

LETTER TO THE EDITOR

Effect of a Local Magnetic Field on the Dissolution of Copper and Iron in Nitric Acid Solution

A new phenomenon has been found on the effect of a magnetic field on the corrosion of metals; when a thin metal plate is dissolving in an acid solution, if a powerful permanent magnet is brought close to one of the surfaces of the plate, a thick diffusion layer of dissolving ions is formed on the other surface just above the magnetic pole. This layer causes a decrease in the corrosion rate here, which forms a raised pattern of the magnetic pole. The present paper reports this phenomenon for copper and iron in nitric acid solution.

The arrangement of the sample and the permanent magnet is shown in Fig. 1. The copper and iron plates used were square ones of $20 \times 20 \text{ mm}^2$, cut from a 0.5 mm thick tough-pitch copper sheet and a 0.3 mm thick cold rolled steel sheet, respectively. Prior to the experiment, they were cleaned in acetone using an ultrasonic-wave bath. The samarium-cobalt permanent magnets on which the specimens were mounted were rectangular blocks of $10 \times 3 \times 5 \text{ mm}^3$ with the magnetization direction parallel to the 5 mm dimension. The strength of the magnetic field about 0.5 mm above the pole surface was 240 kA/m. 6.5 k mol/m^3 and 3.3 k mol/m^3 nitric acid solutions were used for the dissolution of copper and iron, respectively. The temperature of the solutions was 298 K at the start of the reaction.

Soon after a metal plate with a magnet touching its lower surface is immersed in a nitric acid solution, a thick diffusion layer of dissolving ions is observed on the top surface just above the magnetic pole. This layer is of approximately the same size and shape as the

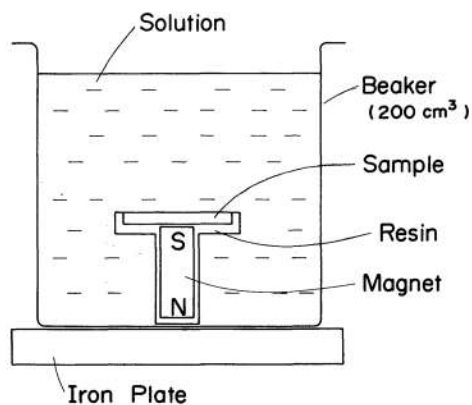


Fig. 1 Arrangement of the sample and the permanent magnet in the solution.

magnetic pole on the opposite surface. Photograph 1 shows these diffusion layers formed on the copper and iron surfaces. For the copper specimens, this layer becomes nearly uniform all over the magnetic pole area after a short time, while for the iron specimens, it forms around the contour of the magnetic pole at the beginning of the reaction and then develops throughout the area within the contour. Thus, the soluble corrosion products formed during the reaction appear to be attracted to the magnetic pole whether the metal specimen is ferromagnetic or not.

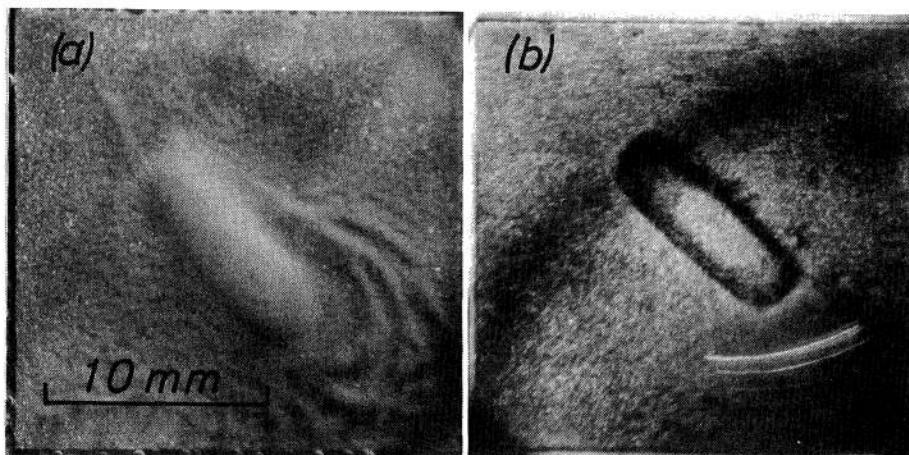


Photo. 1 Surfaces of (a) copper, and (b) iron plates dissolving in 6.5 k mol/m^3 nitric acid solution 10 s after immersion and in 3.3 k mol/m^3 nitric acid solution 5 s after immersion, respectively, with a permanent magnet against the opposite surface.

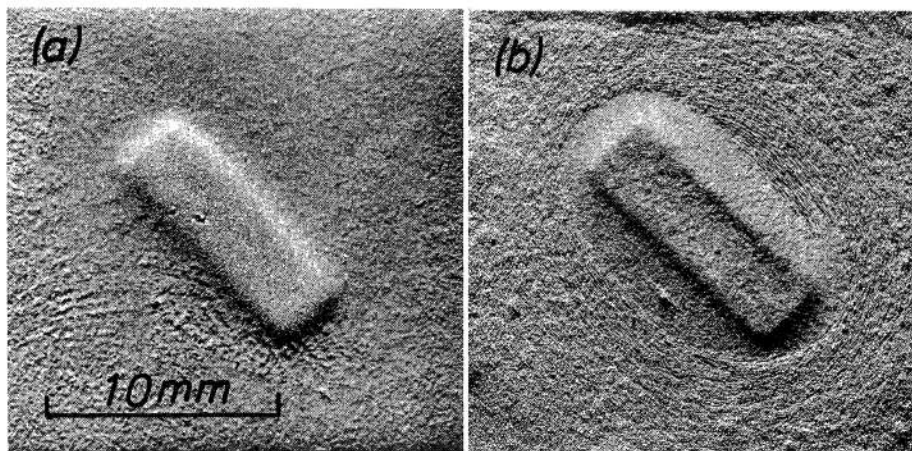


Photo. 2 Shapes of magnetic poles formed on (a) copper, and (b) iron plates immersed in 6.5 k mol/m^3 nitric acid solution for 2.4 ks, and in 3.3 k mol/m^3 nitric acid solution for 1.2 ks, respectively.

The accumulation of the corrosion products just above the magnetic pole causes a decrease in the local dissolution rate. This results in the formation of a raised pattern of the magnetic pole, which is on the opposite surface (Photo. 2). On the copper specimen, the pattern has nearly the same shape as the magnetic pole, while on the iron specimen, it has a complex contour. The area along the perimeter of the magnetic pole is higher than the inner area, and this rectangular pattern is surrounded by an elliptical flat area and numerous elliptical stripes.

Figure 2 shows the decrease in thickness with the reaction time at positions just above the magnet and

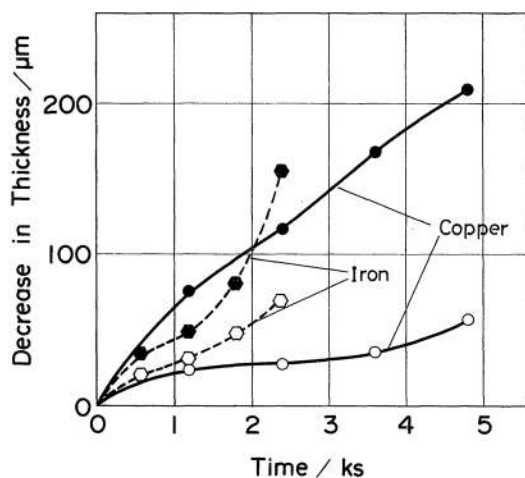


Fig. 2 Decreases in thickness of copper and iron plates in 6.5 and 3.3 k mol/m^3 nitric acid solutions, respectively, at the positions just above the magnet (\bullet , \bullet), and away from the magnet (\circ , \circ).

away from the magnet for the copper and iron specimens. The thickness was measured at the edge of the rectangular pattern on the iron specimen, ignoring the complex morphology. It is evident from Fig. 2 that the strong magnetic field decreases the dissolution rate significantly. This effect is especially prominent in the copper specimen, where the dissolution rate just above the magnet is less than 30% of that away from the magnet.

In Fig. 1, if the metal plate is thin, the magnetic flux from the permanent magnet is nearly vertical at the surface just above the magnetic pole. If there was no magnetic field during the dissolution of the metal plate, the soluble corrosion products, having high specific gravities, would creep across the surface of the metal and fall to the bottom of the solution. However, in the presence of a strong magnetic field perpendicular to the horizontal metal surface as in Fig. 1, the highly charged corrosion products cannot easily leave the area; if they begin to creep on the surface, the path is deflected by the strong magnetic field, which results in the formation of the thick diffusion layer over the magnetic pole.

There have been several studies on the effects of a magnetic field on the corrosion of metals⁽¹⁾⁻⁽³⁾. However, the researchers only deal with Galvanic cells which have two separate electrodes (anode and cathode) with an electric current flowing in one direction between them. In this case, the current interacts with the magnetic flux to generate the Lorentz force in the electrolyte. They have found that the Lorentz force generates vortices in the electrolyte during the reaction, thereby decreasing the diffusion layer thickness and, consequently, enhancing the reaction rate⁽¹⁾⁽²⁾.

In the present experiment, however, a sheet of metal is dissolved through so called local-action cells where the electric current flows in every direction on the metal surface. The applied magnetic field does not generate vortices in the solution and acts to repress the diffusion

of soluble corrosion products across the surface as described above. As a result, the magnetic field increases the diffusion layer thickness, thereby decreasing the rate of mass-transport-controlled reaction.

It seems that a magnetic field has two, opposite, effects on the corrosion of metals and which effect appears depends on the experimental conditions. Even in the corrosion through local action cells, a magnetic field acts to enhance the reaction rate if vortices are generated through the interaction between the magnetic field and the natural convection in a solution⁽⁴⁾.

It should be emphasized that, in ordinary circumstances of corrosion, there are many places where magnetic fields are applied locally. The spontaneous magnetization in ferromagnetic materials generates leakage flux at various defects such as cracks, pits, scratches or inclusions, even if the materials are not magnetized macroscopically. Some phenomena in the corrosion of ferromagnetic metals might be understood more completely by considering the trapping of

the corrosion products by magnetic flux at a variety of surface defects.

REFERENCES

- (1) E. Z. Gak, E. Kh. Rokoson and N. F. Bondarenko: *Sov. Electrochem. (Engle Transl.)*, **11** (1975), 489; *ibid.*, **11** (1975), 495; E. Z. Gak: *ibid.*, **3** (1967), 75; *ibid.*, **3** (1967), 229.
- (2) T. Z. Fahidy: *Electrochim. Acta*: **18** (1973), 607; S. Mohanta and T. Z. Fahidy: *ibid.*, **19** (1974), 771; *ibid.*, **19** (1974), 835.
- (3) E. J. Kelly: *J. Electrochem. Soc.*, **124** (1977), 987.
- (4) M. Sagawa: (to be published).

Masato Sagawa

Fujitsu Laboratories Ltd.,
Nakahara-ku, Kawasaki 211, Japan.

(Received August 24, 1981)
