Passivation of Stainless Steels

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The surface finishing of Stainless Steels is the focus of much discussion both locally (Australia) and Internationally. This paper describes a range of techniques developed and used commercially by the author over the last 5 years.
The Selective Abstraction Process (SAP), is a technique that provides unique opportunities for the enhancement of chromium steel corrosion resistance. SAP is compared to the relative effectiveness of various traditional and chelant (citric acid) techniques presently used. Central to SAP is its uniqueness as being; a non-dangerous good (all volumes), environmentally friendly, and nil OH & S risk for owners/operators. Particular attention is drawn to the interactive nature of passivation chemistry in conjunction with EMF dynamics of alloyed systems, and subsequent REDOX demands of the alloy/liquid and alloy/atmosphere interfaces.

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Occam's Razor

"...... entities are not to be multiplied-without necessity."

William of Occam, (circa 1285 - 1349'?)

Introduction

The purpose of this paper is to provide a description of the processes occurring at, on, and near, the surface of Stainless Steel.

While aspects of the surface chemistry of stainless steel are complex in nature, all the stainless steel alloys obey the fundamental chemical/physical laws in the same way. Whether the alloy of interest is martensitic, ferritic of austenitic the key chemical reactions affecting the surface are the same.

The following document outlines these laws, describes their implications, and provides a guide to their application.

Components of the Alloy in general

Stainless Steels and their composition are well documented. To gain an understanding of how stainless steels interact with their environment it is necessary to fully understand the interaction of the comprising elements with other elements or compounds by understanding their fundamental structure.

The electronic configuration of an element defines how it will interact with its environment. While it is not intended that electronic configuration be studied in absolute detail, as it is a complex and diverse field of study. It is intended that sufficient knowledge is gained by the reader to enable, he or she, to understand the nature of the stainless alloy, and its likely interaction in a given situation.

The elements of interest are Chromium (Cr), Iron (Fe), Molybdenum (Mo), Nickel (Ni), Niobium (Nb) and Titanium (Ti).

These elements are known chemically as d-block transition metals.

Transition elements share many chemical/physical properties. They are all metals, good conductors of heat and electricity, ductile and form alloys with other metals. The melting and boiling points of these metals are generally high as are their densities.

These physical properties are the result of a balance between increased nuclear charge and large numbers of electrons packed into shells in such a manner that the element of interest is able to easily attract and shed electrons. Hence rapid changes in element oxidation states are possible. Electron movement results in reaction chemistry that is very specific.

Elements by Atomic Number

Most people are familiar with the shape of the periodic table, few realize that their is a specific structure to this table.

The structure of the table reflects the organization of elements based on electron configuration and hence chemical reaction similarities may be seen from elements of similar electron configuration as chemical reactions involve the movement of electrons.

Every element has its electrons arranged in shells. These shells "stack' electrons in such a way that the electrons occupy a minimum energy state.

There are four types of shells that electrons can be 'stacked' in; s, p, d & f. These shells may "stack"; 2, 6, 10 or 18 electrons respectively.

There may be several of each shell type present in the electron structure of any given element. These shells fill in the following order:

1s, 2s, 2p, 3s, 3p, 4s, 3d, 4p, 5s, 4d, 5p, 6s, 4f, 5d, 6p, 7s, 5f, 6d ……..

In this way the electrons are structured to give minimum energy orbits around the atom.

For our work the only electron shells of interest are those relating to the outer most shells of the atom. This is because it is these shells that define the elements, or compounds, reactive properties.

Table 1, below lists the elements of specific interest along with their outer shell electron configurations (EC).

Table 1 - Physical Element Characteristics[1 &2]

E	Z	EC.	r									Bond length		EN
			-2	-1	0	+1	+2	+3	+4	+5	+6	α form	β form	
d-block Transition Metals														
Ti	22	$3d^24s^2$	-	-	145	-	94	76	68	-	-	289.6	286.4	1.5
Cr	24	$3d^54s^1$	-	-	125	-	89	63	-	-	52	249.8	-	1.6
Fe	26	$3d^64s^2$	-	-	124	-	74	64	-	-	-	248.2	257.8[3]	1.8
Ni	28	$3d^84s^2$	-	-	125	-	69	-	-	-	-	249.2	-	1.9
Nb	41	$4d^35s^2$	-	-	143	-	-	-	-	69	-	285.8	-	1.6
Mo	42	$4d^55s^1$	-	-	136	-	-	-	70	-	62	272.5	-	2.2
s-block														
H	1	1s1	-	-	-	37	-	-	-	-	-	74.6	-	2.1
p-block														
O	8	$2p^4$	140	-	-	-	-	-	-	-	-	148	-	3.5
S	16	$3p^4$	184	-	-	-	219	-	37	-	30	205	-	2.6
F	**9**	$2p^5$	-	**133**	-	-	-	-	-	-	-	**141.7**	-	**4.0**
Cl	**17**	$3p^5$	-	**181**	-	-	-	-	-	**34**	-	**198.8**	-	**3.6**
Br	**35**	$4p^5$	-	**195**	-	-	-	-	-	**47**	-	**229**	-	**3.3**
I	**53**	$5p^5$	-	**220**	**133**	-	-	-	-	**62**	-	**266.2**	-	**2.5**
Ar	18	$3p^6$	-	154	-	-	-	-	-	-	-	-	-	-

A = Element, Z = atomic number, EC = electron configuration, r = radius of species of oxidation state -/+n, EN = electro-negativity.

The *d*-block

This group of elements has a *d* & *s* shell as there outer shells. The *d* shell will hold a maximum of 10 electrons and the *s* shell 2 electrons.

Electrons spin and so may be arranged in the shell so that they spin in one of two directions. As a result the electrons will attempt to arrange themselves, if possible, so that spins are parallel (minimum energy). In addition the electrons arrange themselves across the two outer shells. A classic example of this cross shell arrangement may be seen within the outer shell structure of the Chromium atom.

Chromium has the outer shell configuration $3d^54s'$. That is it has 5 unpaired, parallel spinning electrons in the d shell and 1 electron in the s shell. The reason is that this arrangement is a lower energy arrangement than if the s electron were placed in the *d* shell where it would need to spin counter to the *d* electrons. Similarly a higher energy state is reached if 1 *d* electron were to try and spin counter to the s electron.

If we look at the next element up, Manganese, we see an outer shell configuration of $3d^54s^2$. That is, 5 unpaired electrons in the d shell and 1 pair of counter spinning electrons in the s shell. It takes less energy to drop the additional electron into the *s* shell and spin counter to one electron than it does to get the electron to spin counter to 5 electrons in the d shell.

However this is the last time such an option is available, and the next 5 electrons must go into the *d* shell.

The transition elements may lose or gain electrons through chemical reaction based on the stability of the resultant electronic configuration.

The *s*-block

These elements lose electrons relatively easily due to the relatively low attractive force the atomic nucleus exerts on the outer *s* shell. As a result they tend to be powerful reducing agents as they are good source of electrons, hence the prevalence of Calcium(Ca) and Magnesium (Mg) in blast furnace slag.

The *p*-block

Although the 5 elements in any group may have many common properties, the following should be kept in mind:

1. There is a marked difference in the properties of the first element in the group to the others.

2. The middle three elements display smoothly changing properties to those of the heaviest element, the lowest oxidation state becomes progressively more stable.

3. The heaviest element will exhibit stable oxidation states lower than the group state and has the most metallic nature.

The Halides, (F, Cl, Br, 1, At), represent a group of p-block elements all with **xp**^{5} configuration. If we refer to Table 1 we see that Fluorine has a considerably smaller ionic radius, and subsequently bond length, as well as a significantly higher EN than Chlorine. In fact it is its very small size that makes Fluorine so electro-negative. (This is why it is so reactive as the acid HF)

The EN of a particular atom is a function of the ionic radius and the oxidation state of that atom. If we compare the relative EN's of the halides with that of O^{2-} we see the following relationships appear:

Ionic Bonds

Each ion in an ionic compound is surrounded by oppositely charged ions. The co-ordinate geometry of these ions is a function of the ratio r+/r-. This ratio is the limiting value for preventing the anions touching and can be obtained from trigonometrical calculation.

The radius ratio for Na^+/Cl^- is 0.52. This corresponds to a co-ordinate number of 6, giving an octahedral structure. That is each ion will have 6 oppositely charged ions oriented around it.

Covalent Bonds

A covalent bond is formed when there is a mutual sharing of a pair of electrons between two atoms. The axial sharing of electrons constitutes the bond and the shared pair of electrons may be seen as contributing to the stable electronic configuration of the atoms in question.

A fundamental example of such a bond is that of the electron arrangement in the water molecule.

In the case of water 2 Hydrogen (1 s^1) atoms and 1 Oxygen ($1s^2$ $2s^2$ $2p^4$) atom are bound together.

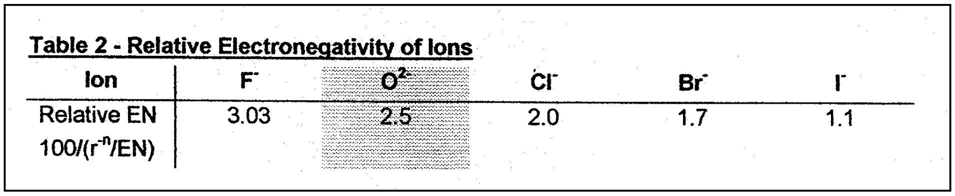


Table 2 - Relative Electronegativity of Ions

Ion	F^-	O^{2-}	Cl^-	Br^-	I^-
Relative EN $100/(r^{-n}/EN)$	3.03	2.5	2.0	1.7	1.1

The magnitude of difference in relative EN between F- and Cl- is substantial, however the table also shows that 0^{2-} is also highly EN.

From observation we know that the acid halides are highly corrosive. The oxide ion, 0^{2-}, is considerably less stable than the halides and is generally present as either the hydroxide, OH^-, or as the peroxide, H_2O_2.

Electro-negativity and the Chemical Bond

Electro-negativity is defined as the power of an atom to attract electrons to itself when combined with a compound. Small atoms are the most electronegative.

The Hydrogen atoms each require 1 electron to fill the outer shell and form the stable Helium (Is) configuration, the Oxygen atom requires 2 electrons to form the stable Neon ($1s^2$ $2s^2$ $2p^6$) configuration.

Where covalent bonds involve one pair of shared electrons they may be referred to as σ (sigma) bonds. In some cases they involve two or more pairs of shared electrons and these additional pairs are known as π (pi) bonds.

Metallic Bonds

Put simply metallic bonding is a de-localized sharing of σ (sigma) electrons. Since the number of outer, or valence, electrons in metals is small it is impossible to form individual σ bonds from one atom to all its neighbors, hence all the valence electrons of the atoms crystal lattice are shared (de-localized) throughout the structure.

These electrons are therefore highly mobile, accounting for the high electrical and thermal conductance in metals.

While metallic bonds are relatively strong, the de-localized electrons are able to be abstracted from the structure more readily than is the case in either ionic or covalent bonds. As a result transition metals will tend to form more stable compounds where they are able to bind ionically or covalently.

A classic example of such a shift is 'rust' formation, oxidation. The overall chemical reaction may be described as follows:

$$\mathbf{2Fe + 2H_20 + 0_2 \Rightarrow 2Fe(OH)_2}$$

The Iron (II) Hydroxide is unstable in aerated solution and is further oxidized to give:

$$\mathbf{2Fe(OH)_2 + 0_2 \Rightarrow Fe_20_3.H_20 + 20H^-}$$

Overall there is an oxidation shift from $Fe_{(s)}$ ($3d^6$ $4s^1$) to Fe^{3+} ($3d^4 4s^1$). Each Iron atom now requires three electrons which are donated stoichiometrically via the negatively charged Oxygen, 0^{2-}, ion.

Thermodynamics and Corrosion

So far we have considered atomic structure and bond types. And, while it is true that we can already see a picture emerging of transition metal chemistry it is far from complete.

To understand corrosion completely requires an understanding of Thermodynamics.

Thermodynamics is the study of energy changes within chemical reactions, as it is energy that drives all chemical changes.

From observation we know that energy in any system attempts to reduce to a minimum. Hence for a reaction to be spontaneous a decrease in total energy must occur between the reactants and products of the reaction.

The 2nd Law

The Gibbs-Heimholtz (2nd law) equation relates enthalpy change, ΔH, and entropy change ΔS by the equation:

$$\mathbf{\Delta G = \Delta H - T\Delta S}$$

Expressed more completely:

$$\mathbf{\Delta G^{\varnothing}_{\mathit{T}} = \Delta H^{\varnothing}_{\mathit{T}} - T\Delta S^{\varnothing}_{\mathit{T}}}$$

Reactions tend to go in the direction that results in an energy decrease:

a) if ΔG is negative a reaction is feasible;

b) if ΔG is positive a reaction is not feasible;

c) if ΔG is zero an equilibrium mixture is obtained, both the forward and reverse reactions occur.

ΔG is very much temperature dependent.

However, ΔG is also dependent on reaction equilibrium as reaction equilibrium gives an indication of reaction rate for the process. From the perspective of corrosion this is of absolute importance.

This equation is a form of the van't Hoff isotherm

$$\mathbf{\Delta G = \Delta G^{\varnothing}H - \mathit{RT}\ln((\alpha^{c}_{C}\alpha^{d}_{D})/(\alpha^{a}_{A}\alpha^{b}_{B}))}$$

This equation my be used to directly express the equilibrium constant, as at equilibrium $\Delta G = 0$ and $((\alpha^{c}_{C}\alpha^{d}_{D})/(\alpha^{a}_{A}\alpha^{b}_{B})) = K$ (the equilibrium constant).

Therefore:

$$\mathbf{\ln Kp = \Delta G^{\varnothing}H / \mathit{RT}}$$

The above equations are used in the calculation of smelting, and/or heat treatment conditions of metals to ensure reducing conditions are maximized.

Ellingham Diagrams

The feasibility of any reaction may be gauged by determining $\Delta G^{\varnothing}$ for the reaction and K (which must be reasonably large).

The feasibility is best studied using free energy-temperature diagrams, otherwise known as Ellingham diagrams. These diagrams have the great advantage of conveying visually information that from a calculation perspective is complex. The graph is constructed from the equation

$$\mathbf{\Delta G^{\varnothing}_{\mathit{T}} = \Delta H^{\varnothing}_{\mathit{T}} - T\Delta S^{\varnothing}_{\mathit{T}}}$$

The equation is of the form $y = mx + c$, a straight line. When $\Delta G^{\varnothing}$ is plotted against T the slope of the line is $- \Delta S^{\varnothing}$, the intercept on the y-axis is $= \Delta H^{\varnothing}$

A reaction, at a particular temperature, is considered feasible so long as the $\Delta G^{\varnothing}$ is negative. Curves may have a negative or positive gradient.

A negative gradient indicates that the $\Delta S^{\varnothing}$ is positive and an increase in system entropy has occurred, that is the system has moved to a lower energy state. An Exothermic reaction.

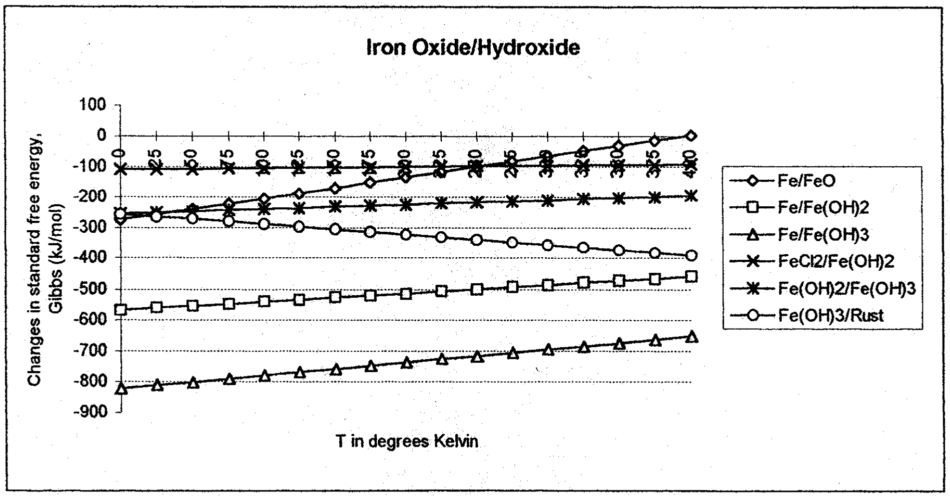
A positive gradient indicates that the $\Delta S^{\varnothing}$ is negative and a decrease in system entropy has occurred, that is the system has moved to a higher energy state. An Endothermic reaction.

The following charts describe the reaction feasibility for Iron, Nickel and Chromium, with various reactants. For simplicity the curves are based on elemental, uni-molar conditions.

The more negative the standard free energy, $\Delta G^{\varnothing}$, of a chemical reaction is the more likely it is to occur. The extent and rate of a reaction may also be calculated to obtain an absolute figure should that be required. From the perspective of this work the relative nature of free energy changes is sufficient.

Of fundamental importance when reading these diagrams is the fact that an element can reduce the oxide of any element appearing above it at a given temperature. In doing this, the element itself is oxidized.

Figure 1 : Iron $\Delta G^{\varnothing}$ - *T* diagram



The chemical reactions that drive the corrosion process, displayed in Figure 1, exhibit very high changes in ΔG, and in addition the $Fe(OH)_3/Fe_2O_3.nH_20$(Rust) reaction has a negative slope indicating that the reaction occurring is producing a net increase in entropy, that is, a loss in over all energy of the molecule.

Figure 2 displays the free energy changes that occur when Iron reacts with various halides. (See Table 2).

Of significance is the magnitude of the reaction involving Fluorine, this reaction is substantially more powerful than comparable reactions with Chlorine, Bromine or Iodine. This should come as no surprise when the EN of Fluorine is compared with that of the other halides.

The data displayed in Figure 4 indicates some interesting information about the reactivity of Chromium with Oxygen and the halides.

The free energy change involved when Chromium reacts with Oxygen is substantial. However the free energy change associated with the Chrornium/Fluorine reaction is twice as large indicating that Chromium is very sensitive to Fluorine and will react very readily. The resulting CrF3 is highly soluble in Hydrofluoric Acid solution.

The following Figure 5 summarizes the data that is immediately relevant to Stainless Steel corrosion by comparing the reactivity of the three base alloying elements metals with Fluorine and Chlorine. It becomes obvious that the position of the Cr/CrF3 line ensures the protection of both the Nickel and Iron due to the Chromium's ability to provide an essentially reducing environment through its own preferential reaction with Fluorine. A similar pattern emerges for Chlorine reactions.

Figure 2 : Iron Halide $\Delta G^{\varnothing}$ - *T* diagram

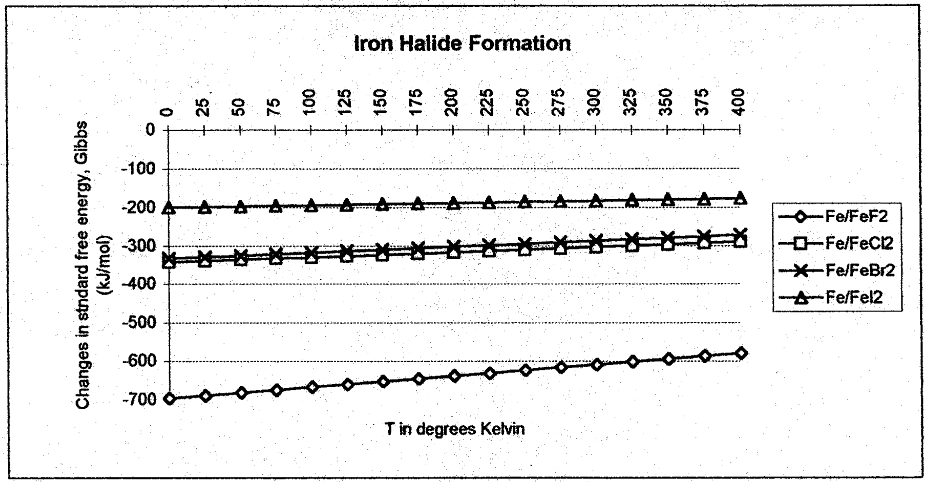


Figure 3 : Nickel $\Delta G^{\varnothing}$ - *T* diagram

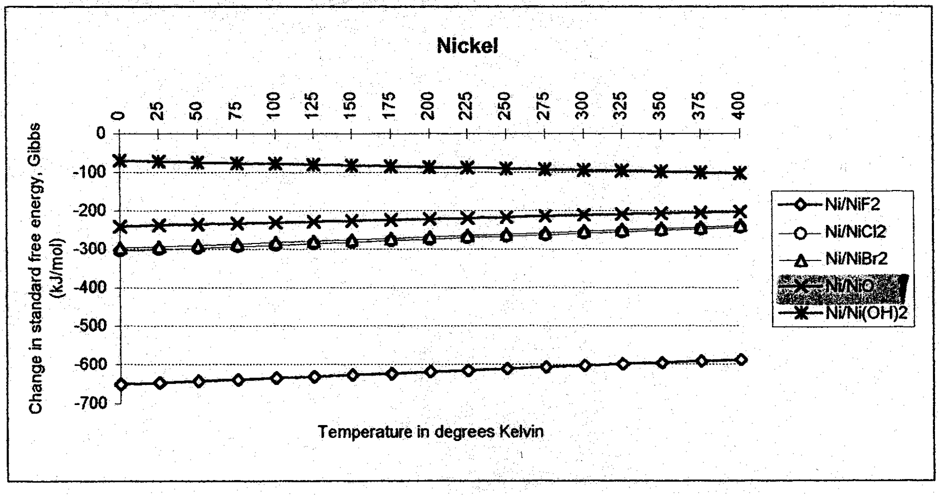


Figure 4 : Chromium $\Delta G^{\varnothing}$ - *T* diagram

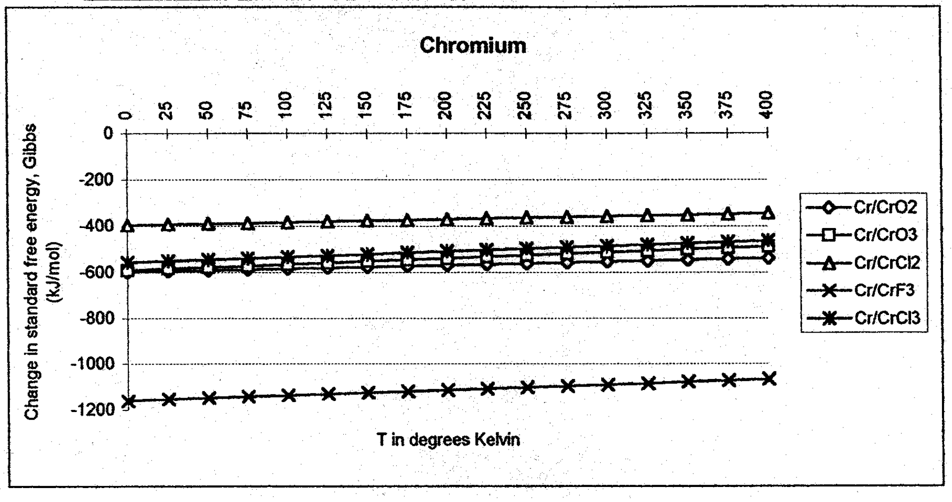


Figure 5 : Metal Halides $\Delta G^{\varnothing}$ - T diagram

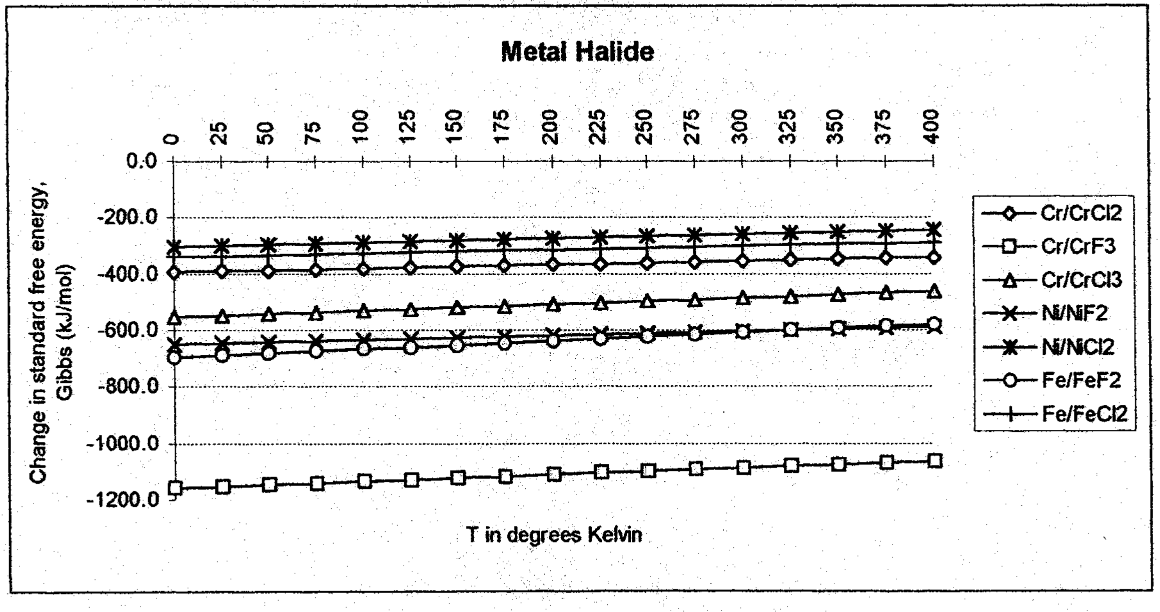
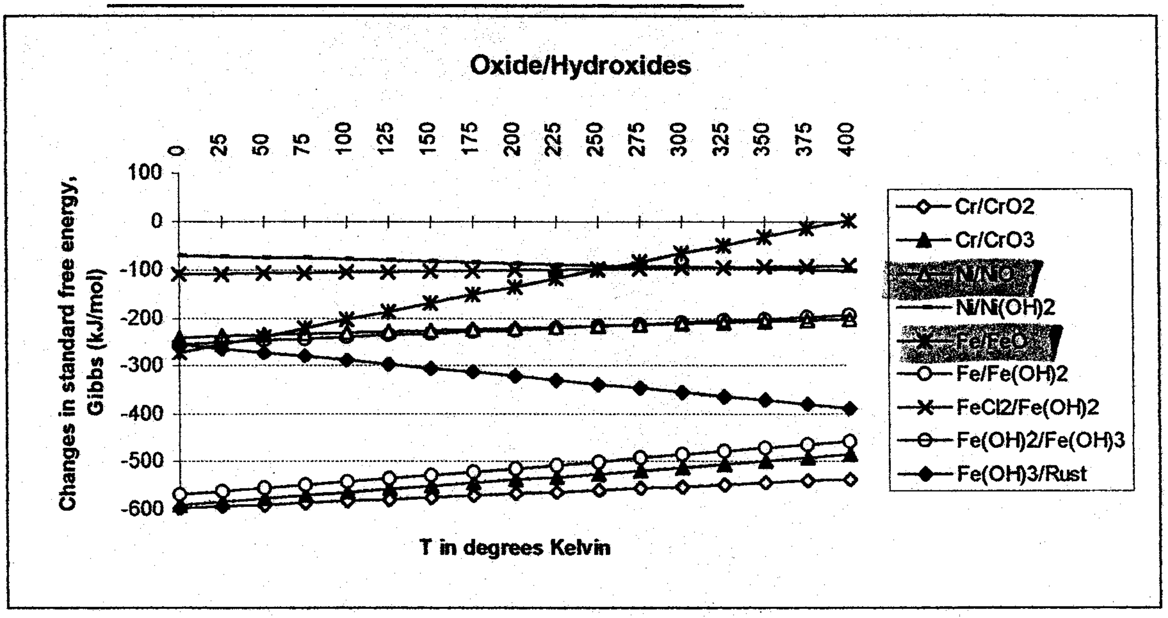


Figure 6 : Metal Oxide/Hydroxide $\Delta G^{\varnothing}$ - T diagram



The reader will observe that of all the elements the chromium oxide(s) derived line(s)have the lowest free energy.

This diagram essential illustrates the weak point in the Chromium Steels as the reader will also observe that Iron within the steel will readily form $Fe(OH)_2$ as the free energy for this reaction is substantial.

Thermodynamics and the Passive Film

These three diagrams describe chemically what we are able to see daily in the real world. Specifically, that Stainless Steel is able to resist quite corrosive environments for substantial periods of time because the Cr/CrOx species is able to reduce species that come in direct contact with it. An active barrier to corrosion.

So why does the stainless steel eventually start to corrode? It is logical to conclude that corrosion commences when the supply of Cr/CrOx species at a particular site are exhausted. It is not conceivable that these species, while in solid solution, are sufficiently mobile to migrate into regions depleted in Chromium.

The structure of the alloys crystal lattice would be totally compromised if such liquid type motion were possible.

With the free energy change for $Fe(OH)_2$ formation so similar in size this reaction is the most likely to occur when the surface Chromium Oxide has been consumed or eroded faster than it can replenish itself.

The presence of Chromium in the base metal ranges from as low as 11 %, to as high as 36%, depending on the alloy.

So the ability of the Stainless Steel to resist corrosion revolves totally around the integrity and overall thickness of the passive film. Obviously the lower the Chromium content the thinner the passive film, and the faster the film is likely to be exhausted.

The need for regular Passivation, the process of CrOx film generation, increases as the level of Chromium in Stainless Steel fails.

The Passive Film

The Passive Film is a film of Chromium enriched oxides in a hydrated gel type structure. As has been shown Chromium forms very stable oxides. These oxides form when the Stainless Steel surface is depleted of acid soluble elements.

Thus dissolved Oxygen in the acid solution, along with the Hydronium (H+) and Hydroxide (OH-) ions, react with the Chromium to produce a hydrated CrOx film over the Stainless Steel some 2 - 4 x 10-9 m thick.

This film provides a chemical barrier protecting the base metal below from oxidation. However the dimensions of this film are many times smaller than the dimensions of abrasive residue or other particulate oxides that may be ground into the steels surface.

When this occurs the Passive Film has been effectively short circuited and the corrosion process may commence.

To Pickle or Passivate.

To the uninitiated, of all the terms used in the Stainless Steel industry, these two words are probably the most confusing. They are continually used interchangeably and usually in the wrong context.

In addition Passivation has managed to cloak itself in such an air of mystery that one wonders if just the incantation of the word might suffice.

A Common Chemistry

Both terms, Pickling and Passivation, are ways of enriching the Stainless Steel surface with the CrOx species by abstracting the soluble base metal ions in acid solution.

T he acid treatment of Stainless Steel happens in an aqueous environment, and it is the combination of hydrolysed water molecules and dissolved oxygen that create the Passive Fiirn.

Pickling

Conventionally Pickling is the term used when very corrosive acid systems are used. However, the need for excessively corrosive acids in any situation, other than for the removal of mill scale, is, from the chemists perspective, unnecessary and often dangerous.

The Pickling process usually utilizes a combination of Hydrofluoric Acid and Nitric Acid.

This combination is particularly aggressive and is ideal for the removal of mill scale, or casting residues.

Table 3 below indicates the relative solubility of metal species in various solutions.

The listed data confirms that the traditional Pickling process can be a very difficult process to control due to the rate at which the chemical reactions occur. Micro-pitting, or etching, of the surface will result if strict attention is not paid to chemical concentration and immersion times.

In addition acid systems of this strength can not be used with equipment containing any kind of composite materials unless a thorough analysis of the sensitivity of the enclosed materials to the acids occurs.

Application of solutions of this nature to electropolished surfaces will result in an increase in surface roughness.

While Pickling does deliver a Passive Film after rinsing, the Pickling Process can be very hard on fabricated equipment containing welds that are not consistent. Hence pin holing of the weld may occur.

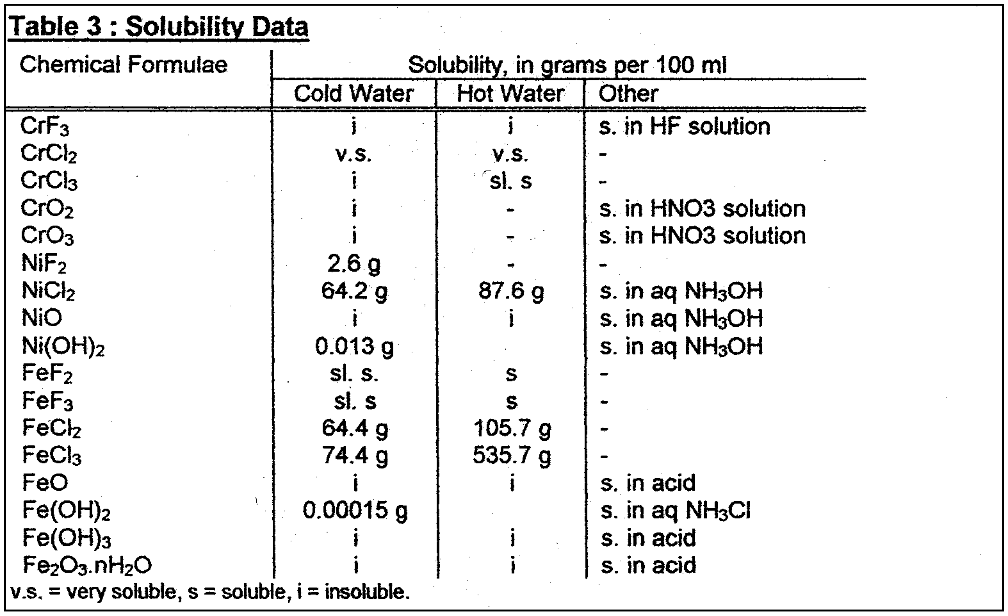


Table 3 : Solubility Data

Chemical Formulae	Solubility, in grams per 100 ml		
	Cold Water	Hot Water	Other
CrF_3	i	i	s. in HF solution
$CrCl_2$	v.s.	v.s.	-
$CrCl_3$	i	sl. s	-
CrO_2	i	-	s. in HNO3 solution
CrO_3	i	-	s. in HNO3 solution
NiF_2	2.6 g	-	-
$NiCl_2$	64.2 g	87.6 g	s. in aq NH_3OH
NiO	i	i	s. in aq NH_3OH
$Ni(OH)_2$	0.013 g		s. in aq NH_3OH
FeF_2	sl. s.	s	-
FeF_3	sl. s	s	-
$FeCl_2$	64.4 g	105.7 g	-
$FeCl_3$	74.4 g	535.7 g	-
FeO	i	i	s. in acid
$Fe(OH)_2$	0.00015 g		s. in aq NH_3Cl
$Fe(OH)_3$	i	i	s. in acid
$Fe_2O_3.nH_2O$	i	i	s. in acid

v.s. = very soluble, s = soluble, i = insoluble.

Passivation

The Passivation process is a much more specific.

Passivation is the process where by a Passive Film is generated across the stainless steel system.

This may be achieved by the use of any number of acid systems, and additives, depending principally on the time frame allowed and the sensitivity of the system.

Independent of corrosion site initiators, such as MgS inclusions, or Al_2O_3 residue from grinding abrasives, the Passive Film will decay on a progressive basis as the natural process of sacrificial Cr oxidation occurs.

The Passive Film attempts to prevent oxidation of the underlying, and adjacent, Fe and Ni atoms through its own stepwise oxidation. Once the Cr is exhausted the base metal starts to oxidize and "rouge" starts to appear.

Replenishment of the Passive Film is possible through the removal of this surface residue however it must be done in such a way as to either reduce or abstract the various CrOx species. Reduction is preferable.

Stainless Steels containing Molybdenum (Mo) show increased levels of passivity because the Mo atom has the same EC as Cr with the added benefit of steric hindrance (size). The MoOx species increases the physical shield over atoms beneath it. (See Table 1).

It should be understood that Passivation is, like Pickling, an overall process of metal removal. Unless the process is closely controlled excessive metal removal can occur.

Chelant Passivation

Sometimes referred to as citric acid passivation may be used for article immersion or for reticulation within a circuit. This process can be readily controlled through monitoring the chemical processes occurring.

Chelant passivation utilizes the well-known effects of chelants, in the complexing of metal residues in conjunction with a reducing acid environment. The process chemistry can be manipulated to target a particular contaminate or widened to target all likely residues.

The process is used in conjunction with surface tension modifiers and flocking agents. The process consists of a series of steps and may use two or three solutions in conjunction with rinsing.

Chelant passivation is a chemically formulated way to remove contaminant residues.

Selective Abstraction

This an extremely effective process. It utilizes specifically formulated abstraction chemistry in conjunction with electrolysis. While it replicates aspects of electropolishing, it is a process that removes **only** the readily soluble passive film contaminants such as Iron, Nickel, Aluminum (grinding residue), etc.

This process may take place in a bath, or the process may be used to spot treat selective structures.

The treated surface is identical in profile to the original surface except for any pitting that may have developed under surface contaminants.

The process is rapid and may be done either cold or hot, 60^0C.

Where the solution is being reticulated through a cell to treat a remote portion of a structure the solution doubles as a coolant.

Electropolishing

This process utilizes a reducing acid environment in conjunction with substantial DC power. The article to be polished is suspended in the medium via means of a conductive support, which is connected, to the +ve terminal, *anode*, of the power supply.

A similarly supported *cathode* is placed in the bath at a suitable location with respect to the article to be polished.

The article is polished by the progressive removal of metal from the article's surface.

The electropolishing process removes Iron and Nickel from the metal surface to a depth of some 20-30 angstroms (depending on exposure time). The result is a dense film of Chromium oxyhydroxide across the metal surface, and so the surface may be defined as *passive*.

At completion of polishing the article is removed from the bath and rinsed.

Electropolishing provides the most dense and durable passive film that it is possible to achieve. Electropolishing should be the consumer's choice of preference for maximizing a stainless products durability.

Measuring the Passive Film

The Passive Film is dynamic, it is constantly interacting with the world around it. So measuring it in absolute terms is not possible.

Measuring it in terms of a relative scale is possible and is done using equipment that is similar in function to a conductivity meter except that it measures the presence, or absence, of free Iron, Fe^{n+} specifically.

Magnetism and Corrosion

A magnetic structure may be induced with in a metal, or alloy, by subjecting the metal to both heat and a magnetic field. This may occur during the cold working of Stainless Steels, and during the welding of these steels.

The implication of a magnetic field is that more ordered crystal lattice structure has been imparted to the steel. A magnetic field implies a moving, circulating, group of electrons. An electric current.

Whether this magnetic field is strong enough to influence corrosion rates is most likely a function of the fields magnitude. Certainly there is a logical association between magnetism and corrosion.

It is quite likely that corrosion occurs around magnetic zones in much the same manner as galvanic corrosion occurs in zones of Cr depletion through the formation of Chromium Carbides.

Essentially any shift in alloy homogeneity will result in the formation of a potential active galvanic cell.

Summary

In review it has been shown how the function of Passivity occurs. It has also been shown how to achieve this condition on the metal surface.

The work has assumed consistency across both Stainless Steel sheet and Weld Zones in order to give a fundamental view of the chemistry involved.

Inconsistencies in Weld Zone metallurgy can significantly affect both the rate of corrosion initiation and the method of treatment.

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Usually a paper such as this is written when what should appear as straightforward chemistry becomes embroiled in controversy. In this instance the catalyst was a meeting of the ISPE Australasian Affiliate in November 1995.

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