Q Since steel expands when it rusts and destroys whatever is around it, why doesn't the rebar used to reinforce concrete footings and foundations—which are in contact with ground water—rust and break the concrete into pieces?

A *Foster Lyons, an engineer and building-science consultant, responds:* The short answer is, it does, but it happens so slowly and takes so long that it is insignificant to us. Properly placed rebar typically corrodes at a rate of about 1/10 micrometer per year across the thickness of the material. So, under normal conditions, a #5 bar (5/8-inch diameter) loses 2/10 micrometer from its diameter every year.

To determine if this is a problem, we have to understand the size of a micrometer. Also known as a micron and symbolized by the Greek letter μ, a micrometer is equal to one millionth (1/1,000,000) of a meter. By way of comparison, fine, thin hair is about 30μ in diameter and thick hair, about 130μ. A razor blade is about 0.4μ at its cutting edge, while a sharp knife blade is about 1μ; 5μ at the cutting edge is considered dull.

Rebar encased in concrete can still corrode, but the process is typically very slow. The surface corrosion shown here doesn't affect the steel's structural integrity and can be cleaned off prior to repriming and concrete repair work.

Photo: Jake Lewandowski

At a corrosion rate of 0.1μ per year, it will take 31,750 years to reduce the diameter of a #5 rebar from 5/8 inch to 1/2 inch, and 158,750 years to corrode it down to nothing. If Stonehenge had been built with well-placed reinforced concrete instead of natural stone, the concrete would still be totally functional today. So, the real questions are:

- Why does rebar corrode so slowly under typical conditions?
- Why does it sometimes corrode quickly?

The answer to both questions lies in the chemistry inside the concrete. Most of the time, this chemistry is unfavorable for galvanic action of steel, with a pH level that is normally about 13.5. That's quite high; stronger than oven cleaner but not quite as strong as the liquid drain cleaner you might use when your tub drain is clogged with 130μ hairs. The high pH in concrete is caused by a lot of loose calcium, sodium, and potassium ions—usually from the cement—and water, making it a little bit like a solid version of rat poison.

A pH level of 13.5 puts the steel into what's called a neutral state, meaning that the iron doesn't dissolve off into any water solution that may be around it (it's really the iron oxide that doesn't dissolve off; it then acts as a protective layer for the pure iron below). Without loose iron atoms, rust can't get started.

If the pH level is reduced to around 8.5 (which is about like hair perm solution, toothpaste, and hand soap), then the iron will loosen up and go into solution. When the pH goes below about 8.5, the protective iron oxide layer starts dissolving off and, voila, rust. This is called carbonation, which is great for soda (pH about 3 or 4) but bad for concrete.

There are a few things that can cause the pH in concrete to dip. The first is chlorine, which reaches the rebar through cracks and voids and messes up that protective layer of iron oxide. As a result (well, there are other factors too, but this is the short version), loose iron atoms are everywhere, and those atoms start oxidizing. So, the lesson here is to keep chlorine away from reinforced concrete.

When you see concrete destroyed by rusty rebar in sidewalks, it's usually because of chlorine. Somebody salted the sidewalk and the chlorine got to the rebar. The same concept applies for roads and bridges and for balconies on high-rise apartment buildings right on the beach in Miami.

Another factor that can cause rebar to rust prematurely is carbon dioxide, or CO_2, which reacts with loose calcium, sodium, and potassium ions and starts reducing the pH in the concrete. When you see concrete within a building that has been damaged by rusty rebar, that's usually because of CO_2-caused carbonation.

Unfortunately, there's a lot of CO_2 around; fortunately, it doesn't migrate into concrete very quickly, with the rate of carbonation affected by the relative humidity in the concrete. When concrete gets wet, there is typically high relative humidity, and the rate of carbonation increases because the CO_2 dissolves in the condensed water in the pores—capillary condensation—and moves faster through the water. When concrete remains dry, it usually stays at a low internal relative humidity, and the amount of carbonation is insignificant. It's those sections of concrete that are exposed to the air and get wet while also providing only a thin layer of cover over the rebar that can lead to corrosion problems on the rebar.

That's why the American Concrete Institute's (ACI) coverage recommendations are so important. CO_2 moves slowly inward from the outer surface of the concrete where it is exposed to air, so keep rebar away from the outer edges as much as structurally possible. The goal is to make sure the rebar stays in an area that is less likely to get wet and less likely to experience carbonation (and therefore less likely to have low pH levels), so the iron is less likely to start rusting.

Reinforced concrete footings, for example, have a very high relative humidity since they exist in the ground. But because there's not much air movement down there, carbonation goes super slow; the CO_2 at the surface of the concrete isn't being replenished by any fresh breezes blowing by. Also, specifying at least 3 inches of cover for the rebar—per ACI recommendations—helps to insulate the rebar. It will take a few hundred years or so for any stray CO_2 to migrate through 3 inches of concrete, and then another few hundred years before there's enough to cause problems. To me, that's nothing to worry about.

Except for the problem with rebar, CO_2 is great for concrete and for mortar, making them stronger and more adherent. And we should all be happy that the CO_2 is getting pulled out of the atmosphere.