Summary

The Galvanic and Pitting Corrosion symposia have presented recent laboratory and field corrosion study results in a broad spectrum of corrosive environments that include controlled clean and polluted air, distilled water, 3.5 percent sodium chloride solutions, tap water, seawater, hot brine solutions, organic solutions, and dry high resistivity to wet low resistivity soils.

Pitting is a form of localized corrosion attack which can lead to early failure. Galvanic corrosion has also been the reason for many premature failures. Unfortunately, there are numerous engineering alloys that are highly susceptible to pitting corrosion, for example, the stainless steels and the 2000 and 7000 series aluminum alloys. The aluminum alloys are additionally susceptible to galvanic attack since they are anodic to all other engineering metals (and their alloys) except magnesium and zinc.

The paper by Baboian on electrochemical techniques for predicting galvanic corrosion covers potential, current, and polarization measurements. Although each of these can be useful in determining galvanic effects, he has pointed out that measurements should be made in the actual environment to which materials are exposed. Where potential and current measurements have limitations with regard to localized galvanic corrosion, polarization techniques can be quite useful in predicting the susceptibility to this type of corrosion.

The examination of the galvanic attack of aluminum alloys by ferrous and nonferrous cathodic materials in aqueous media by Mansfeld and Kenkel presents, in effect, a galvanic series for these galvanic couples in specific media. Although some may quarrel with the relatively short test duration, it is obvious that their data can provide a basis for preliminary design.

Compton found that the distribution of cathodic protection current between members of copper steel and stainless steel aluminum in galvanic couples varied by a ratio 940 to 0.05 as the relative areas were varied from 100:1 to 1:100. Polarization and current distribution measurements have shown that at about a 1:1 ratio of cathode to anode, cathodic protection does not appear to be practical.

The method for performing corrosion tests of weldments by Compton and Turley is a straight-forward approach to determining the susceptibility of weld and heat affected zones to accelerated galvanic corrosion attack. Of the nine ferrous and nonferrous weldment systems tested, there was only one wherein the base metal would provide cathodic protection to the smaller surface areas of the weld and heat affected zones.

The galvanic corrosion tests of Shick and Mitchell on underground cable materials using the galvanostatic polarization technique to determine potential and current density established that semiconducting polyethylene jacketing of power cables becomes the cathode of a galvanic cell (polyethylene coupled to concentric neutral copper wires) because the polyethylene contains carbon particles. Another significant result is that aerated soil increased the corrosion rates by orders of magnitude as compared to deaerated soil.

Escalante and Gerhold in their galvanic coupling of stressed stainless steels to the anodic materials iron, zinc, and magnesium at six different underground sites found that the higher strength work-hardened stainless steel alloy Type 301 was inferior to alloy Type 304 and 26 Cr-1Mo in its resistance to cracking. Alloy Type 301 consistently cracked at stresses that were only 22 to 36 percent of the alloy's yield stress as compared to alloys Type 304 and 26 Cr-1Mo that never failed even though the stress levels were from 34 to 93 percent of yield stress. Since there was no failure of noncoupled Type 301 specimens, it is concluded (rightly so) by Escalante and Gerhold that cracking is the result of hydrogen embrittlement that occurs due to the cathodic reaction at alloy Type 301 cathode.

An extensive galvanic corrosion investigation in the Panama Canal Zone including atmosphere, soil, and seawater environments has been described by Pelensky et al. They describe test techniques and initial results of this work.

Specimens of galvanized steel sheet were exposed to polluted and clean air by Spence and Haynie. They show that corrosion of zinc film is essentially a linear function of time. Although weight losses were approximately the same in both environments, uniform corrosion of the zinc occurred in the polluted exposure, whereas pitting was observed in the clean air environment.

Covington describes the pitting problems encountered in titanium tubes in heat exchangers handling hot saturated brine. Two types of pits appear: symmetrical pits about 0.6 cm in diameter which are associated with scratches containing iron, and irregular pits believed to be associated with salt plugs.

The studies by Cornwell et al of pitting of copper tubing by domestic water conclude that in certain types of domestic waters the presence of of carbon residue from the tube manufacturing operations will result in pitting failure in a period of only three months. The authors' solution to this problem is to reduce the carbon contamination through abrasive cleaning.

This position is questioned by Cohen who maintains that it has never been conclusively demonstrated that carbon films on the inside diameter of copper water tubing are the cause of pitting corrosion. Cohen's position is that the cause of pitting in copper water tubes is the chemical make up of a given water system and that the proper solution to this problem is to treat the corrosive water through the addition of lime or caustic soda.

Cornwell et al, in response to Cohen, agree that pitting of copper water tubing is related to specific waters, but their test results show that carbon free tubes did not pit in the same waters that caused rapid failure of carbon containing copper tubes. It is apparent from the data presented by both parties that the pitting corrosion of copper water tubes can be related to both water chemistry and residue carbon films. The service experience related by both parties support their particular position (carbon removal versus water chemistry control), and there is little doubt that both are correct for the case histories given.

Mansfeld covers the pitting behavior of titanium, nickel, 6061 aluminum and Type 304 stainless steel in methanol in the presence of sulfates or chlorides. The behavior of metals in these environments contrast sharply the behavior in aqueous systems. For example, titanium corrodes rapidly in anhydrous methanol because passivation cannot occur. However, additions of water at a concentration as low as 0.6 percent leads to passivation of the titanium.

The review on "Measurement and Evaluation of Pitting Corrosion" by Rowe elaborates on the visual nondestructive and destructive techniques that are used to determine density of pits (number/cm^2) and maximum depth of pitting attack. This review came about through the development of a Recommended Practice for Measurement and Evaluation of Pitting Corrosion by ASTM Subcommittee G01.05 on Laboratory Corrosion Tests.

The basic approach presented by Rowe is to visually examine metals at low magnification to determine the general magnitude of pitting attack. It is correctly emphasized that metal weight loss alone is not a satisfactory procedure for the determination of the extent of pitting. The destructive cross sectioning of pits to provide microscopic measurement or the progressive machining to the bottom of a pit can provide accurate measurements but these techniques are costly, time consuming, and impractical where numerous specimens are involved. The nondestructive measurement techniques of a micrometer or a dial indicator with a sharp tungsten tip or a microscope with a graduated focusing knob are more rapid but do have the limitation of not being able to measure those pits that are not completely open to their bottom.

Rowe makes a most valid point that measurement of maximum pit depth or the average of a number of deepest pits is often the most meaningful method of demonstrating the magnitude of pitting corrosion. An equally important test of the effect of pitting is the change in mechanical properties of the corroded material. These can include ultimate and tensile yield strength, elongation, and reduction in area. The measure of the effect of pitting on the fatigue strength of a material is most important when the material is to be exposed to cyclical stress in a corrosive environment.

Crews proposes a statistical treatment of pitting corrosion data which calculates the prediction intervals of pit depth which can be used to obtain quantitative estimates of service life or corrosion rate in normally encountered environments. The statistical treatment in this paper utilizes a prepared computer program which provides calculated values of both the regression and the distribution, expressed as prediction intervals of pit depth for times both within the exposure period of the test and extrapolated exposure times.

The crevice corrosion test cell presented by Anderson offers a new method of determining susceptibility of a material to localized corrosion. The advantages of the new test configuration are that it provides 40 small crevices per specimen, is inexpensive to produce, and can be used to statistically predict corrosion initiation and propagation.

Anderson's tests on stainless steel, copper, and nickel alloys were performed in seawater. However, the test fixture uses the plastic material Delrin which is highly resistant to many corrosive environments such as acid and alkali solutions, and it could, therefore, be used in these environments.

Petersen uses a unique apparatus to duplicate the environment of a pit. Although this is a difficult if not an impossible task, the results of his work show some interesting correlations between corrosion of carbon steel and solution changes within a cavity. He finds a correlation between pH change and reaction of magnesium and calcium in the electrolyte.

The problem associated with measurements of the critical potentials of stainless steels is covered by Morris. Using the rapid-scan potentiodynamic polarization technique, crevice corrosion can be prevented, thereby permitting accurate and reproducible measurement of the pitting potential.

The compilation of literature references on pitting corrosion includes sections on aluminum, copper, electroplated coatings, environmental effects, graphite, iron and steel, iron-chromium-nickel alloys, nickel, test methods, theoretical, titanium, tungsten, zinc, and zirconium.

Thus, the authors of the papers have presented a wide range of test techniques and results in various environments with a range of materials. This information represents the cumulative efforts of many years of work and is presented herein as a guide to present and future investigations.