

An Inexpensive Corrosion Laboratory Experiment - Suitable for All Ages.

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Abstract

One of the most obvious effects of corrosion is the damage that road salt can perpetrate on our vehicles. In this paper the author describes how to perform corrosion testing on several metals to demonstrate methods of effective corrosion protection and to make qualitative comparisons between protected and unprotected metals. Student reactions to the exercise are discussed and their suggestions for improvement are presented. Some photographs of the experimental results are shown. Additional photographs are provided in the electronic version of the paper.

Introduction

Most people living in the midwest are very familiar with the rust that produces huge holes in cars and trucks and fills the junkyards with unwanted vehicles. One source indicated that up to 20% of the iron and steel products produced in the USA replaced objects that have been discarded due to rust damage. [1]

One segment of an introductory materials course covers corrosion and its prevention. The course is required for both the AS and BS degrees in MET, and occurs in the plan of study before these students take college chemistry. The students in this course vary in age and background. No assumptions can be made concerning their understanding of electrochemical theory and chemical reactions. The lectures provided information on the chemistry of the iron rusting process and on the galvanic series. As an aid to student understanding, the author has developed a laboratory exercise to demonstrate corrosion effects and to illustrate some methods of preventing corrosive attack. The primary objective of this laboratory is to provide dramatic visual evidence of the progression of corrosive attack as well as its prevention and to accomplish this in a cost effective manner.

Background

Galvanic corrosion is the type that destroys metallic objects. For galvanic corrosion to occur, several conditions must be present simultaneously. [2] These conditions are:

1. the metal is oxidized at the anode of an electrolytic cell.
2. some ions are reduced at the cathode.
3. there is a potential (voltage) between the anode and cathode.
4. an electrolyte must be present
5. the anode must be electrically connected to the cathode

The definitions of some of the terms used in these conditions are: when something is oxidized, it loses electrons, and when something is reduced, it gains electrons. [3] In addition an electrolyte is defined as a chemical substance, usually a liquid, that conducts electricity. [4] Indeed, electrolytes can include vapors, and even solids, such as an oxide film. [5] These definitions are critical to the understanding of techniques of corrosion protection. It is also necessary to understand the effects of cold work on metals. Cold work breaks large grains into smaller grains, thus producing larger numbers of grains and more grain boundaries. The more boundaries and grains, the greater is the opportunity for corrosion to occur. It is important to recognize that this type of corrosion is not the same as stress corrosion cracking. Armed with this background, the students can then be challenged to explain what occurs during the corrosion testing that follows.

Materials Required for Corrosion Testing.

An endless list of materials could be presented, but it is important to choose what is readily available and what will oxidize rather quickly. Conventional corrosion testing often takes long periods of time, uses extremely hazardous corrodents, (such as boiling hydrochloric acid) and requires careful weighing of samples to determine corrosion rates. This laboratory experiment is intended to be performed quickly, perhaps over a period of two or three weeks, and uses relatively innocuous corrodents.

Table 1 lists some candidate materials that can be used for this demonstration.

Table 1. Candidate Corrosion Materials

Low carbon hot rolled steel strip
Low carbon hot rolled steel strip, with weld bead
Low carbon hot rolled steel strip, with magnesium
Straight and bent common steel nails
Aluminum strip, 1100 series
Aluminum strip, 6061 series
CA 360 brass strip
Pure copper strip
Zinc plated hardware, such as an “S” hook
Hot-dipped zinc coated roofing nail
Cadmium coated bolts or screws
Stainless steel bolt
Inconel or Hastelloy strip



Figure 1. Steel Samples

Suggested corrodents are limited to common substances for safety and convenience. Good results have been achieved using household bleach, diluted with tap water in the ratio of 100:1. Bleach, NaClO , is an oxyacid, so it provides additional oxygen to the solution. Household ammonia, Drano, weak hydrochloric acid, weak sulfuric acid, rain water, calcium chloride solution (similar to road salt) are other inexpensive, easily obtained corrodents that can be used.

Glass jars are used to hold the corrodent and the samples. It is best if the sides of the glass are plain, rather than decorated. Canning jars were used first, but the decorations cast into the glass interfered with observation of the reactions. Spaghetti sauce jars, with plain sides, work well for good visibility and for photography. It is necessary to remove any traces of glue from the labels for optimum visibility.

Experimental Procedure

For strip testing, 1-inch wide strips about 0.065 inch thick are used. These strips have been sheared into tensile test specimens, then cut in half. A hole is drilled in the half-inch width section for a support string. Three of these strips are shown in figure 1. A piece of nylon fish line is inserted into the hole and used to suspend the specimen in the jar. A polyethylene film can also be used to suspend the samples, but may hinder observation. The lid is placed over the jar and the string and gently tightened, just enough to hold the sample and string. Do not fully tighten the lid since it may cut the nylon line. In addition, it is acceptable to use clear plastic film over the top of the jar, held in place by a rubber band. A tight seal should be avoided since pressure might build up due to hydrogen generation. However, a good cover is needed to prevent evaporation of the corrodent liquid over time. The same process is used for nails, bolts, hardware items, etc., except the string may need to be tied to the object to adequately support the material in the corrodent.

The students are given a data sheet to use for observations. They are asked to observe the samples about one hour after they are immersed in the corrodent, and to observe every class day until about two or three weeks have elapsed. Some students sketched the appearance of the samples, while others just used words to describe what they saw. One student sketched each of the samples and drew the progress of corrosion using colored pencils.

Typical Results.

The primary objective to help students understand how corrosion occurs or why it does not occur based on these experiments was achieved. Consider the following tests and results.

Steel Strip Samples

Three steel strip samples, each AISI 1010 hot-rolled steel, are used in the dilute bleach solution. One is plain, one has had a weld bead placed on it, using a MIG welder, and one has some magnesium strips bound to it using nylon fishing line. Corrosion begins very quickly at the sheared edges of the strips, where cold work was done during the shearing. Rust completely formed over the plain sample, starting at the outer edges. Rust also formed at the edges of the weld bead, again due to cold work occurring during the weld cooling. However, the magnesium strips provided cathodic protection for that sample. The magnesium will oxidize visibly. It is

essential to ensure good electrical contact between the magnesium and the steel. Figure 2 shows the three steel samples after 48 hours of immersion in the dilute bleach solution.

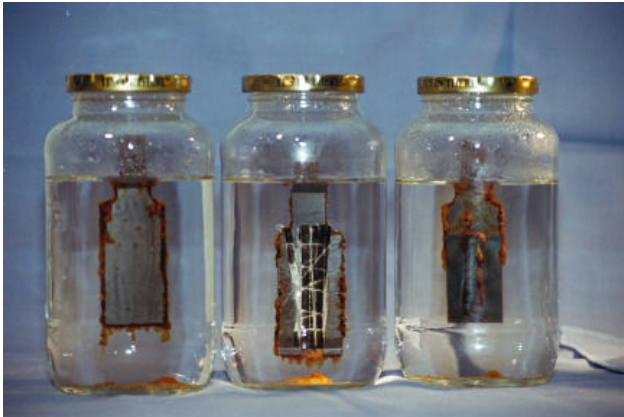


Figure 2. Three Steel Corrosion Samples after 48 hours immersion

Figure 3 is a close-up view of the plain steel sample, while figure 4 is a close-up of the sample protected by the magnesium strip. Both have been immersed for 48 hours.

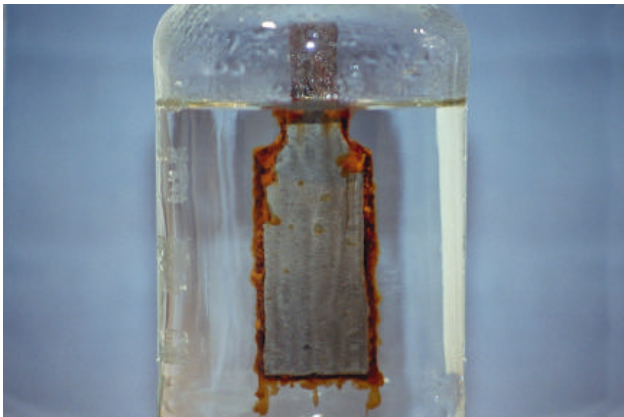


Figure 3. Close-up of the plain steel sample



Figure 4. Close-up of the magnesium protected sample

At first glance, there appears to be little difference between the two samples. However, careful examination showed that the plain sample has undergone more corrosion. It is possible that the magnesium strips did not have good electrical contact with the steel, thus allowing greater oxidation to occur. In previous experiments, significantly less rust was observed on the magnesium protected sample.

Bent and Straight Nails

The head and point of wire nails are formed by extreme cold work. Thus, rust can be expected to form at these points. However, rust will also form in the bend area of the bent nail, again due to cold work. Also, small amounts of rust formed on the shank of both nails due to scratching that occurred during transport and handling. Figure 5 shows the nail samples after 48 hours in the dilute bleach solution. An enlarged detail of the bent nail is shown in the inset.

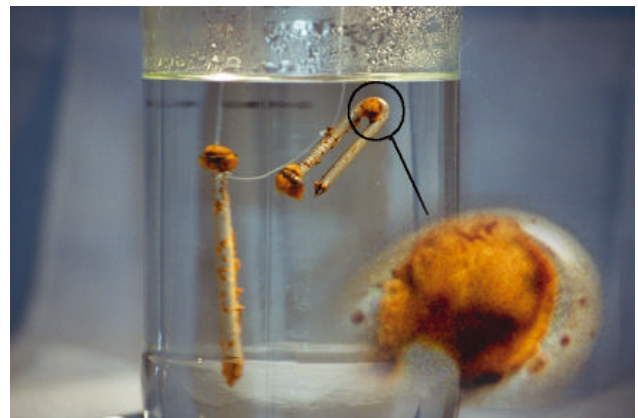


Figure 5. Straight and Bent Nails after 48 hours immersion

In steel corrosion, the grain boundaries become the anode and the grain becomes the cathode. As the boundary is eroded, the grain and boundaries switch roles so the polarity is reversed. This process is repeated until the entire piece has reacted. [6] Also, since the oxide crystal is larger than the steel crystal, the oxide buckles, exposing a fresh surface, allowing complete destruction of the part over time.

Brass and Copper Samples

Strips of brass (CA 260) and pure copper were immersed in the dilute bleach solution. There is little activity and almost no corrosion observed below the liquid level. This is due to the tendency for brass and copper to form passive layers. However, it was noticed that green oxides

formed on the materials above the liquid line, where more oxygen is available.

Zinc Plated and Hot Dipped Samples

Bright plated samples and the rather dull hot-dipped samples showed no evidence of orange rust formation when immersed in the dilute bleach corrodent, because the zinc becomes the anode protecting the underlying steel. The zinc coating will become dull as it oxidizes. Some white crystals may form. If the zinc coating was deeply scratched, rust occurred locally.

Stainless, Inconel, or Hastelloy Materials.

None of these materials showed significant corrosion.

Aluminum

In one experiment, 1100 series aluminum was tested in both the dilute bleach solution and in household ammonia. The strip in the bleach exhibited relatively little chemical reactivity. Eventually white crystals formed in many areas of the strip. The sample in the ammonia exhibited strong reactivity with the rapid evolution of bubbles for two days. The strip began to turn black. Bubble formation stopped and no further reaction was observed. This was due to anodization of the surface, after which, the oxide layer protected the base material from further reaction. The oxide crystals of aluminum are the same size as the grains of the metal, allowing them to stick to the parent metal and prevent further oxidation. [7]

Other Options

If quantitative results are desired, corrosion coupons can be cut, weighed before and after attack to measure corrosion rate as well as simply observed periodically for changes. If proper containers can be obtained, photographic evidence can be collected for visual comparisons. If greater corrosive activity is desired, an aquarium pump could be used to bubble air through the sample jars. This would cause cloudiness due to the agitation, but the bubbling could be stopped for observation. Stress corrosion, mentioned earlier, can be demonstrated by bending a thin strip of steel in a horseshoe shape and holding the ends using a bolt or wire. After long immersion in a corrodent, the sheet should fail by cracking at the bend.

Student Reactions

Students in the Spring, 1996, class commented anonymously on the course and the corrosion lab in particular. The following are some student comments. These remarks are copied as written, including underlining, etc.

“The corrosion lab was not too bad.”

“The corrosion lab, in my opinion, was very interesting. More time was needed to view the specimens.”

“The corrosion lab was an excellent example of the actual corrosion process. Overall, the content and knowledge gained from this lab was excellent.”

“The chemistry stuff is hard since I haven’t had it yet.”

“The corrosion lab was GREAT. I learned a lot about anodes and cathodes on this lab.”

Other student comments were of a similar nature. It was a little surprising to find nearly unanimous agreement on the value of the exercise. A brief chemistry discussion was given to explain iron oxidation. That material would be expected to be difficult for someone who did not have even a high school chemistry course. Even so, the student who complained about the “chemistry stuff” was still able to praise the lab. This result was certainly gratifying.

Future Work

The author plans to include more types of metals as candidates, as well as demonstrating crevice corrosion, stress corrosion cracking and bolting dissimilar metals together. Students will be asked to predict results before the experiment starts.

Note: additional photographs are included in the electronic version of this paper.

Pick

- Steel samples before immersion
- 3 samples at start of immersion
- Nails at start
- 3 samples after 1 hour immersion
- Nails after 1 hour immersion
- 3 samples after 5 hours immersion
- Nails after 5 hours immersion
- 3 samples after 30 hours immersion
- Nails after 30 hours immersion
- Plain steel strip after 30 hours immersion
- Steel strip with magnesium after 30 hours
- Welded steel strip after 30 hours
- Nails after 30 hours immersion
- 3 samples after 48 hours immersion
- Plain steel after 48 hours immersion
- Steel strip with magnesium after 48 hours
- Weeded steel strip after 48 hours
- Nails after 48 hours

References

1. Brown, Theodore L., et. al., *Chemistry: the central science*, 5th edition, Prentice-Hall, 1991, pg. 733.
2. Budinski, Kenneth G., *Engineering materials: properties and selection*, 5th edition, Prentice-Hall, 1996, pg. 384.
3. Brown, Theodore L., op. cit. pg. 121.
4. Dalton, William K., *The technology of metallurgy*, Macmillan Publishing Company, 1994, pg. 307.
5. Budinski, Kenneth G., op. cit., pg. 384.
6. Fellers, William O., *Materials science, testing and properties for technicians*, Prentice-Hall, 1990, pg. 152-153.
7. Ibid.