
Understanding flash rusting

Lyndsie Selwyn

The following activity is for heritage professionals who want to learn about flash rusting on iron. It is part of the Canadian Conservation Institute's [Care of Metals in Collections Workshop](#). A laboratory and ventilation are not required for this activity unless an organic solvent such as acetone is required to remove oils or coatings. If an organic solvent is to be used, consult its safety data sheet (SDS) for health and safety information prior to use.

Learning objectives

By understanding how flash rusting happens, heritage professionals will be able to:

- Recognize flash rusting
- Identify and minimize exposure to environments that cause iron to flash rust

Background

When iron first becomes wet, it can begin to corrode in minutes and become spotted with or covered by bright orange corrosion. The orange corrosion is mainly lepidocrocite, an iron oxide hydroxide with chemical formula $\gamma\text{-FeO(OH)}$, also called iron(III) hydroxide oxide or iron(III) oxyhydroxide (Selwyn 2004). In the conservation community, this corrosion is referred to somewhat informally as “flash corrosion” or “flash rusting,” although some simply refer to it as “rapid corrosion” (Galban 2002).

Flash rusting can occur in various ways. In an archaeological context, it can occur during rinsing of an iron object with water after an alkaline treatment. In non-archaeological contexts, it can happen in a heritage building or industrial site with an uncontrolled atmosphere, when water condenses on an unprotected iron surface as the temperature suddenly drops. Or it can form after roof leaks in historic houses or when a flood occurs in a storage area. The resulting orange rust may not affect the structural integrity of an object, but it produces a disfiguring appearance. The bright orange corrosion can often be brushed off; for an object that was already corroded, such as an archaeological object, cleaning by simple brushing may be enough. For an object that was bright and shiny before the flash rusting, the surface underneath the orange corrosion may be pitted and darkened, and the darkened stain will be more difficult to remove.

For commercial applications, iron is alloyed with other elements to make steel, cast iron, stainless steel and other specialty alloys. Steel refers to iron alloyed with carbon (generally less than 2 wt%); plain carbon steels are iron-carbon alloys that contain few or no additional alloying elements. Cast iron refers to iron with higher carbon contents (usually about 2–4 wt%). Stainless steel refers to iron-

carbon alloys that also contain at least 10.5 wt% chromium and some nickel. They are stainless because they are more resistant to rusting than ordinary steels.

Activity: how to cause flash rusting on iron

This hands-on activity outlines the procedure and required materials to demonstrate how quickly flash rusting can occur on iron. The activity involves exposing iron to tap water.

Equipment and materials required to make iron rust

- New iron putty knife (or an old one where rust has been removed); make sure it is not stainless steel
- Carbon steel coupons (e.g. 4 x 2.5 cm or 2.5 x 2.5 cm, 20 gauge [0.9 mm thick])
- Spray bottle for misting water (e.g. an old window cleaning spray bottle with nozzle)
- Tap water
- Sand paper (e.g. 100 to 400 grit)
- Steel wool (e.g. “finest” no. 0000)
- Blotting paper (e.g. pieces 8 x 10 cm)
- Petri dishes, disposable (small 60 x 15 mm or larger 150 x 15 mm), to hold samples and prevent staining of surrounding material; another approach is to place a sheet of plastic underneath the samples.
- Pipettes (Pasteur or plastic) or eye droppers
- Disposable nitrile gloves
- Paper towel or paper tissues

Procedure to make iron rust

Preparation of iron

Use sand paper to remove old corrosion, marks or protective barriers from both sides of the steel coupons and putty knife. The surface should be bright metal. Abrade the surface along one direction until clean, then turn the surface ninety degrees and repeat. The coarser sand paper (e.g. 100 grit) may be needed to remove stubborn stains. Solvents, such as acetone, may be needed to remove the protective barriers, adhesive labels and oil. If an organic solvent is used, then consult its SDS for health and safety information prior to use. Wear gloves while handling clean iron to avoid contaminating it.

Water sprayed on iron putty knife

1. Fill the spray bottle with tap water.
2. Lightly spray the surface of the blade with water until about 50% of the surface is covered with small drops.

3. Monitor what happens.
4. After the water has dried, wipe off the orange rust with a paper towel or tissue and note any darkening or pitting.

Drop of tap water on carbon steel coupon

1. Place a cleaned carbon steel coupon in the bottom half of a Petri dish.
2. Label the side of the dish with name, date, start time.
3. Use a pipette and add between 5 and 10 drops of tap water at the same spot to form one large drop of water on the coupon and leave the dish uncovered.
4. Monitor what happens as the drop dries completely.
5. It may be necessary to let the drop dry overnight.

Immersion of carbon steel coupon in tap water

1. Place a cleaned carbon steel coupon in a Petri dish.
2. Label the side of the dish with name, date, start time.
3. Add enough tap water to cover the surface of the iron.
4. If the water level drops during the test, top up the water to ensure the iron stays immersed.
5. If left overnight, cover the dish to ensure the water does not evaporate.
6. Monitor what happens over one day or overnight.
7. After orange rust has formed, remove the coupon and observe how easy it is to remove the rust by rinsing under running water or brushing in fresh water.
8. Dry the coupon with paper towel and note any damage to the surface.

Iron staining of paper (optional)

1. Always wear gloves when handling steel wool and cut it to size using scissors rather than tearing a piece off. This avoids cuts and protects the hands.
2. Cut a small piece of fine steel wool (e.g. grade 0000 that is oil-free) smaller than the blotting paper.
3. If the steel wool is not labelled as oil-free, then rinse the steel wool in solvent (e.g. acetone).
4. Pull the steel wool apart to open up the strands.
5. Wet two pieces of blotting paper with tap water.
6. Place the steel wool on top of one piece of wet blotting paper.
7. Spray the steel wool with tap water to make sure it is completely wet.
8. Cover the steel wool with the other piece of wet blotting paper.
9. Add a small inert weight (e.g. a beaker or glass containing water) on top of the blotting paper to provide good contact between the steel wool and the paper.
10. Allow the blotting paper to dry overnight.
11. Open up the blotting papers and observe the results.

Results of this activity

Water sprayed on iron putty knife

Figure 1 shows the grey surface of bare iron on the putty knife just after it has been sprayed with tap water. The surface was cleaned first with acetone to remove the coating, and then it was abraded with 320 grit sandpaper.



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Figure 1. The putty knife just after the iron blade has been sprayed with tap water.

Within a few minutes the droplets of water should take on an orange tinge. Figure 2 shows the putty knife after orange corrosion has formed in the drops (about 2 hours in this example), but before they have dried out.



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Figure 2. The putty knife after about 2 hours. Orange corrosion has formed on the iron blade in the drops of tap water.

When the drops dry (after almost 4 hours in this example), a powdery orange residue should be left on the surface, as shown in Figure 3.



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Figure 3. The putty knife after almost 4 hours. The water has dried leaving orange corrosion, typical of flash rusting, on the iron blade.



[Flash rusting on iron blade](#)

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When the orange residue is wiped off, the surface underneath should be darkened and possibly pitted, as shown in Figure 4.

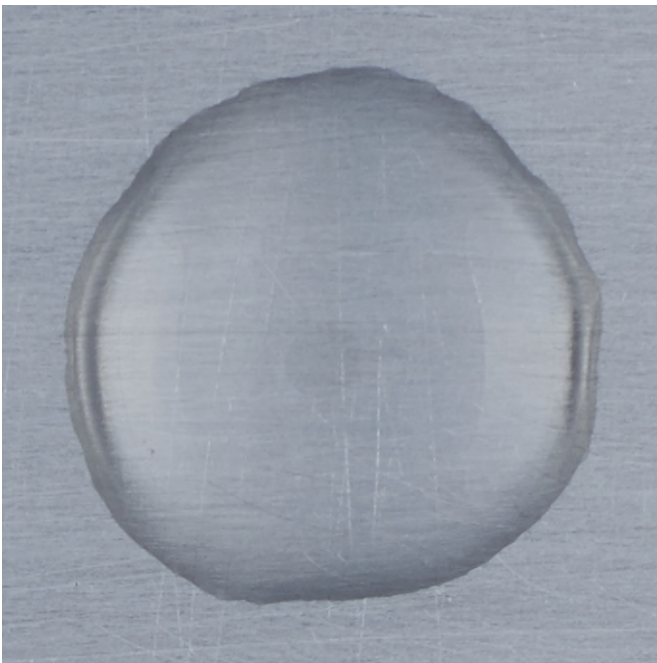


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Figure 4. The putty knife after the orange corrosion has been wiped off the iron blade. The underlying surface has darkened.

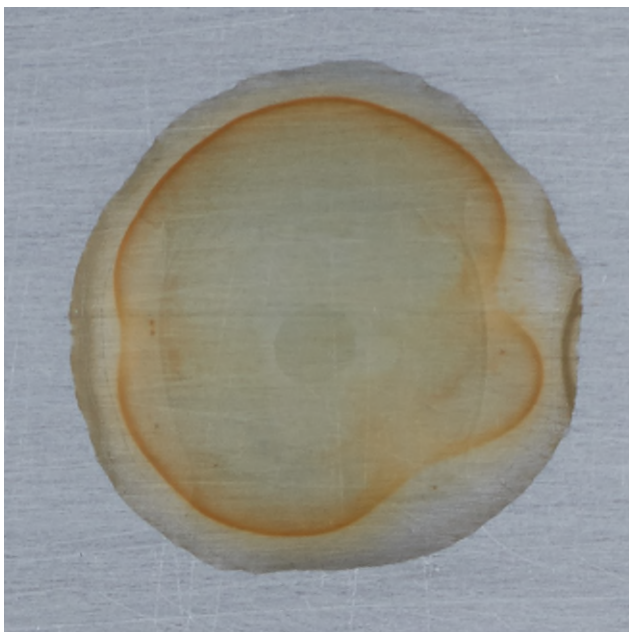
Drop of tap water on carbon steel coupon

The drying time for the large drop of water varies depending on the relative humidity of the room, the temperature and the amount of air circulation. Several hours may be needed before the drop has dried. The visual changes should be similar to those seen on the putty knife sprayed with water. The following sequence of images illustrates what to expect. Figure 5 shows the drop just after being added to a carbon steel coupon that had been cleaned with acetone, then abraded with 220 grit sandpaper. Figure 6 shows the drop one hour after being added, and Figure 7 shows the drop four hours after being added.



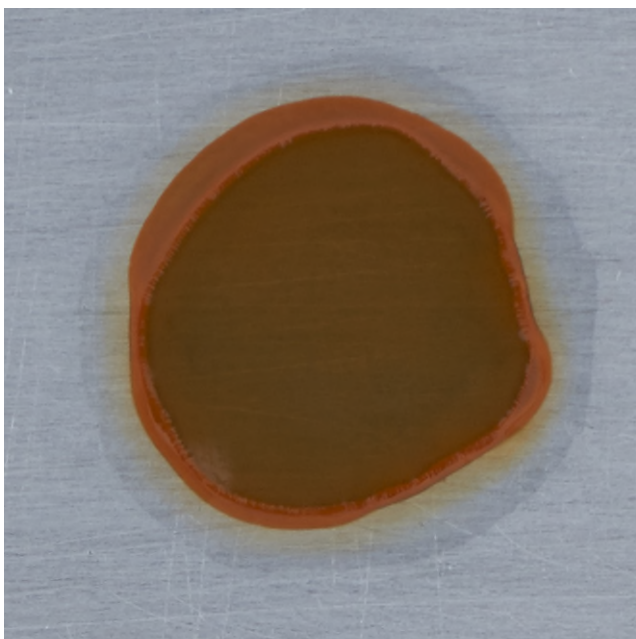
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Figure 5. A drop of tap water just after it has been placed on a carbon steel coupon.



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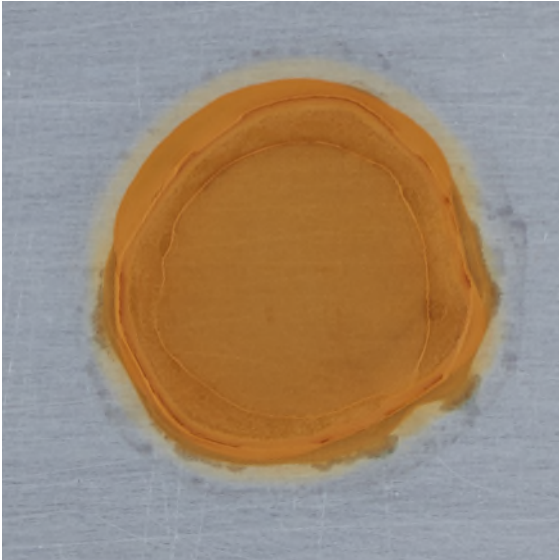
Figure 6. Orange corrosion on the carbon steel coupon one hour after the drop of tap water was added.



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Figure 7. Orange corrosion on the carbon steel coupon four hours after the drop of tap water was added.

After the drop has dried, a powdery bright orange residue should be left on the surface, as shown in Figure 8. After the orange residue is wiped off, the surface underneath should have darkened and possibly pitted, as shown in Figure 9.



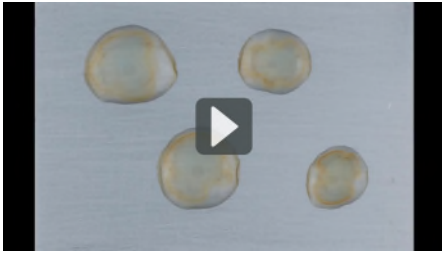
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Figure 8. Bright orange corrosion, typical of flash rusting, on the carbon steel coupon after the drop of tap water has dried.



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Figure 9. The carbon steel coupon after the orange corrosion has been wiped off with 220 grit sandpaper. The underlying surface has darkened.



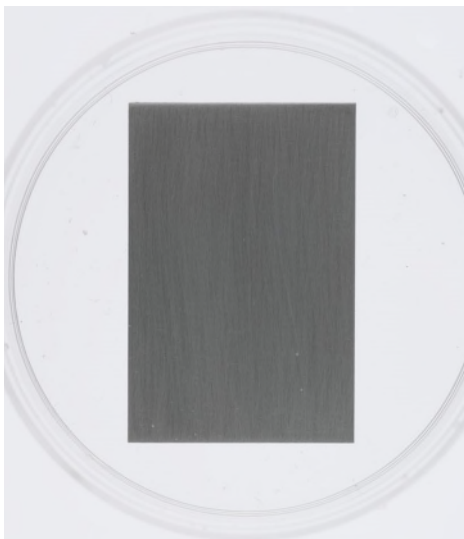
[Flash rusting of four water drops on iron](#)

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Immersion of carbon steel coupon in tap water

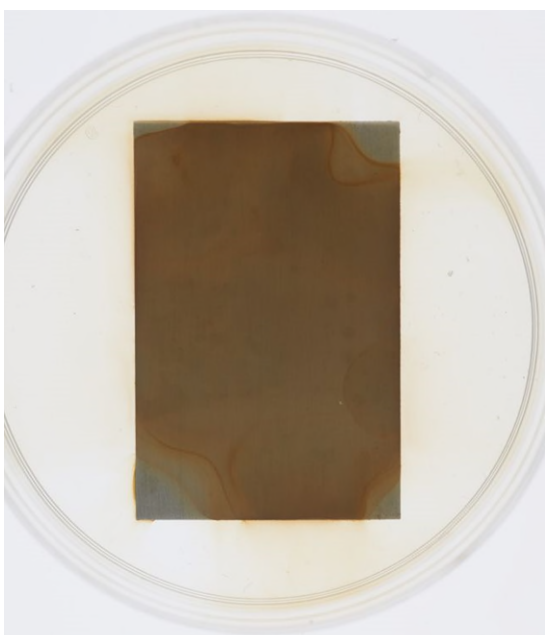
When a carbon steel coupon is first immersed in tap water, the surface is bright and shiny, as shown in Figure 10. Before immersion, this coupon had been cleaned with acetone, then abraded with 220 grit sandpaper. Within 5 minutes, there is evidence of corrosion as orange rust starts to form. Figure 11 shows the surface after it has been immersed for 30 minutes in tap water. The surface of the coupon gradually becomes more orange over the next few hours. Figure 12 shows the carbon steel coupon after 5 hours of immersion.



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Figure 10. A carbon steel coupon just after it has been immersed in tap water.



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Figure 11. A carbon steel coupon 30 minutes after it has been immersed in tap water.



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Figure 12. A carbon steel coupon 5 hours after it has been immersed in tap water.

After several days, the surface of the coupon becomes bright orange. Figure 13 shows the carbon steel coupon after 72 hours (3 days) of immersion in tap water. When the coupon is removed from the solution and the orange residue wiped off, the surface beneath should be darkened, as shown in Figure 14.



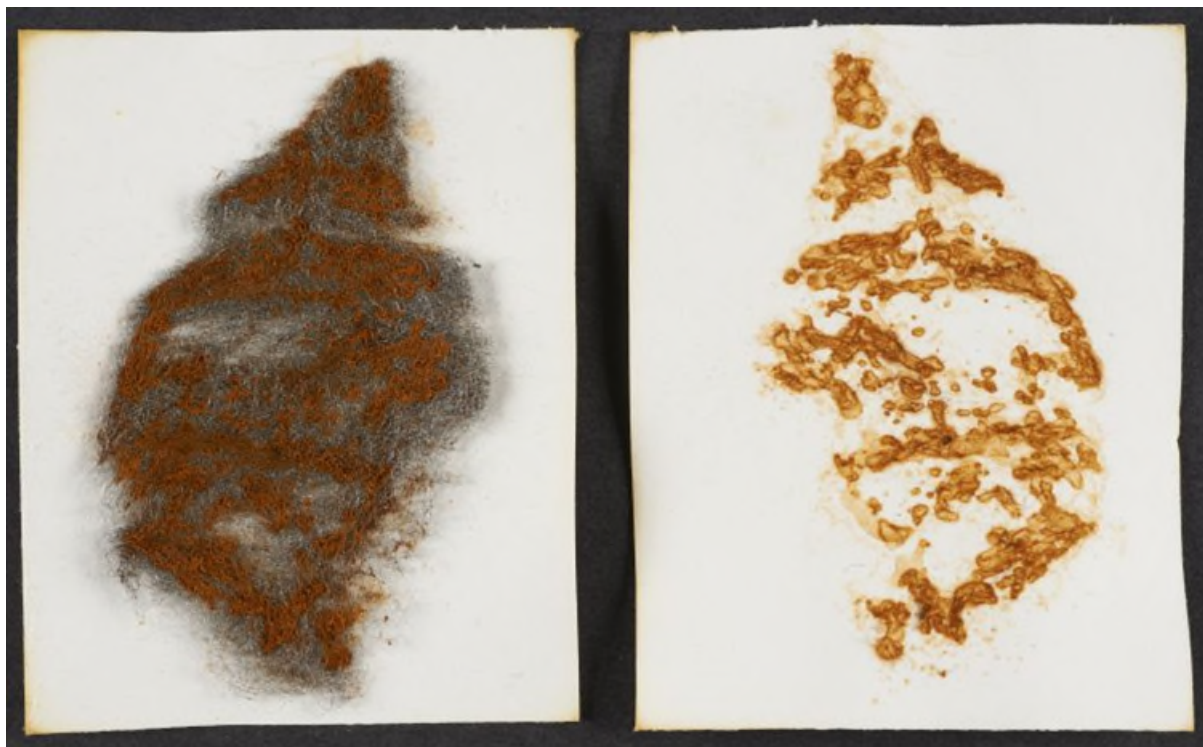
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Figure 13. A carbon steel coupon 72 hours (3 days) after it has been immersed in tap water.



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Figure 14. The carbon steel coupon after the orange corrosion has been gently wiped off. The underlying surface has darkened in areas.

Iron staining of paper (optional)

The fine strands in steel wool can easily flash rust. When wet steel wool is sandwiched between two pieces of wet blotting paper and then allowed to slowly air dry, the steel wool rusts. As the iron in the steel is rusting, some of the iron ions diffuse into the blotting paper where they then precipitate as orange rust. After the blotting paper has dried and the steel wool is uncovered, parts of the steel wool should be covered with some of the orange rust that stained the blotting paper. An example of this is shown in Figure 15.



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Figure 15. On the left is rusted steel wool (grade 0000, ultrafine) on white blotting paper. On the right are the resultant rust stains on blotting paper after contact with the wet rusting steel wool on the left.

Suggestions for additional testing

Compare flash rusting on iron in solutions with different concentrations of salts. Instead of tap water, try deionized water or solutions with different concentrations of sodium chloride. Try using a sodium chloride solution such as a commercial product with a standard chloride ion concentration (e.g. 0.1 M NaCl) or make up a solution where iron has the fastest corrosion rate (0.5 M NaCl). Rust will be faster to develop with salt water, and the powdery residue may be darker than with tap water. Rust will be slower to develop with deionized water and may not form at all before the deionized water evaporates.

If steel wool and carbon steel coupons are not available to show the transfer of rust and iron staining of paper, then try a few common nails (not galvanized nails) instead. Clean the nails with sandpaper to ensure there is no oil or protective coating to interfere with rusting. Tightly wrap the nails in wet paper towel, and allow the paper towel to air dry. Squeeze out excess liquid from the paper towel before wrapping the nails, and then squeeze the paper towel around the nails to provide good contact.

Additional information

Carbon steel sheets

Carbon steel sheets are available in various thicknesses. In this procedure, 20 gauge (0.9 mm) thick pieces were used. New sheets are sold with oil on the surface to prevent rusting; this oil needs to be removed prior to use for this activity. Do not buy hot-rolled carbon steel because the surface is covered with a form of rust called mill scale created by the hot rolling process. If a metal shear is not available to cut the sheets, ask the metal supply company if they can cut the sheets into coupons of the required size.

Flash rusting in non-archaeological contexts

Outdoors and uncovered, iron may be subjected to wet/dry cycles. Large historic iron objects may have to be stored outdoors or in warehouses with uncontrolled humidity. Farm equipment and machine tools lose the oil or paint coating that protected them when being actively used and then become covered with a layer of rust (Prytulak 1999). The dark brown rust is a familiar sight on such objects, but if these rusty objects become wet, they can flash rust, rapidly turning an unsightly orange. Examples of flash rusting on objects are shown in Figures 16 and 17.



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Figure 16. An example of flash rusting on the iron component of a historic fork with a wood handle.



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Figure 17. A cast iron turtle with flash rusting on the left side and stable rust on the right side.

When dealing with an emergency involving water, it has been recommended that unstable metal, such as iron that can corrode quickly, be treated within 48 hours (Galban 2002). The results from the procedure in this learning resource to make iron rust demonstrate that a lot of flash rusting can happen in 48 hours. If there is flash rusting on a wet object, most of the bright orange rust can be removed by brushing with a soft bristle brush and rinsing with clean water, followed by blotting the surface with lint-free towels and then air drying using fans.

If the flash rusting on an iron object has dried, it can be removed mechanically, such as with fine steel wool (000 or 0000 grade) and a few drops of light oil, as outlined in CCI Note 9/6 [Care and Cleaning of Iron](#).

Flash rusting in an archaeological context

Archaeological conservators may encounter flash rusting near the end of a treatment to remove salt from archaeological objects that contain iron. The objects are soaked, sometimes for months or years, in alkaline solutions such as 0.5 M (2% w/v) sodium hydroxide (North and Pearson 1978). The solution is changed when the concentration of chloride ions washed from the object builds up. The treatment can be stopped when the chloride ion concentration in solution remains low for several solution changes; one recommended low value is 5 mg/L chloride ion (Rimmer et al. 2013b). During the soaking, the high pH of the sodium hydroxide solution keeps the iron from rusting, but at the end of the treatment the sodium hydroxide has to be rinsed from the object. During the rinsing, the pH or conductivity are monitored until the rinse solution is close to neutral pH or has low conductivity. When the pH on the iron surface drops below about 11, the remaining iron metal often starts to rust again, forming the bright orange typical of flash rusting.



[Flash rusting of four archaeological iron nails](#)

This video was created by the Canadian Conservation Institute.

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These nails had been treated in 1% w/v sodium hydroxide for several years, soaked in water for 24 days, then removed, brushed to remove any bright orange rust and placed into fresh water prior to recording the video. Figure 18 shows them after three days in the same water bath, and Figure 19 shows them after being dried.



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Figure 18. The four archaeological iron nails after immersion in water for three days, showing the bright orange colour and flocculent nature of flash rusting and the orange staining of the water.



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Figure 19. The four archaeological iron nails after immersion in water for three days followed by immersion in acetone and then air drying. The bright orange corrosion was not intentionally removed, but most of it came off during the transfer to acetone.

Archaeological conservators deal with flash rust during rinsing by brushing off small objects or hosing off large ones at the end of each washing cycle, prior to placing the object in a fresh bath. Any remaining flash rusting at the end of treatment is removed mechanically, such as with a stiff brush.

Finishes to minimize flash rusting after treatment

Various finishes can help minimize future flash rusting after treatment. These include the application of wax, lacquer or oils, as outlined in CCI Notes 9/6 [Care and Cleaning of Iron](#) and 15/4 [Indoor Display of Industrial Collections](#), or a non-protective but aesthetically pleasing black layer formed using tannic acid, as outlined in CCI Note 9/5 [Tannic Acid Coating for Rusting Iron Artifacts](#). Cast iron stoves are often coated with stove polish to turn them black. Such polishes contain a black pigment and may or may not contain wax.

Flash rusting in industry

The term “flash rusting” has a specific, technical meaning in the world of coatings. There, flash rusting is a problem that occurs after iron has been washed with high-pressure water spray in preparation for

painting (ASTM 2015; SSPC/NACE 2002). As the iron dries, it corrodes rapidly and becomes covered with a layer of orange rust. If the rust layer is thin and adherent, paint can be applied over it; if it is thicker and rubs off easily, it must be removed before any paint is applied. Coatings manufacturers specify what degree of flash rusting is acceptable for their products, according to defined standards of flash rusting (SSPC/NACE 2002). Corrosion inhibitors have been developed to be added to the spray water, to slow the flash rusting until the coating can be applied (ASTM 2015).

Dangers of iron contamination on other metals from steel wool or other tools

The use of steel wool and steel wire brushes on other metals (e.g. stainless steel, copper alloys, aluminum) is never recommended because their use can leave tiny pieces of iron trapped in the surface. Over time, especially outdoors, high humidity or rain will cause the iron to undergo flash rusting and result in ugly rust stains. Similarly, grinding wheels used on iron should not be used later on other metals, because bits of iron can be transferred to the other metals. Any grinding of iron should be done well away from other metals, so that any iron ejected from the grinding wheel does not land on the other metals.

Damage to organics by iron ions

When iron corrodes, it produces iron ions that can damage natural polymeric organic materials, such as cellulose and proteins (Selwyn 2004). Cellulose is the main organic constituent in paper, wood, cotton and linen. Proteins (e.g. keratin, collagen and fibroin) are present in materials such as wool, leather, parchment, skin and silk. Iron ions catalyze (accelerate) the oxidation reaction of these organic polymers, degrading them and causing them to become fragile, brittle and easily damaged. For example, when a sewing needle is left in a piece of fabric, the needle can rust during periods of high humidity. Then, as the iron ions migrate into the fabric, they not only damage it but also stain it when they eventually precipitate as rust.

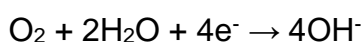
The science behind flash rusting

Reactions between iron and water

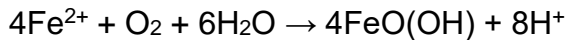
In water, iron metal is oxidized (loses electrons) and something else, usually dissolved oxygen gas, is reduced (gains electrons). These two reactions happen at the same time but not necessarily at the same place on the surface. The reaction for oxidation of iron to iron(II) ions (Fe^{2+}) is:



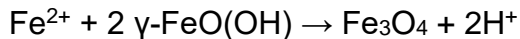
The reaction for reduction of dissolved oxygen to hydroxide ions (OH^{-}) is:



The iron(II) ions dissolve in the water and diffuse away from the metal surface. They can react with dissolved oxygen to form iron(III) ions, which are much less soluble than iron(II) ions and so precipitate out as an iron hydroxide or oxyhydroxide (rust) (Cornell and Schwertmann 2003). The reaction is:



The iron oxyhydroxide formed in flash rusting is usually lepidocrocite, $\gamma\text{-FeO}(\text{OH})$, which is produced when there is rapid oxidation of a solution containing iron(II) ions (Misawa et al. 1974). Lepidocrocite gradually transforms to the more thermodynamically stable form of goethite, $\alpha\text{-FeO}(\text{OH})$ (Stratmann 1990). Another form of iron oxyhydroxide, akaganéite, $\beta\text{-FeO}(\text{OH})$, forms if there are chloride ions present in the solution in a concentration above about 2 M (Refait and Génin 1997). The black compound, magnetite, Fe_3O_4 , may also form, through the combination of iron(II) and iron(III) ions through a reaction such as:



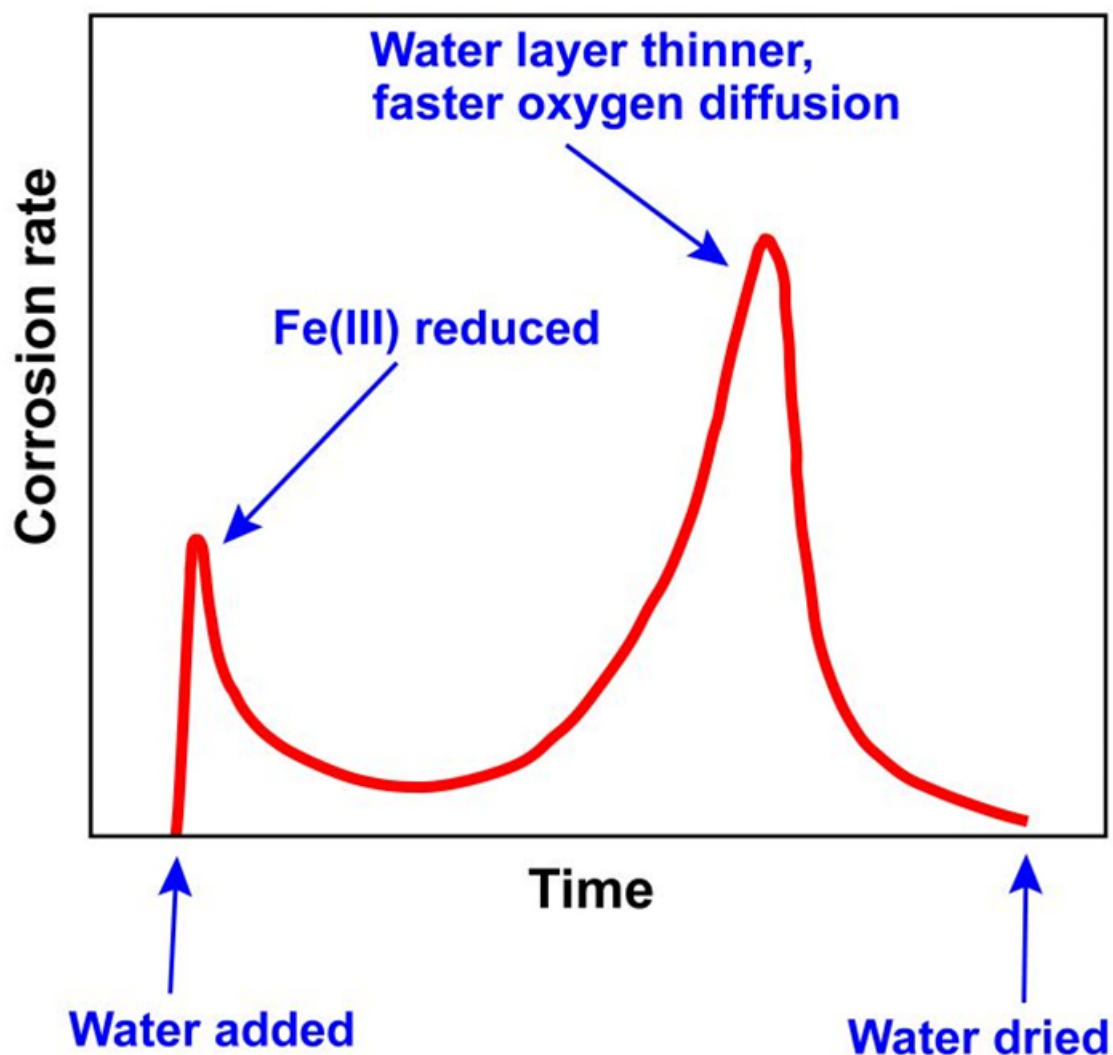
Because most of the solid precipitate does not form directly on the metal surface, it does not offer much protection against further rusting (Evans 1948).

Rust forming in a drop of water

Rust in water droplets is sometimes observed to form in a ring (Evans 1981), as shown in Figure 7. The reduction of oxygen occurs mainly around the outer edge of the drop because the water layer is thinnest there, so oxygen diffuses most rapidly to the metal surface. The oxidation of iron occurs mainly in the centre of the drop where the concentration of dissolved oxygen is lowest and the accompanying reduction of oxygen is mainly at the edges. When the iron(II) ions diffusing outward from the centre of the drop encounter oxygen diffusing inward from the outside of the drop, iron(III) oxyhydroxide precipitates and the inside of the drop fills with orange rust.

Corrosion rates

As a wet iron surface dries, the water layer gets thinner and oxygen can reach the iron surface more quickly, speeding up the corrosion rate (Stratmann 1990). The corrosion occurs most rapidly just before the surface dries completely (the second, larger peak shown schematically in Figure 20). If the iron already has a layer of lepidocrocite when it gets wet, iron(III) ions in the rust can be reduced to iron(II), supplementing the reduction of oxygen and giving an initial burst in the corrosion rate (Stratmann 1990) (the first, smaller peak in Figure 20). After the surface dries, the iron(II) formed in this way is oxidized back to iron(III).



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Figure 20. Schematic diagram showing corrosion rate graphed against time for rusted iron. When the already rusted iron first becomes wet again, there is a spike in the corrosion rate [from iron(III) ions being reduced], then a steady corrosion rate for a period of time until the highest rate happens as the surface dries. Adapted from Stratmann (1990).

There is a second reason why flash rusting speeds up as the surface is drying: ions in the water become more concentrated as the water evaporates. The ions are produced by salts dissolved in the water. Outdoors, rain water is a source of various ions, such as chloride, sodium, potassium, calcium and sulfate (Junge and Werby 1958); tap water also contains various ions. Ions are needed for ionic

current to flow in the liquid between areas where iron is being oxidized and areas where oxygen is being reduced. A higher concentration of ions allows the current to flow more easily. For this reason, flash rusting occurs more slowly in tap water than in a solution of sodium chloride, and even more slowly in deionized water. Some ions, notably chloride ions, also increase the corrosion rate by interfering with the ability of the corrosion layer to protect the surface.

Iron has the highest corrosion rate in a sodium chloride solution when the concentration is around 0.5 M NaCl (Foley 1970). For concentrations below 0.5 M, the corrosion rate of iron increases with concentration because the solution conductivity also increases. Above 0.5 M, the corrosion rate of iron decreases because the solubility of oxygen decreases. The concentration of chloride ions in seawater is about 0.54 M (mostly from NaCl) (Stumm and Morgan 1996).

Corrosion at high relative humidity

The term “flash rusting” usually refers to corrosion of wet iron and can begin within minutes. Iron exposed to high relative humidity (RH) also corrodes, but more slowly. At high RH, even if the iron does not appear to be wet, the surface is covered by adsorbed water. The thickness of the water on a metal increases with RH, becoming several molecules thick at high RH (Leygraf and Graedel 2000). The corrosion rate increases rapidly above a certain RH, called the critical RH, which is about 65% RH for iron (Phipps and Rice 1979). Above this RH, there is enough adsorbed water on the surface to resemble bulk water and promote corrosion.

Rusting of iron may also be promoted if impurities such as dirt particles, salts (such as from fingerprints) and acidic pollutants are present on the surface (Rimmer et al. 2013a). These impurities can attract and trap moisture next to the metal surface, thereby promoting local corrosion. Regular cleaning to reduce deposited dust from metal surfaces will help to reduce corrosion and damage to the surface (Thickett and Costa 2014).

Many salts are hygroscopic (take up water), and so can produce moisture on the surface of iron, even at relatively low RH. Dust accumulating on the surface of bare iron is often the source of these salts. These may lead to local corrosion spots when these salts pick up moisture.

Acknowledgements

Special thanks to Alyson Tang and Megan Doxsey-Whitfield (former CCI interns), Liz Croome (Parks Canada) and Miriam Harris (Fleming College) for their help in developing this activity.

Suppliers

Note: The following information is provided only to assist the reader. Inclusion of a company in this list does not in any way imply endorsement by the Canadian Conservation Institute.

Carbon steel sheets

Flat sheets of cold-rolled carbon steel are available from metal supply stores, such as [Metal Supermarkets](#).

Chemicals and laboratory supplies

Sodium chloride, organic solvents, pipettes, disposable Petri dishes and disposable nitrile gloves are available from chemical supply companies such as [Fisher Scientific](#).

Chloride ion standards

[Ricca Chemical](#) makes a range of chloride ion standards and these are distributed by chemical supply companies such as [Fisher Scientific](#).

Putty knives

Putty knives are available in most hardware and low-cost dollar stores. Buy inexpensive ones made of carbon steel, not the more expensive ones made of stainless steel.

Steel wool

Steel wool is available in different grades ranging from the fine (0000) to coarse (4) and is available in many hardware stores. Oil-free steel wool is also available, such as from [Lee Valley](#).

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