Corrosion of Stainless Steel with Case Studies

An Online Continuing Education Course for Engineers

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Corrosion of Stainless Steels with Case Studies

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Introduction

Stainless steels compose a small fraction of total United States steel production. However, due to their corrosion-resistant properties, stainless steels are a key component in the chemical, petroleum, process, and power industries. The technological and economic impact of stainless steels extends far beyond what would be inferred by looking at its market share.

Stainless steels are iron-based alloys containing a minimum of approximately 11% chromium. This chromium content results in the formation of a thin, protective oxide film that provides corrosion resistance in certain environments. The corrosion resistance of the stainless steel depends on the integrity and durability of the oxide film. The oxide film prevents rust in unpolluted atmospheres and gives "stainless steel" its name. If the film breaks down, localized corrosion, such as pitting, can occur. In order for this film to be effective, it must be in the passive state. The passive state exists over a range of environments, with the breadth of the range depending on the particular chemical composition and microstructure. Furthermore, the corrosion resistance of stainless steels is strongly impacted by design, fabrication, surface condition, and maintenance practices.

The presence of oxygen in the environment is essential to the stability of the oxide film. In fact, corrosion resistance is highest when stainless steels are freely exposed to a flowing environment, and the surface is free of deposits. Deposits, or covering the surface, can result in an oxygen-depleted region on the surface, leading to localized corrosion.

There are over 170 different stainless steel alloys, and each year, new grades are added. Some grades contain 30% or more chromium, and other elements are added to obtain the desired properties. For example, nickel and molybdenum are added to improve corrosion resistance, while carbon, molybdenum, titanium, aluminum, and copper are added for strength. To increase machinability, sulfur and selenium are added, while adding nickel improves formability and toughness.

Stainless steels can perform adequately for extended periods of time when the grade is appropriately selected for the environment. However, a grade that is inadequate for the environment can fail more rapidly than carbon steels via uniform corrosion. It is important to consider more than just the design conditions during the material selection process, such as anticipated process excursions or upset conditions and maintenance procedures. The selection of suitable grades can be assisted with laboratory and field testing in similar environments to the anticipated process. Once the types with the appropriate corrosion resistance are selected, issues such as fabrication and availability should be considered. Appropriate material selection is ultimately the balancing of cost with the required corrosion resistance.

Families of Stainless Steels

It is common practice to divide stainless steels into five (5) groups according to metallographic structure:

Ferritic – Body-Centered Cubic (BCC)

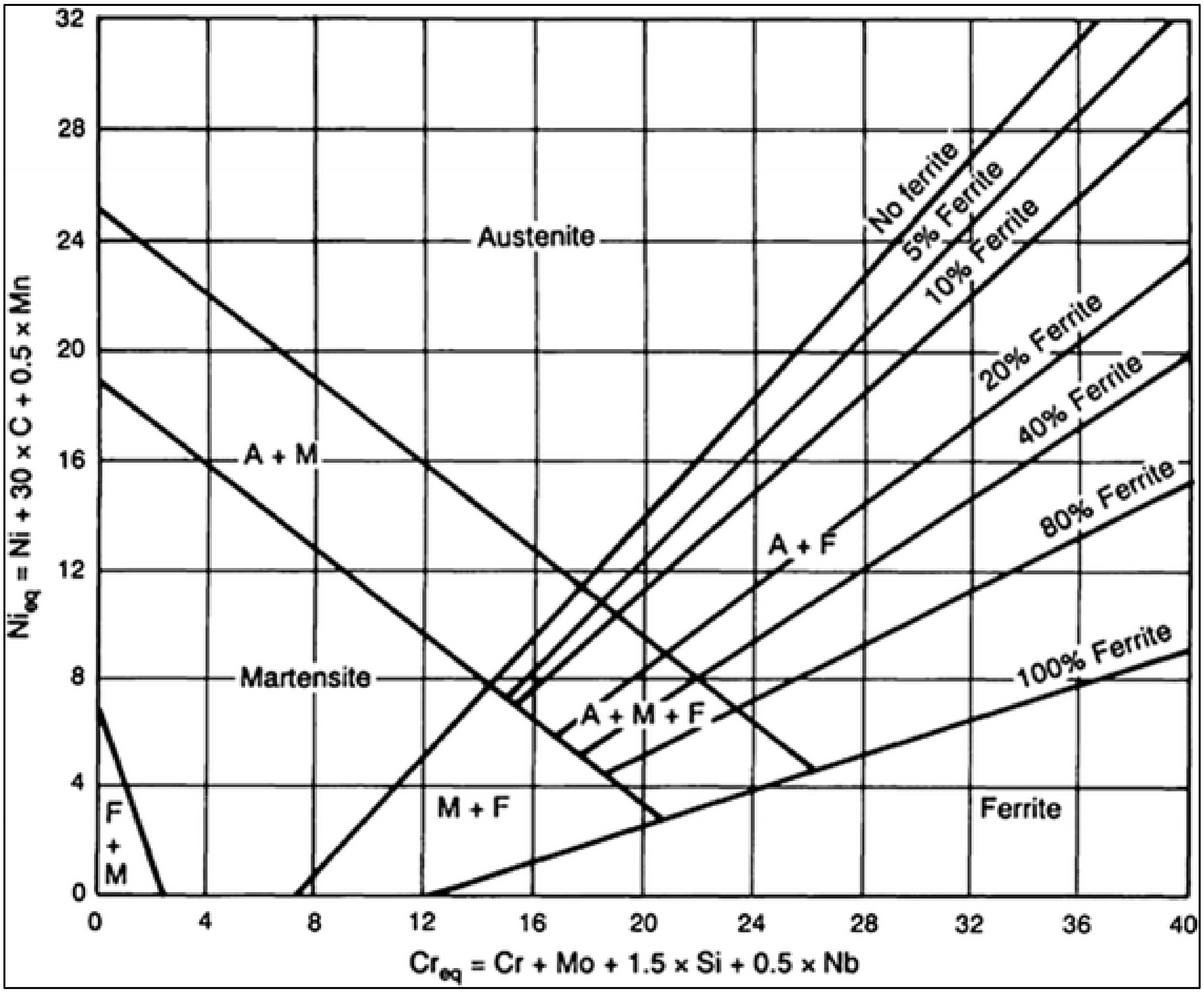
Austenitic – Face-Centered Cubic (FCC)

Martensitic – Body-Centered Tetragonal (BCT)

Duplex – Ferrite and Austenite

Precipitation Hardening – Austenite and Martensite

The Schaeffler diagram provides an approximate way to correlate chemical composition to the metallurgical structure of the alloy. The diagram was originally established to estimate delta ferrite content in the welds of austenitic steels by heating the sample to 1050 °C and rapidly cooling to room temperature. When using the diagram, the two common alloying elements, nickel and chromium (or their equivalent value), are expressed in terms of austenite and ferrite stabilizing, respectively.



Schaeffler Diagram (https://www.welderdestiny.com/dissimilar-metals-welding.html)

Each family is generally distinct in regard to mechanical properties but shares commonality in corrosion resistance/susceptibility to particular forms of corrosion. It is generally accepted that austenitic steels are the most corrosion-resistant. Ferritic stainless steels show corrosion resistance to more mild environments. Martensitic and precipitation hardening steels show adequate corrosion resistance and are used when their strength and hardness are required. It should be noted that even the most highly alloyed austenitic types are not resistant to severe environments and can be damaged due to crevice or pitting corrosion. In these environments (particularly high-temperature water, caustic, or chlorine gas service), it is recommended that nickel alloys be selected.

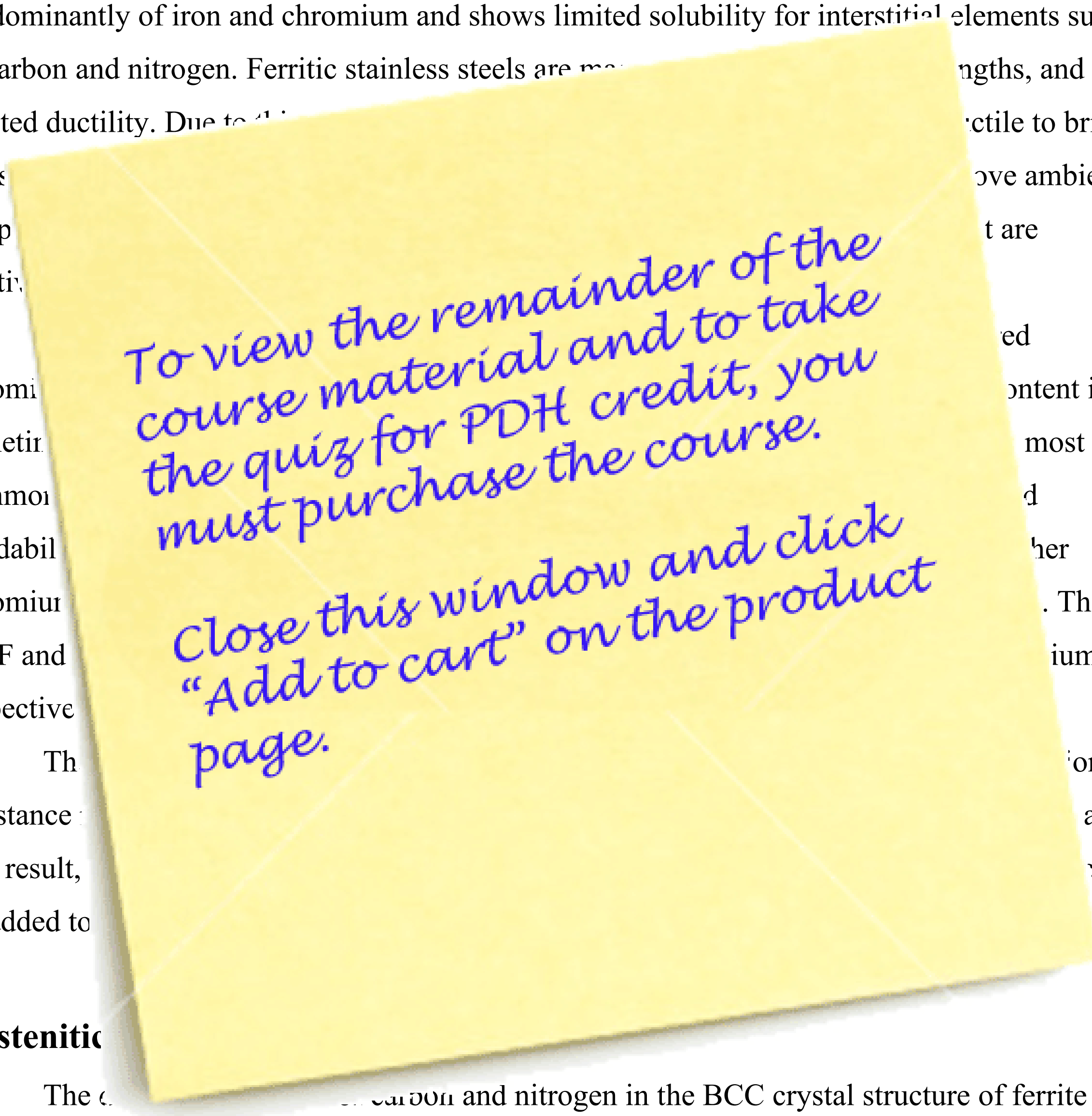
The discussion of the various stainless steel groups below is not intended to be exhaustive but is intended to be a solid overview of the characteristics of the various groups.

Ferritic Stainless Steels

Ferritic stainless steels are the simplest form of stainless steel. This type is composed predominantly of iron and chromium and shows limited solubility for interstiti... elements such as carbon and nitrogen. Ferritic stainless steels are m... ngths, and limited ductility. Due t... ctile to brittle trans... ove ambient temp... t are relati...

...ed chromi... ontent is sometir... most commoi... d weldabil... her chromiur... . The 430F and... ium, respective...

Th... ion resistance ... and, as a result, ... an be added to...



Austenitic...

The ... carbon and nitrogen in the BCC crystal structure of ferrite can be diminished by adding austenite stabilizers like nickel, manganese, and nitrogen, which results in an austenitic microstructure. Austenite is nonmagnetic with relatively low yield strength, high ductility, and good toughness. Good mechanical properties, in conjunction with its