grain, in which the alloy disintegrates (i.e., grains fall out) and/or loses its strength [20].

Stress corrosion cracking: SCC is defined as premature cracking in the presence of tensile stress and corrodents, neither of which acting alone causes failure [13]. The presence of dissolved oxygen or other oxidizing species is critical to the cracking of austenitic SS in chloride solutions; specifically, if oxygen is removed cracking does not occur [21]. SCC is aggravated by low pH [6].

Pitting/cavitation erosion/pinpoint corrosion: Pits are formed by the significant reduction of the chromium-to-iron ratio surrounding a particle impurity [22]. Cr in the passive layer becomes dissolved exposing iron and creating an active site [5]. Rapid dissolution occurs within the pit, producing excess positive charge and resulting in chloride ion migration to maintain electro-neutrality. Pitting possesses a similar mechanism to crevice corrosion.

Crevice corrosion (deposit corrosion): Crevice corrosion is a type of galvanic corrosion comprised of four stages. For chloride crevice corrosion specifically, these stages are: (1) depletion of oxygen from the electrolyte within the crevice causing it to become anodic (i.e., unbalanced excess of positive charge) to adjacent exposed surfaces owing to metal dissolution in the crevice but not the adjacent surface [4], (2) increase of acidity and rebalance of charge when metal ions combine with hydroxyl ions (slower migration) and chloride ions (faster migration owing to greater mobility), and rise in metal chloride concentration in the crevice electrolyte [23] , (3) permanent breakdown of the protective passive film and onset of rapid corrosion, and (4) crevice corrosion propagation [14,24].

Corrosion preventive aspects of SS

Though stainless steel is naturally passivated by exposure to air and other oxidizers, additional surface treatments often are needed to prevent corrosion. Passivation, pickling, electro-polishing, and in some circumstances, mechanical cleaning, are important surface treatments for the successful performance of stainless steel used for piping, pressure vessels, tanks, and machined parts in a wide variety of applications [17]. Among them: pulp mills, nuclear power plants, hospital sterilization systems, food processing equipment, biotechnology processing plants, breweries, electronic-chip washing facilities, swimming pool hardware, water treatment plants, and chemical process plants [12]. Determining which treatment should be used for specific applications is confusing to many specifiers. Cleaning and De-scaling of Stainless Steel Parts, Equipment and Systems, an excellent resource document for the cleaning of stainless steel, although it does not cover electro-polishing [1].

Passivation treatments: Exposure to air is the natural, primary passivation treatment for stainless steel. This exposure produces a thin, durable chromium oxide film that forms rapidly on the alloy surface and gives stainless steel its characteristic “stainless” quality. Exposure of the surface to water orother oxidizing environments also produces this passivating film [25]. Additional passivation is called for in many specifications to remove light surface contamination from machined stainless steel parts, including shop dirt, iron particles from cutting tools, and machining lubricants [5]. Passivation treatments of stainless steel with nitric or mild organic acids are useful mild cleaning operations performed after machining to enhance the protective nature of the natural, air-formed film. Nitric acid treatment enhances the level of chromium in the protective film on stainless steels [17].

Electro-cleaning and electro-polishing: Electro-cleaning, an electro-polishing technique, is a useful alternative to pickling treatments. It is widely used to remove imperfections from the surface of stainless steel after fabrication. It removes embedded iron particles and similar film defects as does pickling [25]. A copper cathode and an electrolyte usually phosphoric acid are then used to corrode away the protective film and several layers of the surface in a controlled manner by varying the current and dwell time [17].

Mechanical cleaning: Mechanical de-scaling methods commonly used to clean welds. These include abrasive blasting, brushing, grinding, and chipping. However, if these mechanical cleaning procedures are not performed carefully, they can do more harm than producing good effect [12].

Conclusion

Stainless steels of various grades are widely used as engineering material for the fabrication of equipment. Stainless steels are corrosive

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resistant but under certain conditions the materials can stain and can corrode. Dairy and food industries are concerned with reliability of equipment and product purity. To achieve these, stainless steels are often the economical and practical materials of choice for process equipment. It is necessary to select most suitable grade of SS depending on the requirements for the specific application. The food and dairy processing industries, corrosion becomes a critical factor directly influencing equipment, and indirectly, overall equipment longevity. Key to minimizing corrosion impact needs better understanding of factors affecting corrosion as early as the equipment design phase and throughout subsequent processing operation.

References

1. Raghavan CV, Shrichandan BR, Shrinivas RPN (1994) Selection and uses of stainless steel in food industry. Indian Food Industry 13: 26-32.
2. Covert RA, Tuthill AH (2000) Stainless steels: an introduction to their metallurgy and corrosion resistance. Dairy Food Environmental Sanitary 20: 506-517.
3. Ryan MP, Williams DE, Chater RJ, Hutton BM, McPhall DS (2002) Why stainless steel corrodes in nature. Food Processing 415: 770-774.
4. Dillon CP, Rahoi DW, Tuthill AH (1992) Stainless steels for bio-processing, Part I: materials selection. Bio-pharmaceutical 5: 38-42.
5. Tverberg JC (2000) A stainless steel primer. Part I. The types of stainless steel. Flow Control 6: 30-42.
6. Dillon CP, Rahoi DW, Tuthill AH (1992) Stainless steels for bio-processing, Part III: Classes of alloys. Bio-pharmaceutical 5: 30-38
7. Dillon CP, Rahoi DW, Tuthill AH (1992) Stainless steels for bio-processing, Part II: Classes of alloys. Bio-pharmaceutical 5: 32-35.
8. Gonzalez MM (2001) Stainless steel in bio-technology tubing industry. Biotechnology/Pharmaceutical Facilities Design 7: 23-30.
9. Tuthill AH, Avery RE, Lamb S, Kobrin G (1998) Effect of chlorine on common materials in fresh water. Mater performs 37: 52-56.
10. Weeks DT, Bennett TM (2006) How to specify equipment for high-purity processes. Pharmaceutical Processing 23: 16-20.
11. Avery RE (1991) Resist chlorides retain strength and ductility with duplex stainless steel alloys. Chem Eng Prog 87: 78-82.
12. Tuthill AH, Avery RE, Covert RA (1997) Cleaning stainless steel surfaces prior to sanitary service. Dairy Food Environmental Sanitary 17: 718-725.
13. Raman RKS (2003) Interplay of microbiological corrosion and alloy microstructure in stress corrosion cracking of weldments of advanced stainless steel. Sadhana 28: 467-473.
14. Johnson MJ (1988) The beneficial effects of increasing Cr, Ni, Mo and N on the corrosion resistance of stainless steels. Bioprocess EngineeringSymposium 4: 53-58.
15. Tverberg JC (2000) A stainless steel primer. Part III. Proper selection of stainless steels. Flow Control 6: 28-36.
16. Francis FJ (2000) Wiley Encyclopedia of Food Science and Technology. (2ndedn) John Wiley and Sons, Inc, New York.
17. Tuthill AH, Brunkow R (2004) Stainless steels for bio-processing. Bio-processing 2: 46-53.
18. Dauffin G (1985) An introduction to the commercially available surface finishes of stainless steels and notes on their corrosion resistance. Bulletin- Federation International de Laiterie.
19. Tuthill AH, Avery RE (1999) Phorgotten phenomena: heat tints on stainless steels can cause corrosion problems. Mater Perform 38: 72-73.
20. Weeks DT, Bennett TM (2006) Specifying equipment for high purity fluid flow. Chem Eng 113: 27-30.
21. Tverberg JC (2000) A stainless steel primer. Part II. Corrosion mechanisms. Flow Control 6: 34-39.
22. Freemantle M (2002) Stainless steel failure explained corrosion is caused by chromium depletion around sulfide impurities. C&EN 80: 11.
23. Fontana MG (1986) Corrosion engineering. (3rdedn) McGraw- Hill, New York.
24. Borenstein SW (1994) Microbiologically influenced corrosion handbook. Industrial Press, New York.
25. Gilmore TM, Maller RR, Mills V (1998) Protecting stainless steel dairy equipment from corrosion. Dairy Food Environmental Sanitary 18: 510-514.