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FINAL TECHNICAL REPORT

April 1982

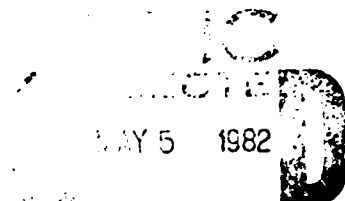
OFFICE OF NAVAL RESEARCH

Contract No. N000-14-75-C-0264,  
N000-14-67-A-0385-0022

USE OF METALLURGICAL VARIABLES AND SURFACE  
PROPERTIES TO CONTROL HYDROGEN EMBRITTLEMENT

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1. REPORT NUMBER Final Technical Report	2. GOVT ACCESSION NO. AD A114170	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Use of Metallurgical Variables and Surface Properties to Control Hydrogen Embrittlement	5. TYPE OF REPORT & PERIOD COVERED Final Technical Report	
	6. PERFORMING ORG. REPORT NUMBER	
7. AUTHOR(s) H. W. Pickering	8. CONTRACT OR GRANT NUMBER(s) N000-14-75-C-0264 N000-14-67-A-0385-0022	
9. PERFORMING ORGANIZATION NAME AND ADDRESS Metallurgy Section, 209 Steidle Building The Pennsylvania State University University Park, PA 16802	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS	
11. CONTROLLING OFFICE NAME AND ADDRESS Metallurgy Branch Office of Naval Research Arlington, VA 22217	12. REPORT DATE April 28, 1982	
	13. NUMBER OF PAGES 10	
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report)	
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE	
16. DISTRIBUTION STATEMENT (of this Report)  Distribution of this document is unlimited		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number)  Hydrogen embrittlement, Electroplating, Hydrogen catalysts, H. Diffusivity and solubility.		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number)  This final report summarizes research carried out during the course of a program directed toward evaluating the factors affecting the absorption of hydrogen by iron and steels during exposure to aqueous solutions. The effects of deposits, barrier-type layers and certain electrolyte additions were investigated. An add-on project was directed toward evaluating the mechanism of protection of Cu10Ni alloy in simulated seawater.		

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H. W. Pickering

Final Technical Report

to

Office of Naval Research

Contract NO. N000-14-75-C-0264,  
N000-14-67-A-0385-0022

April, 1982

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## INTRODUCTION

As an important approach to prevent hydrogen-induced cracking in metals, this project's goal was to evaluate the methods for reducing the absorption of hydrogen in metals and, in particular, in steels when exposed to aqueous solutions. At the time this project started, it was well known that certain additions to the electrolyte, known as poisons, greatly increase hydrogen absorption and that certain metals, e.g., Ni, could be effectively used as barrier-type coatings on steel to reduce hydrogen uptake. Otherwise little was known about either electrolyte or alloy conditions which could affect the absorption step itself, in particular in the direction of reducing hydrogen absorption, or about the factors, diffusivity and solubility of hydrogen, important in the permeability of hydrogen in nickel and other candidate barrier-type layers at ambient temperatures.

A broad based program for studying this problem would include the effects of compositional changes at the surface produced from either the solution or alloy sides of the interface, as well as of local changes in the electrode potential. The latter had been recently shown to vary greatly within pits in iron during anodic polarization (1), so that this possibility during cathodic polarization and open circuit corrosion could not be overlooked. Such a program would also include the study of coatings. Metal coatings are used commercially for preventing hydrogen entry into steel, e.g., austenitic stainless steel and nickel. In this study metal and oxide coatings were investigated with emphasis on the former. The virtual absence of information on the solubility and diffusivity of hydrogen at room temperature in metals which are candidate barrier layers is mainly due to inadequate sensitivity and/or resolution of experimental techniques, e.g., the hydrogen permeation technique

was inadequate at the time for metals like nickel whose permeability for hydrogen is several orders of magnitude lower than for iron. An improved technique was needed.

Research proceeded along two directions. These were:

(a) Examination of the factors which affect the ratio of hydrogen absorbed by the metal to that evolved as H<sub>2</sub> gas. These factors include electrolyte and metal compositions and electrode potential at the local site of the hydrogen evolution reaction. Different metal compositions at, and specific deposits on, the surface were produced by variation of the alloy composition and by ion implantation and electroplating.

(b) A study of adhesion of continuous metal and certain oxide coatings, and of the permeability, including the development of a modified hydrogen permeation method for the measurement of the diffusivity and solubility of hydrogen in the coatings.

For both (a) and (b) the main experimental approach was to use a hydrogen permeation cell in which hydrogen discharges from aqueous solution and absorbs on one (entry) surface of a metal membrane, diffuses through the membrane and oxidizes under appropriate experimental conditions at the other (exit) surface.

## RESULTS AND CONCLUSIONS

### Hydrogen Absorption

A theoretical study was initiated to explore the possibility that certain deposits on the surface would decrease hydrogen absorption, thereby producing the opposite effect to the well known poisons which increase hydrogen absorption. The main prediction of the study was that deposits with higher

hydrogen exchange currents than the substrate surface would decrease absorption if the hydrogen evolution mechanism on the substrate surface involves a dependency of the hydrogen coverage on the overpotential (2-5). Such a dependency has been generally accepted to exist for hydrogen evolution on iron. Hydrogen absorption was determined for three metals meeting this exchange current criterion, Pt, Cu and Ni, and for two different application methods, electrodeposition (2,5) and ion implantation (3,4). The data were consistent with the concept, and hydrogen absorption and permeation were reduced in all cases.

Systematic polarization and permeation data on the effects of  $\text{Cl}^-$  ion and  $\text{H}_2\text{S}$  gas in the charging solution were initiated and are currently being completed. Chloride ion and  $\text{H}_2\text{S}$ , which have opposite effects on absorption, have similar effects on the overpotential for hydrogen evolution.

A theoretical study was initiated on the mass transport kinetics of a solute, e.g., H, diffusing through a bilayer membrane. Solutions available at the time were all based on analogous solutions in the heat transfer literature. The implicit assumption in these solutions is that the concentrations of the solute is the same on both sides of the interface. A solution was not available in the heat transfer literature for the general case in which the concentration differs on either side of the interface (often by a significant amount) since temperature, its counterpart in the heat transfer calculation, is the same on both sides of the interface. This mass transport problem has been solved and has direct application to hydrogen diffusion through bilayer membranes (6), as well as more generally in physical metallurgy.

One of the advantages of the above modeling solution is for using permeation data to obtain the diffusivity and solubility of hydrogen in metals in which their product is very low. The latter is a characteristic of all barrier-type layers. Preliminary data of this kind have been obtained for Sn and Cd (5) and measurements are currently underway for Ni and certain other barrier-type metals.

Oxide coatings were prepared on steel by sputtering and by selective oxidation of solute, e.g., Zr, Ti, Al, and Si. Adhesion was found to be inadequate for the sputtered oxides under typical laboratory, hydrogen-charging conditions and only marginally acceptable of those formed by selective oxidation. While adherent, the oxides were quite good as barriers to hydrogen absorption (7).

#### Local Conditions of Electrode Potential and Solution Composition

In order to see whether or not large changes in electrode potential occurred in cavities during cathodic polarization, both theoretical and experimental studies were initiated. The incentive was the earlier observation of large electrode potential variations in pits in iron during anodic polarization (1).

Model solutions for the concentration profiles of the ionic species and for the electrode potential have been obtained (8-10). These results give semi-quantitative information needed for understanding mechanisms and kinetics of electrode reactions in local regions, e.g., cracks.

Experimental measurement of the electrode potential, solution composition and hydrogen gas formation in slots in iron during hydrogen charging showed (8,9,11)

- (i) hydrogen gas bubbles readily formed and remained in the slot.
- (ii) the local electrode potential shifted in the noble direction with the magnitude of the shift increasing as the bubbles formed.
- (iii) iron dissolution became a thermodynamic possibility as E became more noble than the iron reversible potential, and it was observed to occur at the base of the slot.

Similar results were shown for Ni and Cu, except that the limiting potential for Cu is less than its reversible potential and, consistent with this thermodynamic condition, no Cu dissolution was observed in the slot during hydrogen charging (8,9,12).

Considering the magnitude of the measured shifts of electrode potential and the theoretical limiting values for both anodic and cathodic polarization, it becomes clear that the electrode potential for gas-filled cavities remains virtually independent of the potential at the surface even for large polarization in either direction (8-12).

#### Cu-Ni Alloy Corrosion in Simulated Seawater

Though not an original goal of the project, work was initiated on the mechanisms of protection of CuNi alloy in 3.4 wt.% NaCl solution. The following aspects of the mechanism were determined from electrochemical and spectroscopy methods (13,14):

- (i) the anodic metal dissolution reaction rate increases sharply with potential and is mainly determined by the diffusion of cations in the electrolyte within the porous corrosion product at potentials in the vicinity of the corrosion potential.
- (ii) The cathodic reduction rate of oxygen is weakly dependent on electrode potential and is much suppressed by the poor catalytic nature of outer (porous) corrosion product layers.
- (iii) The low corrosion rate in 3.4 wt.% NaCl and, therefore, probably also for seawater is due to (ii).

REFERENCES

1. H. W. Pickering and R. P. Frankenthal, J. Electrochem. Soc., 119, 1304, 1309 (1972).
2. S. S. Chatterjee, B. G. Ateya and H. W. Pickering, Met. Trans. A, 9A, 389 (1978).
3. M. Zamanzadeh, A. Allam, H. W. Pickering and G. K. Hubler, J. Electrochem. Soc., 127, 1688 (1980).
4. H. W. Pickering and M. Zamanzadeh, "Hydrogen Effects in Metals", I. M. Bernstein and A. W. Thompson, ed., TMS-AIME, Warrendale, PA pp. 143-152 (1981).
5. M. Zamanzadeh, A. Allam, C. Kato, B. Ateya and H. W. Pickering, J. Electrochem Soc., 129, 284 (1982).
6. M. Zamanzadeh and H. W. Pickering, to be published.
7. M. Zamanzadeh and H. W. Pickering, to be published.
8. B. G. Ateya and H. W. Pickering, J. Electrochem Soc., 122, 1018 (1975).
9. B. G. Ateya and H. W. Pickering, "Hydrogen in Metals", A. W. Thompson and I. M. Bernstein, ed., ASM, pp. 206-222 (1974).
10. B. G. Ateya and H. W. Pickering, "Passivity of Metals", R. P. Frankenthal and J. Kruger, ed., Electrochem. Soc., Princeton, NJ, pp. 350-368 (1978).
11. D. Harris and H. W. Pickering, "Effect of Hydrogen Behavior of Materials", A. W. Thompson, I. M. Bernstein and A. J. West, AIME, pp. 229-231 (1976).
12. H. W. Pickering, "H. H. Uhlig: Corrosion and Corrosion Protection", R. P. Frankenthal and F. Mansfeld, ed., The Electrochem Soc., Inc., Pennington, NJ, pp. 85-91 (1981).
13. C. Kato, B. G. Ateya, J. E. Castle and H. W. Pickering, J. Electrochem. Soc., 127, 1890, 1897 (1980).

TECHNICAL REPORTS

B. G. Ateya and H. W. Pickering, "Conditions for Which Iron Dissolution Occurs in Cracks During Hydrogen Charging of Steel," Technical Report No. 1, July, 1973.

B. G. Ateya and H. W. Pickering, "Electrochemical Processes within Cavities and Their Relation to Pitting and Cracking," Technical Report No. 2, October, 1973.

I. M. Bernstein and H. W. Pickering, "The Mutual Occurrence of Cathodic and Anodic Cracking in Iron," Technical Report No. 3, 1974.

B. G. Ateya and H. W. Pickering, "On the Nature of Electrochemical Reactions at a Crack Tip During Hydrogen Charging of a Metal," Technical Report No. 4, November, 1975.

D. Harris and H. W. Pickering, "On Anodic Cracking During Cathodic Hydrogen Charging," Technical Report No. 5, 1975.

S. S. Chatterjee and H. W. Pickering, "A Means of Inhibiting Hydrogen Entry into Steel," Technical Report No. 6, November, 1975.

B. G. Ateya and H. W. Pickering, (reprint), "On the Nature of Electrochemical Reactions at a Crack Tip During Hydrogen Charging of a Metal, Technical Report No. 7, 1975.

S. S. Chatterjee, B. Ateya and H. W. Pickering, "Effect of Electrodeposited Metals on the Permeation of Hydrogen Through Iron Membranes," Technical Report No. 8, February, 1977.

S. S. Chatterjee, B. Ateya and H. W. Pickering, (reprint), "Effect of Electrodeposited Metals on the Permeation of Hydrogen Through Iron Membranes," Technical Report No. 9, May, 1978.

M. Zamanzadeh, A. Allam, H. W. Pickering and C. K. Hubler, "Effect of Helium-, Iron-, and Platinum-Ion Implantation on the Permeation of Hydrogen Through Iron Membranes," Technical Report No. 10, July, 1979.

C. Kato, J. E. Castle, B. G. Ateya and H. W. Pickering, "On the Mechanism of Corrosion of Cu-9.4Ni-1.7Fe Alloy in Air Saturated Aqueous NaCl Solution. I. Kinetic Investigation," Technical Report No. 11, 1979.

C. Kato, B. G. Ateya, J. E. Castle and H. W. Pickering, "On the Mechanism of Corrosion of Cu-9.4Ni-1.7Fe Alloy in Air Saturated Aqueous NaCl Solution. II. Composition of the Protective Surface Layer," Technical Report No. 12, 1979.

H. W. Pickering and M. Zamanzadeh, "A Model for Decreasing Hydrogen Absorption in Metals Applicable to Ion Implanted Membranes, Technical Report no. 13, October, 1980.

M. Zamanzadeh, A. Allam, H. W. Pickering and G. K. Hubler (Naval Res. Lab., Washington, DC), (reprint), "Effect of Helium, Iron, and Platinum Implantation on the Absorption of Hydrogen by Iron," Technical Report No. 14, November, 1980.

C. Kato, B. G. Ateya, J. E. Castle and H. W. Pickering, (reprint), "On the Mechanism of Corrosion of Cu-9.4Ni-1.7Fe Alloy in Air Saturated Aqueous NaCl Solution. I. Kinetic Investigation. II. Composition of the Protective Surface Layer," Technical Report No. 15, November, 1980.

M. Zamanzadeh, A. Allam, C. Kato, B. Ateya and H. W. Pickering, "Hydrogen Absorption During Electrodeposition and Hydrogen Charging of Sn and Cd Coatings on Iron," Technical Report No. 16, February, 1981.

H. W. Pickering, "The Limiting IR Voltage within Electrolyte in Cavities During Localized Corrosion and Hydrogen Charging of Metals," July, 1981.

H. W. Pickering and M. Zamanzadeh, (reprint), A Model for Decreasing Hydrogen Absorption in Metals Applicable to Ion Implanted Membrane, (reprint), January, 1982.

M. Zamanzadeh, A. Allam, C. Kato, B. Ateya and H. W. Pickering, (reprint), "Hydrogen Absorption During Electrodeposition and Hydrogen Charging of Sn and Cd Coatings on Iron," April, 1982.

PUBLICATIONS

B. G. Ateya and H. W. Pickering, "Conditions for which Iron Dissolution Occurs in Cracks During Hydrogen Charging of Steel," pp. 1182-1188 in Stress Corrosion Cracking and Hydrogen Embrittlement of Iron Base Alloys, R. W. Staehle, J., Hockman, R. D., McCright, H. W. Slater, ed., NACE, Houston, Texas (1977).

B. G. Ateya and H. W. Pickering, "Electrochemical Processes Within Cavities and Their Relation to Pitting and Cracking," pp. 206-222 in Hydrogen in Metals, A. W. Thompson and I. M. Bernstein, ed., ASM (1974).

B. G. Ateya and H. W. Pickering, "On the Nature of Electrochemical Reactions at a Crack Tip during Hydrogen Charging of a Metal", J. Electrochemical Soc., 122, 1018 (1975).

I. M. Bernstein and H. W. Pickering, "The Mutual Occurrence of Cathodic and Anodic Cracking in Iron," Corrosion 31, 105 (1975).

H. W. Pickering, "On Oxide-Film Stability from the Point of View of Mass and Charge Transfer in the Aqueous Phase", pp. 124-125 in Passivity and Its Breakdown on Iron and Iron Base Alloys, R. W. Staehle and H. Okada, ed., NACE, Texas, (1976).

D. Harris and H. W. Pickering, "On Anodic Cracking During Cathodic Hydrogen Charging," pp. 229-231 in Effect of Hydrogen Behavior of Materials, A. W. Thompson, I. M. Bernstein, and A. J. West, ed., AIME (1976).

S. S. Chatterjee and H. W. Pickering, "A Means of Inhibiting Hydrogen Entry into Steel," pp. 182-185 in Effect of Hydrogen Behavior of Materials, A. W. Thompson, I. M. Bernstein, and A. J. West, ed., AIME, (1976).

S. S. Chatterjee, B. G. Ateya, and H. W. Pickering, "Effect of Electro-Deposited Metals on the Permeation of Hydrogen Through Iron Membranes", Metallurgical Trans. A, 9A, 389-395 (1978).

B. G. Ateya and H. W. Pickering, "Effects of Mass Transfer in the Aqueous Phase on Repassivation of Activated Surfaces and the Stability of Protective Films, pp. 350-368 in Passivity of Metals, R. P. Frankenthal and J. Kruger, ed., Electrochemical Soc., Princeton, NJ (1978).

M. Zamanzadeh, A. Allam, H. W. Pickering and G. K. Hubler, "Effect of Helium, Iron and Platinum Implantation on the Absorption of Hydrogen by Iron," J. Electrochemical Soc., 127, 1688 (1980).

C. Kato, B. G. Ateya, J. E. Castle and H. W. Pickering, "On the Mechanism of Corrosion of Cu-9.4Ni-1.7Fe Alloy in Air Saturated Aqueous NaCl Solution. I. Kinetic Investigations," J. Electrochemical Soc., 127, 1890 (1980).

C. Kato, J. E. Castle, B. G. Ateya and H. W. Pickering, "On the Mechanism of Corrosion of Cu-9.4Ni-1.7Fe Alloy in Air Saturated Aqueous NaCl Solution, II. Composition of the Protective Surface Layer," J. Electrochemical Soc., 127, 1897 (1980).

H. W. Pickering and M. Zamanzadeh, "A Model for Decreasing Hydrogen Absorption in Metals Applicable to Ion Implanted Membranes," pp. 143-152 in Hydrogen Effects in Metals, I. J. Bernstein and A. W. Thompson, ed., TMS AIME, Warrendale, PA (1981).

B. Ateya and H. W. Pickering, "Effects of Ionic Migration on the Concentrations and Mass Transfer Rate in the Diffusion Layer of Dissolving Metals", J. Applied Electrochemistry, 11, 263 (1981).

M. Zamanzadeh, A. Allam, C. Kato, B. Ateya and H. W. Pickering, "Hydrogen Absorption During Electrodeposition and During Hydrogen Charging of Sn and Cd Coatings on Iron", J. Electrochemical Soc., 129, 284 (1982).

H. W. Pickering, "The Limiting IR Voltage Within Electrolyte in Cavities During Localized Corrosion and Hydrogen Charging of Metals", pp. 85-91 in H. H. Uhlig: Corrosion and Corrosion Protection, R. P. Frankenthal and F. Mansfeld, ed., The Electrochemical Soc., Inc., Pennington, NJ (1981).

A. Allam, B. G. Ateya, H. W. Pickering and L. L. Tongson, "Effect of Chloride Ion on the Absorption and Permeation of Hydrogen in Iron", J. Electrochem. Soc., to be submitted.

I. Takeuchi and H. W. Pickering, "Effect of H<sub>2</sub>S in Aqueous Solutions on the Absorption and Permeation of Hydrogen in Iron", in preparation.

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