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Metallurgy and Corrosion

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Introduction

Metallurgical research at Rensselaer spans development and processing of advanced alloys for structural and aerospace applications, to interconnects and contacts for electronic technologies, in addition to fundamental studies of their degradation and corrosion mechanisms. This research combines strengths in advanced characterization techniques and predictive computational simulations to uncover the dependence of microstructure on composition, growth and processing techniques, its effect on mechanical properties and chemical stability, as well as to actively control it to target desired properties. Engineering microstructures of metals and alloys depends critically on quantitative understanding of nucleation and solidification. This involves experimental characterization of microstructure, mechanical, thermal and electrical properties using electron microscopy, differential thermal analysis, electrodeposition and directional solidification studies, coupled closely with computational modeling using phase field methods. Present focus areas for microstructural design include aluminum alloys for mechanical properties, and lead-free solders such as Sn-Ag-Cu alloys for electrical contacts. Chemical stability, corrosion and degradation are key concerns for metallic materials, which become increasingly important at reduced nanoscale dimensions in new technologies. Advanced characterization tools such as in situ electron microscopy combined with electrochemical measurements enable investigation of fundamental nanoscale mechanisms of corrosion of materials and solid-state electrode degradation in batteries. Corrosion research at Rensselaer also extends beyond metals to ferroelectric materials under extreme conditions of low pH, high pressures, and high temperatures for applications in oil and gas exploration.

Corrosion is the disintegration of an engineered material into its constituent atoms due to chemical reactions with its surroundings. In the most common use of the word, this means electrochemical oxidation of metals in reaction with an oxidant such as oxygen. Formation of an oxide of iron due to oxidation of the iron atoms in solid solution is a well-known example of electrochemical corrosion, commonly known as rusting. This type of damage typically produces oxide(s) and/or salt(s) of the original metal. Corrosion can also refer to other materials than metals, such as ceramics or polymers, although in this context, the term degradation is more common. Corrosion is the primary means by which metals deteriorate. Most metals corrode on contact with water (and moisture in the air), acids, bases, salts, oils, aggressive metal polishes, and other solid and liquid chemicals. Metals will also corrode when exposed to gaseous materials like acid vapors, formaldehyde gas, ammonia gas, and sulfur containing gases. Corrosion specifically refers to any process involving the deterioration or degradation of metal components. The best-known case is that of the rusting of steel. Corrosion processes are usually electrochemical in nature, having the essential features of a battery. When metal atoms are exposed to an environment containing water molecules, they can give up electrons, becoming themselves positively charged ions, provided an electrical circuit can be completed. This effect can be concentrated locally to form a pit or, sometimes a crack, or it can extend across a wide area to produce general wastage. Localized corrosion that leads to pitting may provide sites for fatigue initiation and, additionally, corrosive agents like seawater may lead to greatly enhanced growth of the fatigue crack. Pitting corrosion also occurs much faster in areas where microstructural changes have occurred due to welding operations. Corrosion is possible only as long as certain metals have impurities, oxygen and moisture. The corrosion of metals such as iron is an electrochemical process. Very pure samples of iron seem to resist corrosion. In contrast, when a piece of iron containing specks of impurities such as copper are exposed to moist air, the iron becomes pitted with rust spots. Iron rust is a reddish-brown hydrated compound of varying composition have the formula Fe(OH)3.x H2O. Therefore, rust spots indicate the location at which pure iron has been oxidized.

When a metal corrodes in water, the atoms lose electrons and become ions that move into the water. This is called an anodic reaction, and for the corrosion process to proceed there must be a corresponding cathodic reaction that adsorbs the electrons. The process can be stopped by isolating the metal from the water with an impermeable barrier. One of the older applications of this idea is the tin can. Unlike steel, tin is not affected by the acids in food, so that a layer of tin placed on steel sheet protects the steel in the can from corrosion. The exterior surfaces of many large household appliances consist of steel covered with a layer of colored glass called enamel. Enamel is inert and adheres tightly to the steel, thus protecting it from corrosion as well as providing an attractive appearance. Decorative chromium plating is another example of a protective-barrier coating on steel. Since chromium does not adhere well to steel, the steel is first electroplated with layers of copper and nickel before being plated with a thin layer of chromium. The protective layers described above are metallic, but the most common protective barriers are organic. Paints, polymers, and thin lacquer films are used for various applications near room temperature.

Types of corrosion

There are several types of corrosion and the science and understanding of these processes are constantly evolving. Here is a brief overview of some common types of corrosion:

- Galvanic cowrrosion is the most common and impactful form of corrosion. It occurs when two dissimilar (different) metals are in contact in the presence of an electrolyte. In a galvanic cell (bimetallic couple), the more active metal (anode) corrodes, and the more noble metal (cathode) is protected. There are a number of factors that affect the galvanic corrosion including types of metals, relative size of anode, and environment (temperature, humidity, salinity, etc.)
- Pitting Corrosion occurs under certain conditions, which leads to accelerated corrosion in certain areas rather than uniform corrosion throughout the piece. Such conditions include low concentrations of oxygen or high concentrations of chlorides (anions) that interfere with the alloys ability to reform a passivating film. In the worst cases, most

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of the surface remains protected, but tiny fluctuations degrade the film in a few critical areas. Corrosion at these points is amplified and can cause pits.

- Microbial corrosion, commonly referred to as microbiologically influenced corrosion (MIC) is caused by microorganisms. It applies to both metallic and non-metallic materials with or without oxygen. When oxygen is absent, sulfate-reducing bacteria are active and produce hydrogen sulfide causing sulfide stress cracking. When oxygen is present, some bacteria may directly oxidize iron to iron oxides and hydroxides. Concentration cells can form in the deposits of corrosion products, leading to localized corrosion.
- High-temperature corrosion, as its name suggest, is deterioration of a metal due to heating. This can occur when a metal is subjected to a hot atmosphere in the presence of oxygen, sulfur, or other compound capable of oxidizing the material.
- Crevice corrosion occurs in confined spaces where access of fluid from the environment is limited such as gaps and contact areas between parts, under gaskets or seals, inside cracks and seams and spaces filled with deposits.

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Conflict of Interest

Author declares there is no conflict of interest

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