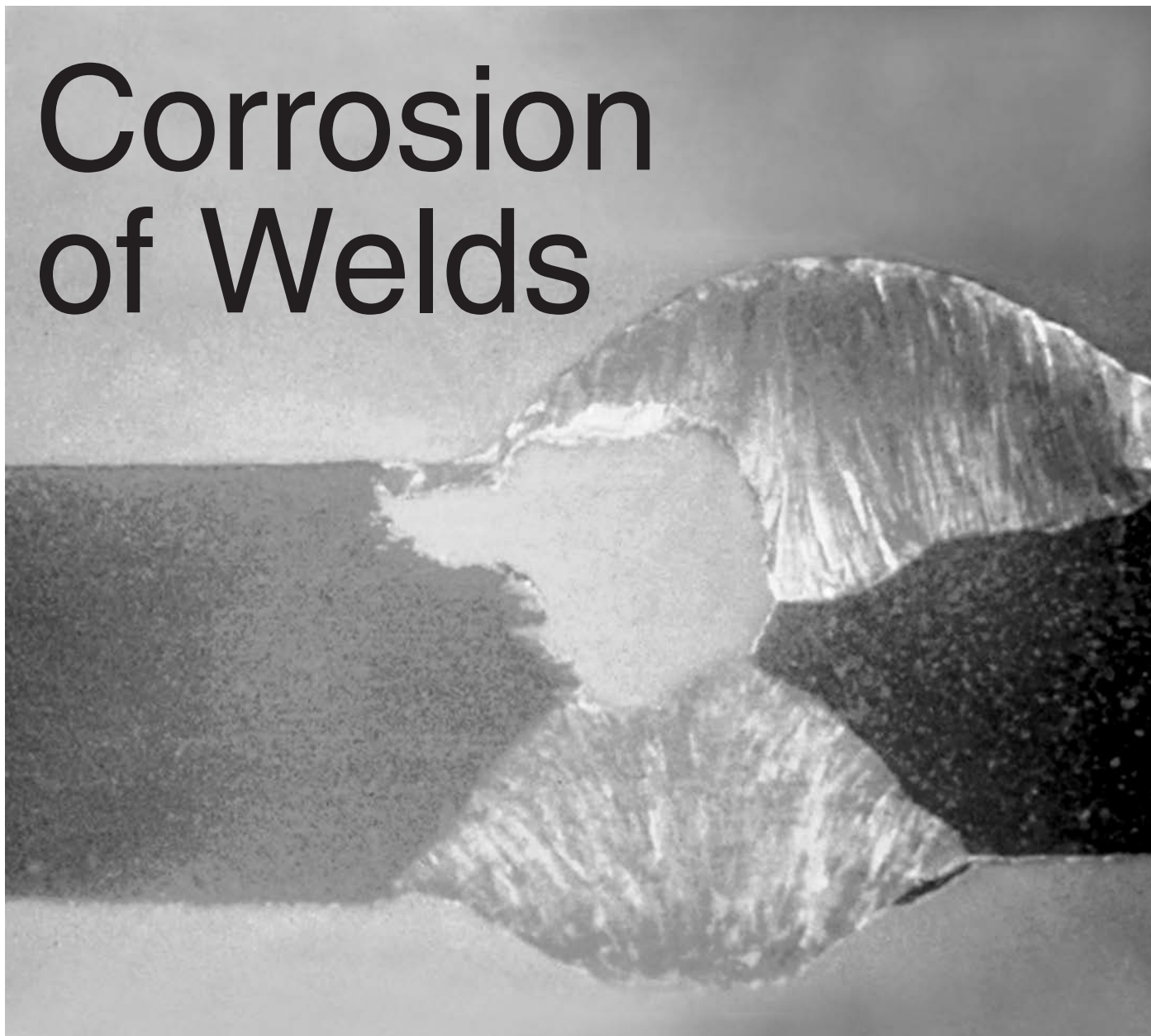




American Welding Society

The Practical Reference Guide for

Corrosion of Welds



Causes and Cures

THE PRACTICAL REFERENCE GUIDE for CORROSION OF WELDS— CAUSES AND CURES

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AUTHOR NOTES

The primary objective of this Practical Reference Guide is to review several common causes of weld corrosion, along with suggested cures. Additionally, several case histories are documented as examples of these solutions. To meet these objectives, I relied on my 28 years experience in Materials Consulting for the Du Pont Company as well as more recent consulting efforts for Weber & Associates. It is my hope this Guide will increase your basic knowledge of corrosion, aid you in your career efforts, and lead you to pursue additional training in this very interesting subject.

Dealing with weld corrosion requires a basic understanding of the various corrosion mechanisms. Therefore, I have included general information on several corrosion mechanisms as well as weld corrosion. For those interested in greater depth of treatment, a short list of additional references is noted at the end.

I must first thank Debrah Weir, Corporate Director of Marketing for AWS, who persisted in her request for the preparation of a basic primer on weld corrosion. After more than 2 years of delays, I finally acquiesced and blocked out the time to prepare this text. The new digital camera technology simplified capturing photographs of metal samples and these are used liberally throughout the text. Additionally, thanks are given to Dr. Richard Campbell, Welding Solutions, Inc., Steven Springer, Du Pont Company, and Greg Kobrin, Beaumont, TX for their editing comments. Also, a second thanks to them, to Ray Strong, Beaumont, TX, and to Don Johnson, Mt. Juliet, TN, for supplying samples, slides, photographs, or data. A few figures have also been included from the *AWS Welding Handbook*, Volume 4.

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Introduction

Corrosion, resulting in the severe degradation of materials, is one of the most expensive engineering problems in our industrial society; estimates have been made that the *annual* cost of corrosion in the U.S. exceeds 100 billion dollars. As you might imagine with the financial stake so high, manufacturers and end users expend significant amounts of engineering time and money avoiding, protecting against, or repairing damages from corrosion. A very large majority of industry must, or should, consider the environmental effects on its products or equipment and guard against premature failure due to corrosion.

Most of us are aware of a very common corrosion problem, corrosion of our automobiles. If you have lived near a coastal water area, or in the snow belt areas that keep the roads clear of ice and snow by spreading salt on the highways each winter, you are probably familiar with the rusted-out car bodies that occur quite quickly when exposed to the moist salt-air environment. Our automakers spend considerable effort to protect their products from frame and body corrosion by these severe environments, but quite often, Mother Nature wins the battle.

Other common examples of items needing corrosion protection include bridges, electrical connections in appliances and electronic devices, chemical processing plants, water pipes, hot water heaters, structural steel, welds; the list is endless. Suffice it to say that corrosion is a pervasive problem and industry must first understand corrosion before they can take steps to solve the unique problems it presents.

Welded structures are often subjected to corroding environments; in some cases, the weld and base metal corrode uniformly at the same rate. In other cases, the results are accelerated corrosion of the weld compared to the base metal, or the base metal may corrode at a much faster rate leaving the weld metal relatively intact. Welding, and its associated heat input, can also contribute to other corrosion problems; these will be discussed in greater detail later.

A logical starting point for dealing with corrosion of welds is to define corrosion and then list the various types of corrosion that can occur, with examples. Definitions used are those developed by Dr. Mars Fontana and/or NACE. There are many



Figure 1. Carbon steel pipe butt joint weld showing severe internal corrosion of weld root and heat affected zone.

different forms of corrosion recognized that include the various corrosion mechanisms, and the most common are defined and discussed below. The next logical step after defining the various forms of corrosion is to then develop methods for avoidance of each and these are also listed following each definition. Several case histories are also noted to demonstrate actual, practical solutions.

Corrosion

Corrosion has been defined as *“The destruction of a metal by chemical or electrochemical reactions with its environment.”* In today’s world of ever-increasing materials available to the designer, this definition must be expanded to cover other materials in addition to metals since environmental failures of non-metallics also occur. And since many nonmetallics are joined (welded), the degradation of nonmetallics must be dealt with when selecting them for a particular application. Since our primary interest is in weld corrosion of metals, the discussion of weld corrosion will be limited to consideration of metals only.

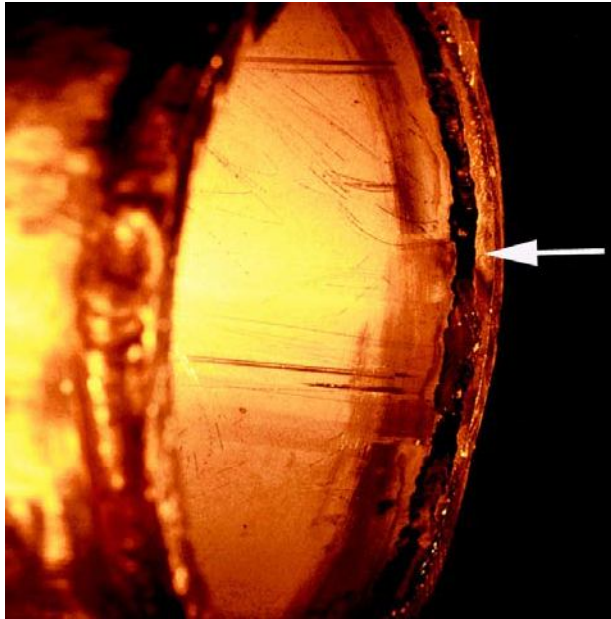


Figure 2. Section of stainless steel piping showing severe corrosion of weld root. Arrow points to an area of complete perforation.



Figure 3. Pipe section showing localized corrosion of longitudinal seam weld.

Within metallic systems exposed to aqueous corrosive environments, anodes (the positive electrode) and cathodes (the negative electrode) of different potentials, or voltages, are formed. These areas of differing potentials can be formed several ways: by dissimilar



Photo courtesy of Don Johnson, Mt. Juliet, TN.

Figure 4. Severe general corrosion of a very old cast steel cannon barrel recovered after many years of being submerged in seawater. Note heavy scale of iron oxides that have completely filled the cannon bore.

alloys used in combination, by weld metal versus base metal, by mill scale versus clean metal surfaces, by segregated constituents within a metal structure, or by concentration cells within the corrosive environment itself. There are several general statements that can be made regarding metal corrosion:

- Corrosion of metals always occurs at the anode (oxidation), with the cathode (reduction) being protected.
- There is electron flow between the anode and cathode during corrosion.
- Nascent, or atomic, hydrogen (H^+) is always formed at the cathode during corrosion.

With these general truths in mind, we will now move to the various forms of corrosion.

General Corrosion

The most common form of corrosion is referred to as General Corrosion; an alternate term is Uniform Attack. One formal definition is “A chemical or electrochemical reaction which proceeds uniformly over the entire exposed surface, or over a large percentage of the exposed surface.” During this type of corrosion, the material corrodes quite evenly over its surface, or the majority of its surface, that is exposed to the corroding environment.



Figure 5. A carbon steel piping exterior showing moderate general corrosion of the pipe exterior and butt joint weld.



Figure 6. Bulge in boiler tube caused by loss of wall thickness by general corrosion and internal pressure on the thinned pipe wall.

A piece of 10 gauge, uncoated, plain carbon steel left outside and exposed to the rain and sun will usually corrode in a general manner with time. The entire surface begins to “rust” and turn a dark reddish brown color (see Figure 5). If sufficient time passes, the original metal thickness is reduced in a uniform or general manner, and eventually the entire piece will transform back to its natural state of iron oxides. The steel combines with oxygen and hydrogen during the corrosion process, which is aided by moisture. The iron oxides and iron hydroxides form a scale on the surface and while the scale would seem to offer protection from further

corrosion, it does not in this example. In fact, the porous and relatively lightly adhering scale of iron oxide and iron hydroxide may even promote faster corrosion by absorbing moisture and trapping it in close contact with the steel. (Protective corrosion scales will be discussed in greater detail when we review corrosion of the austenitic stainless steels.)

Generally, when carbon steels corrode uniformly and corrosion scales form, the thickness of the scale can be about 7 to 10 times as thick as the original metal thickness consumed to form the scale. Thus, a 1/4 inch steel plate completely corroded can form a scale of 1.5 inches to 2 inches or more. Aluminum alloys also can form thick scales in some exposures, and this scale formation has been termed “blooming.” These aluminum scales are quite loose, almost fluffy in nature, are very unprotective, and can be easily removed with a little light mechanical scraping.

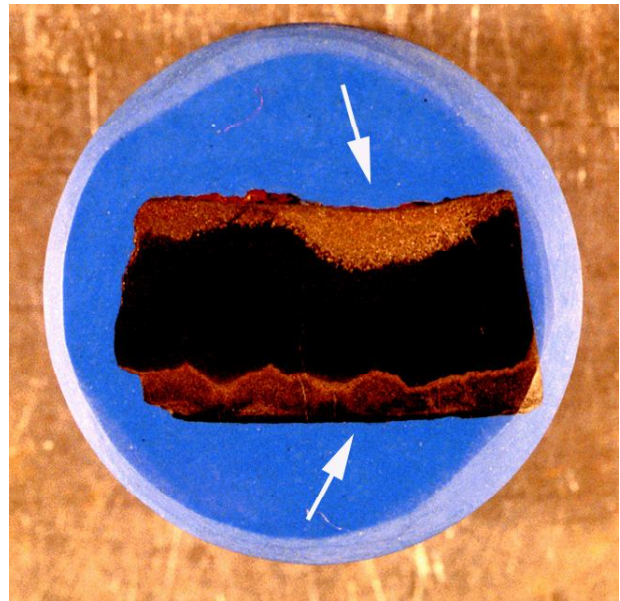


Figure 7. Metallurgical mount of carbon steel plate cross-section showing depth of oxidation scaling at arrows due to exposure to hot gases.

Many other examples of general corrosion can be listed. A few are: copper in a weak nitric acid solution will dissolve; steel immersed in sea water eventually becomes entirely consumed; aluminum in a caustic solution will dissolve; water pipes in houses become quite thin and fail; bolted connections suffer corrosion and fail.

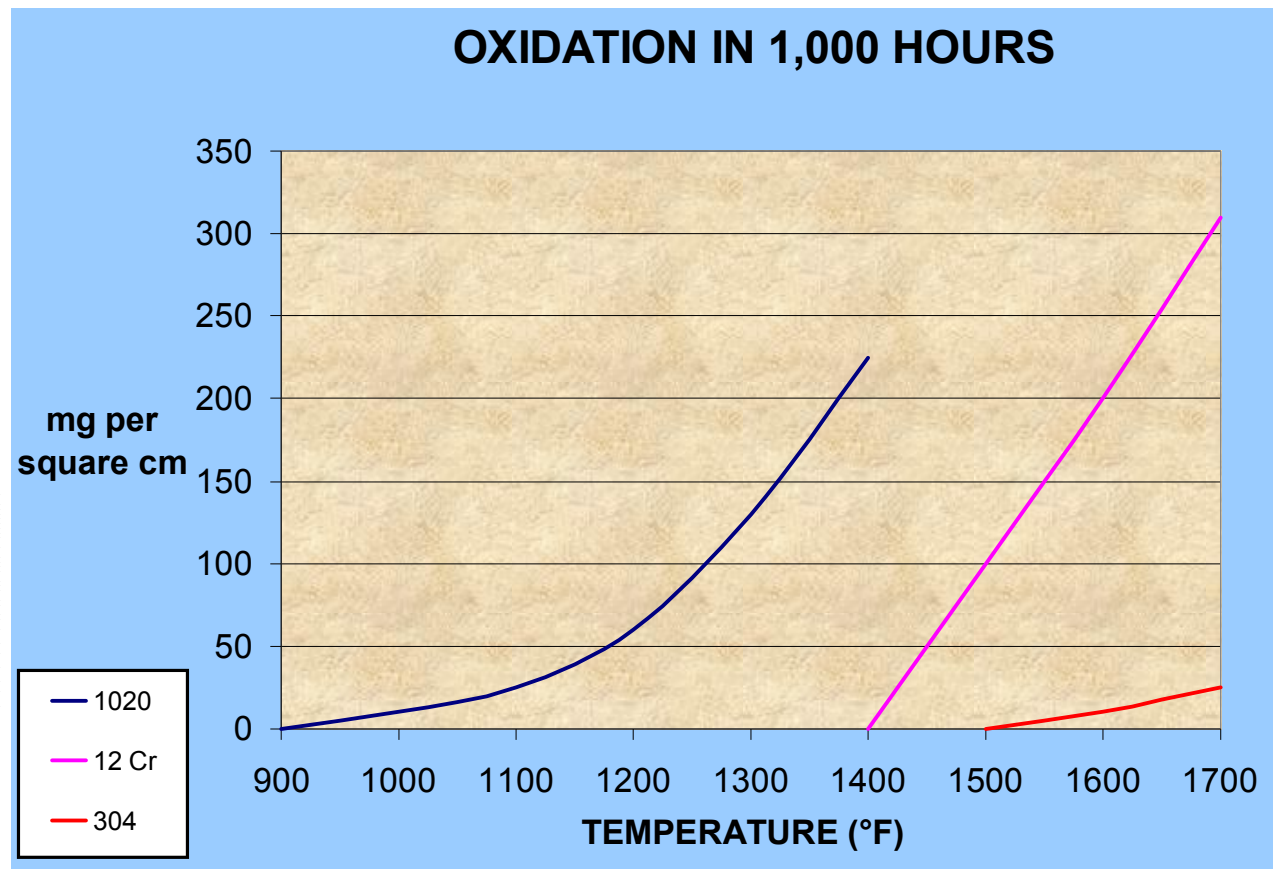


Figure 8. Curves showing weight gain in 1,000 hour hot air exposure tests for three materials. The carbon steel begins to oxidize (gain weight) at about 900°F and begins to oxidize very rapidly. The 12 Cr alloy and the 304 stainless steel have much better oxidation resistance and are useful at much higher temperatures.

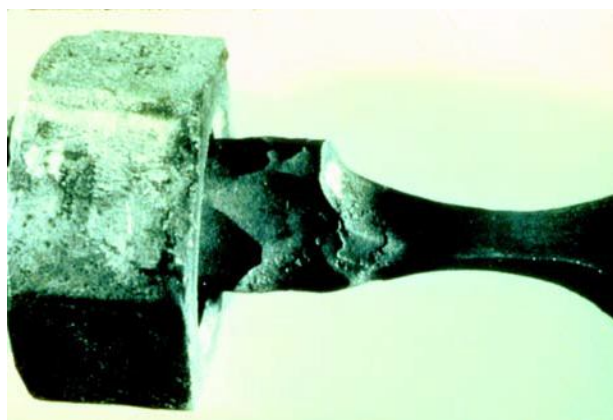


Figure 9. Shank of stud and nut showing severe general corrosion of stud.

We usually describe the rate of general corrosion in terms of the thickness lost per unit time. A common term in the U.S. is mils per year (mpy) thickness loss. A mil is 0.001 inch, and an acceptable corrosion rate for steel used in common applications such as storage tanks or petrochemical equipment is usually 10 mpy or less, depending on the particular application. Corrosion data are also given in inches per year (ipy), but this approach becomes a bit impractical when dealing with normally acceptable corrosion rates. To demonstrate this, a 7 mpy rate can also be written as 0.007 ipy, requiring the use of several zeroes and a decimal point in the ipy format.

Corrosion rates can be determined by exposing a specimen to the corroding environment and measuring the actual metal thickness loss with time. Corro-