

Effects of Magnetic Fields on Corrosion

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It is well known that magnetic fields can affect the rate of electrochemical reactions by changing mass transport of ions in the solution (e.g.1,2,3). In the present work, we demonstrate that magnetic effects can be observed both during corrosion of magnetic materials such as NdFeB and in “artificial pit” electrodes commonly used for studying the growth of corrosion pits. Magnetic fields can either accelerate or reduce the rate of corrosion, depending on the geometry. However, significant effects are only observed under conditions where there are high local current densities (with a correspondingly high rate of corrosion) and high or highly inhomogeneous fields.

NdFeB is a permanent magnet material that is highly susceptible to corrosion owing to the presence of a reactive Nd-rich phase. If a droplet of dilute HCl is placed on the surface of a piece of NdFeB, vigorous corrosion will take place with the evolution of hydrogen. If the sample is in its magnetized state, the droplet will rotate (and the direction of rotation is reversed in a droplet is placed on the opposite pole of the magnet). No rotation is observed for demagnetized samples. Furthermore similar rotation is observed during potentiostatically-controlled hydrogen evolution. In addition, the morphology of corrosion attack of immersed samples is affected by the state of magnetization.

Corrosion pits grow at local occluded sites on otherwise passive metal surfaces. They are stabilized by the aggressive nature of the solution that develops adjacent to the dissolving interface: the metal ions produced undergo hydrolysis, lowering the pH, and also draw chloride ions into the pit cavity to balance charge. Both a low pH and high chloride ion concentration catalyze dissolution. However, if the aggressive solution is able to diffuse out of the pit cavity, then the metal surface within the pit is able to regrow its passive film, and the pit will “die”. The criterion for stability of a pit is that the metal cations produced at the dissolving interface should be produced faster than they can escape from the cavity. If ions are produced faster than they can escape, the solution will become supersaturated, and a salt film will deposit on the metal surface.

Real pits have a complex geometry that evolves with time, so it is difficult to study the stability parameters. Instead, investigations frequently use artificial pits (e.g. 4), as illustrated in Figure 1. Here the diffusion is 1-dimensional, and readily modeled.

Experiments were carried out with 0.25 mm diameter wires embedded in epoxy in the presence and absence of a magnetic field of 0.35 T. The behavior of the ferromagnetic materials Fe, Ni, and Co was compared with that of paramagnetic austenitic stainless steel.

Addition of ferroxyl inhibitor to the solution

showed that the Lorentz force acted on the ions in the external solution for both Fe and stainless steel. However, the current/voltage characteristics of pits were affected by the field only for ferromagnetic Fe. This appears to be a result of the effect of high field gradients at the periphery of the wire that can either trap ions or cause stirring depending upon the field orientation.

Figure 2 shows the effect of a magnetic field applied parallel to an iron wire. The field gradient at the periphery of the wire traps ferrous ions, leading to easier precipitation of a salt film and a lower dissolution rate than in the center of the wire, and thus a deeply-concave end to the wire at the end of the experiment. The overall effect is to suppress corrosion within the pit, which can be observed in the current/voltage characteristic of the pit.

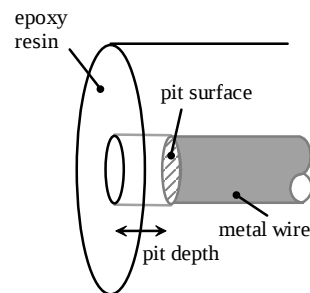


Figure 1. Schematic diagram of an artificial pit.

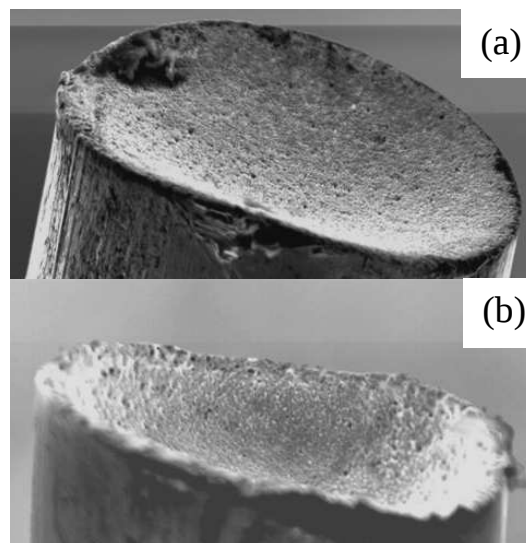


Figure 2. Fe in 1 M NaCl without (a) and with (b) a 0.35 T magnetic field applied parallel to the wire.

References

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