GEC-1128
Understanding Stainless Steel

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INTRODUCTION

Stainless Steel

Many types of stainless steel are readily available as common construction material in today's world. Stainless steel is the preferred material for a multitude of applications. Stainless steel is used extensively in the chemical-process industry and the food-processing industry. The transportation and aerospace industries use stainless steel and stainless steel dominates the tool industry.

Stainless steel is used primarily in applications requiring high mechanical strength and inherent corrosion resistance. It is not surprising that it has gained wide acceptance in the utility industry. Stainless steel has major applications in power generation and is now used for power distribution equipment to provide the long life the utility industry requires. In fact, proposed ANSI C57.12.29 (Enclosure Integrity for Coastal Environments) requires the use of an inherently corrosion-resistant material equal to or better than AISI 409 stainless steel.

Despite its widespread use, many facts about stainless steel are not understood and, in some cases, this can significantly shorten its useful life. The purpose of this paper is to provide an overview on proper selection, design and fabrication of stainless steel. The paper will also attempt to answer many frequently asked questions about stainless steel.

TYPES OF STAINLESS STEEL

Stainless steel is made by adding chromium to iron. Although there are many different compositions of stainless steel, every composition must have chromium to be a stainless. There are three (3) basic families of stainless steel; the ***martensitics***, the ***ferritics*** and the ***austentics.***

Martensitic steels are tool steels. They are hardenable by heat-treating to obtain extremely high tensile strength. They are not used in corrosion-resistance applications and subsequently will not be discussed further.

The ***ferritic steel*** family is shown below, in diagram 1.

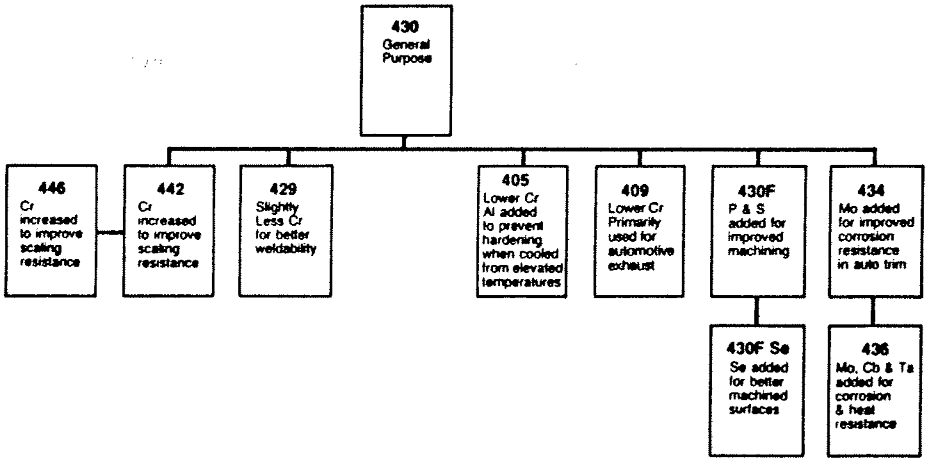

Diagram 1: The Ferritic Stainless Steel Family, from Metals Handbook, Ninth Edition, Volume 3, pg. 8, American Society of Metals.

TYPES OF STAINLESS STEEL (Cont'd)

AISI[1] type 430 is considered the general-purpose ferritic stainless steel from which all other types of ferritics have been developed. Ferritic stainless steels are commonly called the "400 series" or "straight chromium" stainless steels. The ferritic steels cannot be hardened by heat treatment and have good ductility. One of the unique characteristics of ferritics, and one which can propose a serious manufacturing concern, is that ferritic steels are magnetic. If ferritic steels are not segregated or properly identified they can easily be mistaken for carbon steel. Once painted, there is no method to distinguish ferritic stainless from carbon steel. However, unpainted ferritic stainless can be differentiated from carbon steel by a quick and simple chemical spot test. The test, useful in a manufacturing facility or in the field, is shown at right.

COPPER SULFATE TEST

One of the simplest methods for differentiating quickly between carbon or alloy steels and all types of stainless steel is a spot test using a solution with 5 to 10% copper sulfate (blue vitriol) in water.

Before running the spot test, the areas to be tested should be thoroughly cleaned of grease or any foreign substances, and a mild abrasive should be used on a small area before applying the test solution, which is dropped on the clean area from a drop bottle. Ordinary carbon steel or iron will become coated with the metallic copper in a few seconds, whereas stainless steel will show no deposit or copper color.[2]

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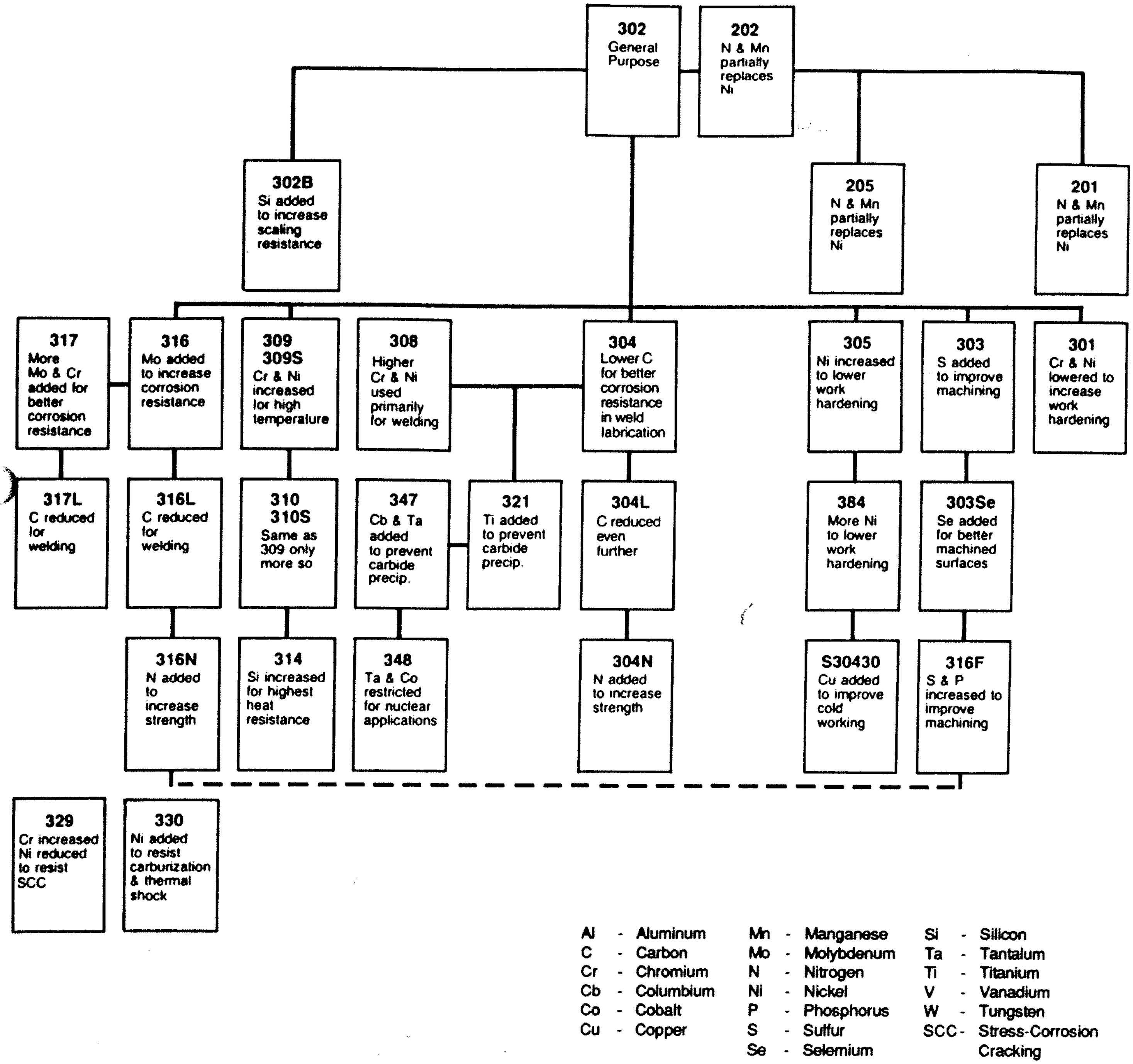
[1] American Iron and Steel Institute (AISI).

[2] Metals Handbook, Volume II, Eighth Edition, page 279, American Society of Metals.

TYPES OF STAINLESS STEEL (Cont'd)

The third family of stainless steels are the ***austentics*** (shown in diagram 2).



Al - Aluminum
C - Carbon
Cr - Chromium
Cb - Columbium
Co - Cobalt
Cu - Copper

Mn - Manganese
Mo - Molybdenum
N - Nitrogen
Ni - Nickel
P - Phosphorus
S - Sulfur
Se - Selemium

Si - Silicon
Ta - Tantalum
Ti - Titanium
V - Vanadium
W - Tungsten
SCC - Stress-Corrosion Cracking

Diagram 2: The Austenitic Stainless Steel Family, from Metals Handbook, Ninth Edition, Volume 3, page 7, American Society of Metals.

TYPES OF STAINLESS STEEL (Cont'd)

As diagram 2 reveals, the austenitic stainless steel family is more complicated than the ferritic family. Austenitic steels are often referred to as the "300 series" steels but, technically, this is not correct. The austenitic family is comprised of 300 and 200 series steels. All 300 series steels have chromium and nickel as common alloying elements. All 200 series austenitic steels contain chromium, nickel and manganese. Additional alloying agents used within the austenitic family can include molybdenum, nitrogen, silicon, columbium, and tantalum-to to name a few. Austenitic steels can be hardened by cold working but not by heat treatment. Austenitic steels are non-magnetic, making them also have good formability and making them easy to identify whether painted or not. AISI type 302 steel is considered the basic 300 series steel, whereas AISI type 202 steel is considered the basic 200 series steel. During the Korean conflict, austenitic 200 series steels came into extensive use to conserve nickel by replacement with manganese and nitrogen. They exhibit approximately 40% greater yield strength and comparable corrosion resistance as the 300 series.

CORROSION RESISTANCE

The corrosion resistance exhibited by stainless steels is attributed to a protective or "passive" film which they possess. The protective layer is chromium oxide, so it is not surprising that the degree of corrosion resistance offered by stainless steel is directly proportional to the amount of chromium it has. This is vividly shown in laboratory testing (Figure 1) as well as from actual field data (Figure 2).

Both figures show that stainless steel requires a minimum level of chromium before the protective layer builds thick enough to become effective. In severe corrosive environments, a 10% minimum chromium content is necessary to build a sufficient oxide protection layer. One of the most familiar misconceptions about stainless steels is that they do not rust or corrode. If the protective chromium oxide layer is breached, stainless steel will corrode - in certain instances at a faster rate than carbon steel. However, corrosion of stainless steel usually is not a general surface attack but a highly localized form of corrosion. The most common localized forms of stainless steel corrosion are pitting corrosion and crevice corrosion, both caused by chloride salts in aqueous solution.

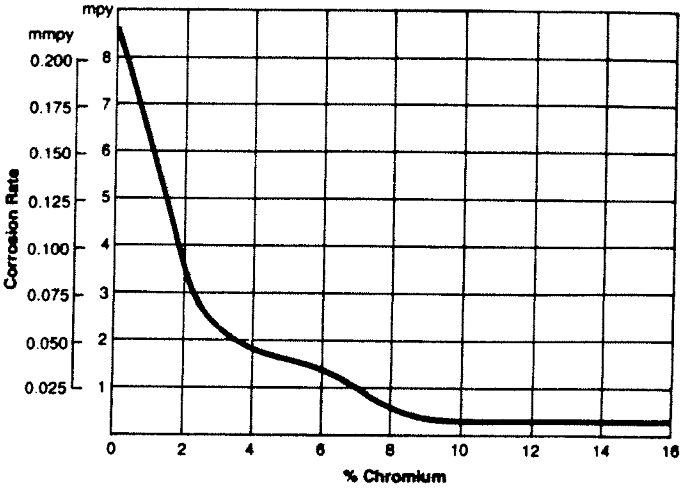


Figure 1: Corrosion Rate as Function of Chromium Content. Design Guidelines for the Selection and Use of Stainless Steel, Nickel Development Institute, 1987, page 7.

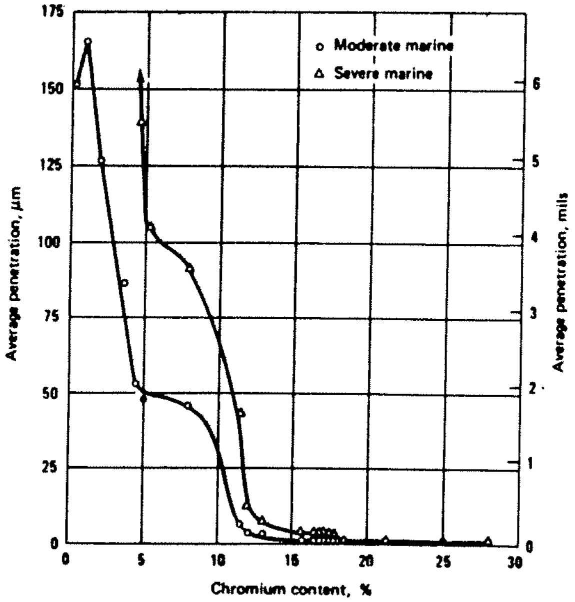


Figure 2: Chromium Content Effect on Corrosion Rate. Stainless Steel, R.A. Lula, American Society for Metals, 1988, page 133.

CORROSION RESISTANCE (Cont'd)

Chloride salts can dissolve the protective chromium oxide film to cause formation of a small, highly concentrated galvanic cell. The stainless steel can be completely perforated with no signs of corrosion adjacent to the perforation. Diagram 3 details the proposed mechanism for pitting corrosion. Diagram 4 details the proposed mechanism for crevice corrosion. Both mechanisms are remarkedly similiar.

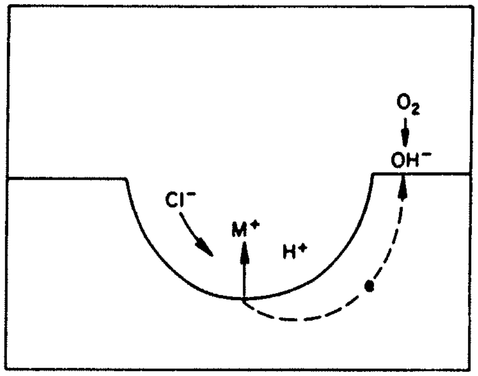


Diagram 3: Proposed Mechanism for Pitting Corrosion Attack. Corrosion Engineering, Fontana and Greene, McGraw-Hill, 1967, page 51.

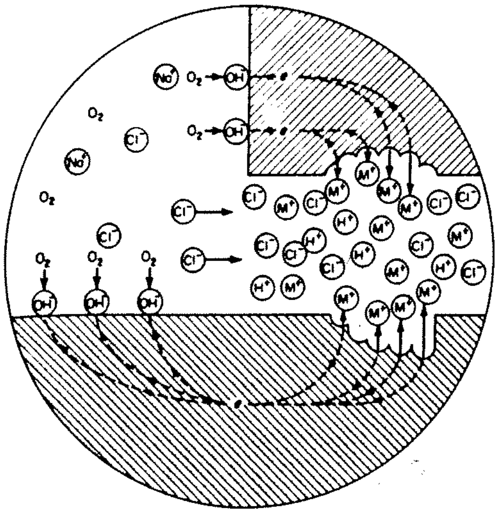


Diagram 4: Proposed Mechanism for Crevice Corrosion Attack. Corrosion Engineering, Fontana and Greene, McGraw-Hill, 1986, page 55.

Pitting corrosion can initiate wherever chloride salts can contact the steel surface. Crevice corrosion can occur wherever small amounts of water can collect and become stagnant - under gaskets, bolt heads, washers or lap joints. Since this type of corrosion is hidden in the crevice, it is usually found only when failure occurs. Stainless steel can be alloyed (see Diagram 5) to improve resistance to pitting corrosion. The best solution for crevice corrosion is not to have crevices in the design. It should surprise no one that 304 or 304L austenitic steels exhibit better corrosion resistance than 409 due to additional chromium and nickel content.

Element	Effect on pitting resistance
Chromium	Increases
Nickel	Increases
Molybdenum	Increases
Silicon	Decreases; increases when present with molybdenum
Titanium and columbium	Decreases resistance in $FeCl_3$; other mediums no effect
Sulfur and selenium	Decreases
Carbon	Decreases, especially in sensitized conditions
Nitrogen	Increases

Diagram 5: Alloy Effect on Pitting Resistance. Corrosion, Greene and Fontana, Vol. 15, 1959, pages 41-47.

CORROSION RESISTANCE - Field Experience

What is the useful life of stainless steel used in the electrical industry? Why does proposed ANSI C57.12.29 permit a 409 stainless substrate when 304/304L stainless can be expected to exhibit superior corrosion resistance? One must refer to actual long-term field test data for answers. Unfortunately, this type of date can be misleading and, at best, confusing.

Corrosion test data is usually noted as an average weight loss. Since stainless steels lose so little weight, it has been found convenient to report weight loss as thickness loss in mils per year.* Digest this data carefully, however, because stainless steels exhibit localized corrosion, not general surface corrosion. A particular sample could have pitting perforation and still exhibit very little average in thickness loss.

One should look for average thickness and pitting evaluation (number and depth) for a true understanding of how a stainless will perform. Chart 1 summarizes all actual field exposure data on 409 and 304 stainless steels that could be found within available corrosion libraries. **Much of the 409 test data was used by ANSI in developing the proposed C57.12.29 document.** All corrosion data has been converted to mils/year for comparison purposes.+

The corrosion rate data from Chart 1 (on the following page) reveals a number of important points. First of all, 304 exhibits corrosion resistance that is superior to either 409 or 430, and this is to be expected. Secondly, the corrosion rate and severity of pitting drops dramatically as distance from the shore increases. (The Kure Beach 250 meter lot is significantly less severe than the 25 meter lot). The final conclusion drawn from Chart 1 is the extraordinary corrosion resistance afforded by all the stainless steels over extremely long time periods. Remember that the specimens used in these studies were bare, not painted. None of the steels exhibited pitting attack severe enough to be of concern. Only when stainless steel is located adjacent to the shoreline or exposed to actual seawater immersion is concern warranted. Additional corrosion resistance is provided by the protective coating on the apparatus. Data from Chart 1 plus additional corrosion protection afforded by the paint system is strong support for proposed ANSI C57.12.29.

* 1 mil = .001"

\+ weight loss data reported as mils per year.
[mils per year = 534W/DAT]
where W= weight loss, mg
D = density of speciman, g/cm^3
A = area of speciman, in^2
T = exposure time, hr

Steel Type	Exposure	Location	Corrosion Rate (mils)	Pit Depth	Reference
409	16 year	Panama Canal	.01 / year	.005"	(5)
430	12 year	Bayonne, NJ	.006 / year	.007" / .008"	(6)
409	15 year	Kure Beach / 25m lot	.006 / year	----	(7)
409	10 year	Kure Beach / 250m lot	.003 / year	----	(7)
430	1 year	Pier Gulf Mexico	.02 / year	----	(7)
430	15 year	Kure Beach / 25m lot	.003 / year	----	(7)
430	26 year	Kure Beach / 25m lot	----	<.01mm / 5%	(7)
430	26 year	Kure Beach / 250m lot	----	<.01mm / .5%	(8)
304	10 year	Kure Beach / 25m lot	.001 / year	----	(7)
304	10 year	Kure Beach / 250m lot	<.0001 / year	----	(7)
304	8 year	Caplen, TX / 400m lot	<.001 / year	----	(7)
304	1 year	Pier Gulf Mexico	.003 / year	----	(7)
304	26 year	Kure Beach / 25m lot	----	<.01mm / 5%	(8)
304	26 year	Kure Beach / 250m lot	----	<.01mm / .1%	(8)
304	12 year	Bayonne, NJ	.012 / year	.006" / .007"	(6)
304	15 year	Kure Beach / 250m lot	<.001 / year	.0012"	(9)

Chart 1: **Corrosion Rate Comparison for 409 and 304 Stainless Steel** (Many references to 430 stainless are found. Although both 409 and 430 are ferritic, 430 can be expected to exhibit better corrosion resistance due to a higher chromium content).

5 Volume 13 - Corrosion, page 915, Metals Handbook, Ninth Edition, 1988, published by American Society of Metals.

6 Volume 3 - Porperties and Selections: Stainless Steels, page 67, Metals Handbook, Ninth Edition, 1988, published by American Society of Metals.

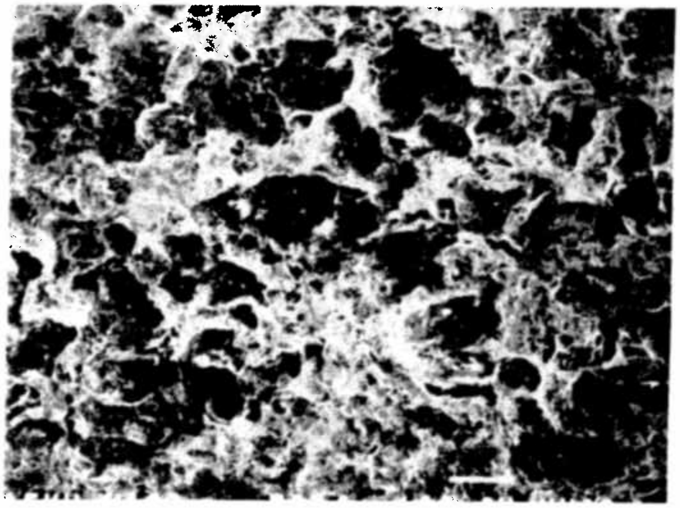
7 Internal Correspondence, 10-12-88, Armco test data.

8 **Degradation of Metals in the Atmosphere,** "Long Term Atmospheric Corrosion Behavior of Various Grades of Stainless Steel", Baker and Lee, pages 52-67, ASTM STP 965.

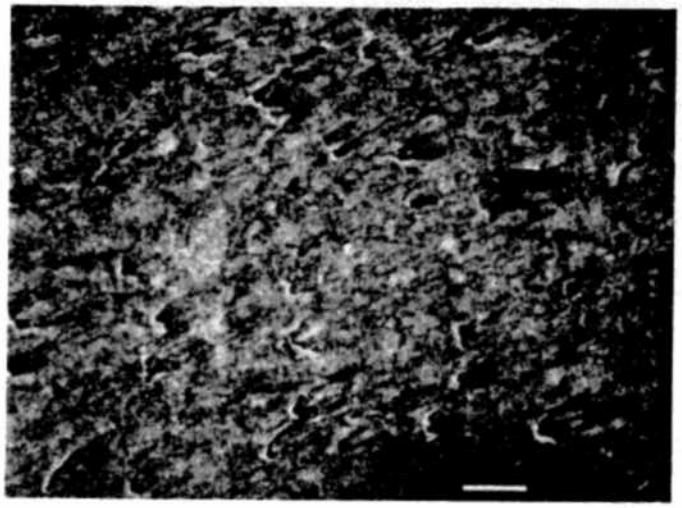
9 Atmospheric Corrosion, A.H. Ailor, Ed. 1982, Wiley and Sons.

PAINTING STAINLESS STEEL

In many situations, the painting of stainless steel has only been an aesthetic function. However, if the stainless steel is located in close proximity to chloride salts, i.e. seawater, the paint system will provide enhanced corrosion resistance by protecting the stainless steel from chloride attack. Paint can also "seal" extremely thin crevices, thereby eliminating this mode of corrosive attack. For a coating system to provide this protection, it must adhere or bond tightly to the stainless steel surface. How does a coating bond to a metal surface? In a typical carbon steel pretreatment system, a layer of iron phosphate or zinc phosphate is chemically formed on the steel surface. The phosphate layer is chemically bonded to the metal, but also forms a chemical bond to the paint. Carbon steel phosphate pretreatment, however, is totally ineffective on stainless steel. Stainless steel does not react with carbon steel pretreatment chemicals to form the phosphate layer; therefore, there is no paint adhesion promotion. Paint adhesion on stainless steel requires a mechanical bond. The mechanical bond is most often accomplished by acid etch or abrasive blasting the stainless surface to create numerous valleys and ravines for the paint to fill and lock into. The effect of abrasive surface roughening of carbon steel is vividly shown in Photomicrographs 1 and 2. Abrasive blasting is a unique science and requires special considerations in order to assure that the coating will anchor into the surface profile. Abrasive media is available as shot or grit. Shot is spherical in shape and intended to "hammer" or peen the metal surface clean.



Photomicrograph 1: Carbon steel surface "as received" from manufacturer (x100 - scanning electron microscope).



Photomicrograph 2: Carbon steel surface after abrasive blast pretreatment (x100 - scanning electron microscope).

The energy of the heavy shot particle imparts sufficient kinetic energy to the surface to dislodge heavy brittle surface contamination such as mill scale. On the other hand, shot is not a very efficient cleaning media and alone usually does not provide an adequate surface profile. Grit media is irregular or semisharp in shape and creates more of a cutting action on the surface. Most operations utilizing abrasive blast use a mix of grit and shot for optimum surface preparation. Figure 3 is the resultant surface of steel using grit abrasive to achieve a .002" valley to peak profile. Figure 4 is the profile of steel using shot abrasive to achieve the same .002" valley to peak profile. Grit provides a "rougher" anchor pattern.

The hardness of abrasive media is important. One of the most important parameters in using abrasive blasting is the surface profile, expressed in mils (.001") or micro-inches (min). If surface roughness is insufficient, the coating will not adhere to the metal. If the roughness is too large, the coating will not adequately cover the peaks to provide corrosion protection. As a rule of thumb, surface profile should be approximately 25% of the coating thickness, but should never exceed the primer thickness.

The type of abrasive media is also extremely critical. Abrasive media should be sand, glass, stainless shot/grit or aluminum oxide. These media, if lodged on the stainless steel surface, do not cause a localized galvanic cell. Never never use steel grit/shot which will cause localized galvanic cells wherever the media becomes lodged.

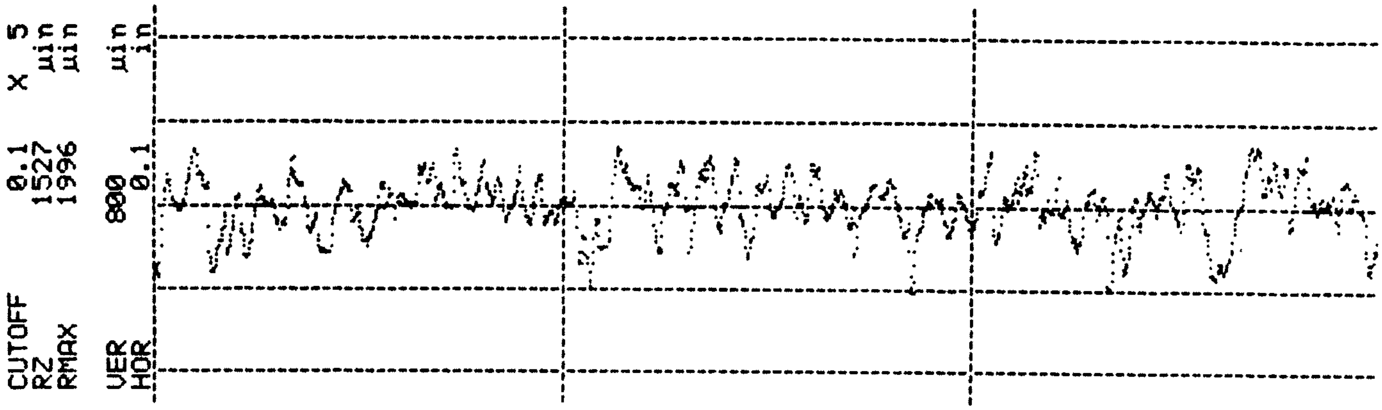


Figure 3: Steel surface exhibiting .002" valley-to-peak roughness using grit abrasive.

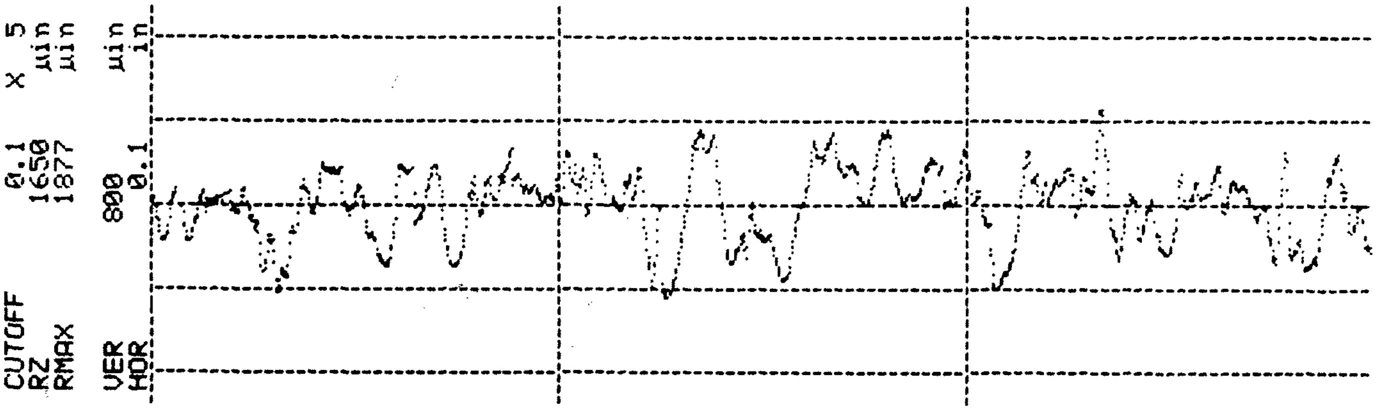
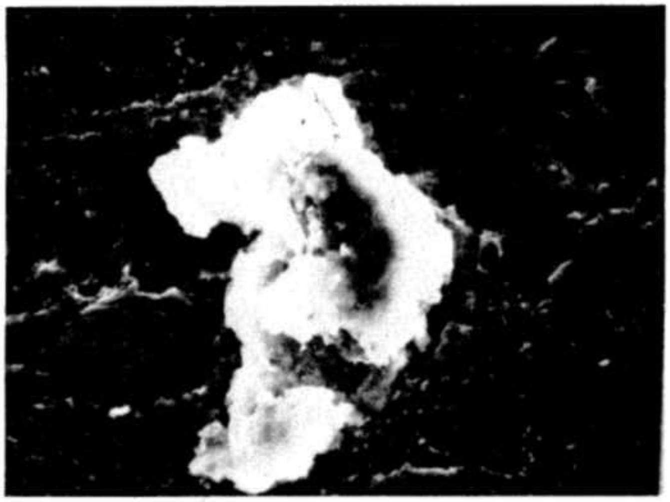


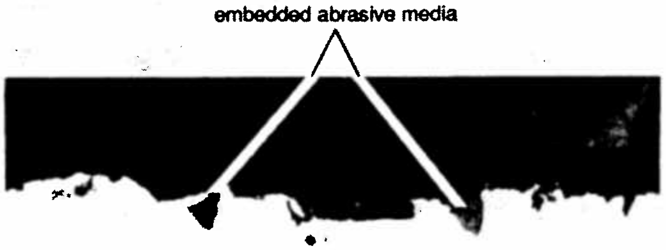
Figure 4: Steel surface exhibiting .002" valley-to-peak roughness using shot abrasive.

PAINTING STAINLESS STEEL (Con't)

Photomicrograph 3 shows a carbon steel particle anchored into a piece of 409 stainless steel. Photograph 4 reveals what affect any lodged steel grit/shot media can have on salt spray corrosion resistance of 409 stainless steel. After 1,000 hours exposure, the result is catastrophic localized corrosion perforation through the substrate. Most abrasive problems with stainless steel can be traced back to the use of media that has been contaminated with carbon steel. The same considerations apply to any coating repair on stainless steel apparatus in the field. Many repair crews use the same sandpaper, grinding disks or wire brushes on stainless steel that are used on carbon steel apparatus. The result is more harm to the stainless steel than benefit from the paint. Equipment used on carbon steel surfaces must not be used on stainless steel. Keep equipment used on both steels properly segregated to prevent problems.



Photomicrograph 3: Steel shot particles lodged into the stainless steel surface (x100 - scanning electron microscope).



Photomicrograph 4: Cross-section of abrasive blasted metal showing embedded balst media (x200).

Photograph 1: 409 stainless steel test panel with steel abrasive treatment after 1,000 hours salt spray exposure.

GALVANIC CONCERNS

In the last few years, many utilities have requested "multi-metal" apparatus in an attempt to solve corrosion problems at less cost. Certain corrosion-susceptible components are specified to be stainless steel while all remaining parts are carbon steel. Blindly substituting stainless steel for carbon steel can result in accelerated corrosion on the carbon steel components due to galvanic attack. Carbon steel and stainless steels (passive) are widely separated from one another in the galvanic series, indicating that there is a strong possibility for galvanic corrosion to occur (see Diagram 5). The galvanic series also predicts that the carbon steel component will be preferentially attacked because it is the anodic or the active metal. If an electrolyte such as seawater, acid rain or stagnant water is available to complete the electrical circuit between the carbon and stainless steel members, galvanic corrosion will occur. The aggresiveness of the galvanic corrosion attack depends on the contact area ratio between the two metals. The worse-case senario exists where a large stainless steel area would contact a localized area on the carbon steel. In this situation, a 17x acceleration of the corrosion process could be expected. The best engineering approach for the utility, especially in marine and/or wet climates, is to specify only 100% use of stainless steel to eliminate any change of galvanic corrosion. A more detailed review of galvanic corrosion is discussed in the General Electric technical paper entitled **"Mixing Metals - Solution or Problem?"**

↑ Noble or cathodic

Platinum
Gold
Graphite
Titanium
Silver
[Chlorimet 3 (62 ni, 18 cr, 18 Mo)
  Hastelloy C (62 Ni, 17 Cr, 15 Mo)]
[18-8 Mo stainless steel (passive)
  18-8 stainless steel (passive)
  Chromium stainless steel 11-30% Cr (passive)]
[Inconel (passive) (80 Ni, 13 Cr, 7 Fe)
  Nickel (passive)]
Silver solder
[Monel (70 Ni, 30 Cu)
  Cupronickels (60-90 Cu, 40-10 Ni)
  Bronzes (Cu-Sn)
  Copper
  Brasses (Cu-Zn)]
[Chlorimet 2 (66 Ni, 32 Mo, 1 Fe)
  Hastelloy B (60 Ni, 30 Mo, 6 Fe, 1 Mn)]
[Inconel (active)
  Nickel (active)]
Tin
Lead
Lead-tin solders
[18-8 Mo stainless steel (active)
  18-8 stainless steel (active)]
Ni-Resist (high Ni cast iron)
Chromium stainless steel, 13% Cr (active)
[Cast iron
  Steel or iron]
2024 aluminum (4.5 Cu, 1.5 Mg, 0.6 Mn)
Cadmium
Commercially pure aluminum (1100)
Zinc
Mangesium and magnesium alloys

Active or anodic ↓

Diagram 5: **Galvanic Series of Commercial Metals and Alloys in Seawater,** Corrosion Engineering, Fontana, McGraw-Hill, 1986, page 43.

WELDING STAINLESS STEELS

Stainless steels have been in use for such a long time that they should not be considered problem metals to fabricate. One of the most misunderstood fabrication issue of stainless steel is welding. To properly weld stainless steel requires knowledge of the basic metallurgy of stainless steel during the weld operation. The ferritics (400 series) and the austenitics (300 series) stainless steel families react somewhat similarly during welding. When welding is in progress and the metal is in the liquid state, chromium molecules preferrably migrate to join with adjacent carbon molecules to form chromium carbide. Chromium carbide has no inherent corrosion resistance and the end result is a phenomenon known as chromium depletion, which makes the weld area low in chromium content with little if any corrosion resistant properties. The important thing to know about chromium depletion is that it is well understood and can be prevented by three methods. In one approach, the 300 series stainless steel is heat-treated to "re-dissolve" the chromium carbide back into the original carbon and chromium components. This is followed by a very carefully controlled cool-down to prevent chromium carbide from redeveloping. This is not a viable approach after a transformer product has been fabricated. In the second approach, 300 stainless steel is alloyed with columbium or titanium. These metals are known as stabilizers. When the weld operation is in progress, carbon preferentially combines with these metals rather than chromium, thereby eliminating the formation of chromium carbide. The chromium is left intact to provide corrosion-resistance. The third and final approach specifies a low carbon-content steel. Low carbon-content steels are indicated by an "L" designation after the AISI numerical designation. Typical 300 series stainless steel has a nominal carbon content of .08%. Low carbon content 300 series stainless steel will have a maximum carbon content of .03%. The extraordinarily low carbon content prevents the formation of chromium carbide because there is not enough carbon for the reaction to preceed. The second and third approaches are both acceptable options within the electrical industry, but the use of "L" grade 300 series steels dominates.

There is a misconception that weld performance problems are limited to the austenitic 300 series stainless steels. The 400 ferritic stainless series are also prone to premature weld corrosion attack, but for a different reason. The 400 series stainless steels are extremely heat sensitive during the welding process. Rapid cooling of the metal above 925°C (1700°F) causes formation of a different structure that does not exhibit resistance to corrosive attack.

The most common fabrication/repair error when welding stainless steels is the use of incorrect weld wire. This error can cause insufficient chromium content to provide corrosion reisistance. In addition, incorrect weld chemistry can initiate a galvanic cell with adjacent metal. Diagram 6 provides recommended weld wire chemistry when welding various types of stainless steel.

Base metal	Condition of weldment for service (a)	Electrode or welding rod (b)	Notes
Austenitic stainless steels			
301, 302, 304, 305, 308	1 or 2	308	(c)
302B	1	309	(d)
304L	1 or 4	347, 308L	•••
303, 303(Se)	1 or 2	312	(e)
309, 309S	1	309	•••
310, 310S	1	310	•••
316	1 or 2	316	(f)
316L	1 or 4	318, 316L	(f)
317	1 or 2	317	(f)
317L	1 or 4	317(Cb)	(f)
318 [316(Cb)]	1 or 5	318	(f)
321	1 or 5	347	(g)
347	1 or 5	347	(h)
348	1 or 5	347	(j)
Martensitic stainless steels			
403, 410, 416, 416(Se)	2 or 3	410	(k)
403, 410	1	308, 309, 310	(m)
416, 416(Se)	1	308, 309, 312	(m)
420	2 or 3	420	(n)
431	2 or 3	410	(n)
431	1	308, 309, 310	(p)
Ferritic stainless steels			
405	2	405(Cb), 430	(q)
405, 430	1	308, 309, 310	(m)
430F, 430F(Se)	1	308, 309, 312	(m)
430, 430F, 430F(Se)	2	430	(r)
446	2	446	•••
446	1	308, 309, 310	(s)

Source - Welding Characteristics of Stainless Steels, by George E. Linnert: *Metals Engineering Quarterly*, Nov 1967.

(a) 1, as welded; 2, annealed; 3, hardened and stress relieved; 4, stress relieved; 5, stabilized and stress relieved. (b) Prefix E or ER omitted. (c) Type 308 weld metal also referred to as 18-8 and 19-9 compositions. Actual weld requirements are 0.08% max C, 19.0% min Cr and 9.0% min Ni., (d) Type 310 (1.50% max Si) may be used as filler metal, but pickup of silicon from the base metal may result in hot cracking of the weld metal. (e) Free-machining base metal increases the probability of hot cracking of the weld metal. Type 312 filler metal provides weld deposits that contain large amounts of ferrite to prevent hot cracking. (f) Welds made with types 316, 316L, 317(Cb) electrodes or welding rods may occasionally display poor corrosion resistance in the as-welded condition. In such instances, corrosion resistance of the weld metal may restored by the following heat treatments: for types 316 and 317 base metal, full anneal at 1065 to 1120°C (1950 to 2050°F); for types 316L and 317L base metal, 870°C (1600°F) stress relief; for type 318 base metal, 870 to 900°C (1600 to 1650°F) stabilizing treatment. Where postweld heat treatment is not possible, other filler metals may be specially selected to meet the requirement of the application for corrosion resistance. (g) Type 321 covered electrodes are not regularly manufactured, because titanium is not readily recovered during deposition. (h) Caution is needed in welding thick sections, because of cracking problems in heat-affected zones. (j) In base metal and weld metal, for nuclear service, tantalum is restricted to 0.10% max, and cobalt to 0.20% max. (k) Annealing softens and imparts ductility to heat-affected zones and weld metal. Weld metal responds to heat treatment in a manner similar to the base metal. (m) These austenitic weld metals are soft and ductile in the as-welded condition, but heat-affected zones have limited ductility. (n) Requires careful preheating and postweld heat treatment to avoid cracking. (p) Requires careful preheating. Service in as-welded condition requires consideration of hardened heat-affected zones. (q) Annealing increases ductility of heat-affected zones and weld metal. Type 405(Cb) weld metal contains niobium (columbium) rather than aluminum, to reduce hardening. (r) Annealing is employed to increase ductility of the welded joint. (s) Type 308 filler metal will not display scaling resistance equal to that of the base metal. Consideration must be given to differences in the coefficients of thermal expansion of the base metal and the weld metal.

Diagram 6: **Weld Metals for Joining Stainless Steel,** from Metals Handbook, Ninth Edition, Volume 3, page 49, American Society of Metals.

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