

MONDAY, AUGUST 25, 2003, P.M.

SESSION 2: INTERNATIONAL SYMPOSIUM ON ENVIRONMENTAL DEGRADATION OF MATERIALS AND CORROSION CONTROL IN METALS

ELECTROCHEMISTRY AND CORROSION OF METALS

Sponsor: Materials Performance and Integrity, The Metallurgical Society of CIM

Room: Finback

Chairman: A. PLUMTREE, University of Waterloo, Department of Mechanical Engineering, Waterloo, Ontario and D.C. KATZ, Williams Gas Pipeline West, Salt Lake City, Utah, U.S.A.

PAPER 2.1 — 14:00 (KEYNOTE)

THE EFFECT OF SEMI-SOLID PROCESSING ON THE CORROSION BEHAVIOUR OF MG-ZN-RE ALLOYS.

E.D. MORALES-GARZA, C. BLAWERT, N. HORT, W. DIETZEL, K.U. KAINER, Institute for Materials Research, GKSS Research Center, Geesthacht, Germany, and

E. GHALI, Mining, Metallurgical and Materials Engineering, Laval University, Québec, Québec, Canada

New processing routes for magnesium castings claim to produce finer microstructures and better corrosion resistance. Therefore, it is of great interest to compare the corrosion properties of two Mg-Zn-RE alloys produced by standard squeeze casting and new semi-solid casting technique. The influence of the two different processing routes on the corrosion behaviour will be studied in 3.5% NaCl and ASTM water by (1) analyzing the corrosion morphology, (2) measuring electrochemical polarization curves, and (3) immersion tests at constant pH-value. By using LM, SEM, and XRD to evaluate the microstructure before and after the corrosion measurements, the corrosion results will be related to the microstructures of the specific alloys.

PAPER 2.2 — 14:30

POLARIZATION BEHAVIOUR AND PASSIVITY BREAKDOWN OF COPPER ALLOYS IN CHLORIDE ENVIRONMENTS

T.M. AHMED, D. TROMANS and A. ALFANTAZI, Department of Metals and Materials Engineering, The University of British Columbia, Vancouver, British Columbia, Canada

The potentiodynamic polarization behaviour of copper alloys in chloride solutions (1 M NaCl) of different pH (6.5 and 10) was investigated. Three commercial alloys of nominal composition Cu-30Ni (Cu-Ni), Cu-30Zn (Cu-Zn) and 90Cu-8Al-2Fe (Cu-Al) were considered. Results at pH of 6.5 showed no evidence of passivity with polarization behaviour being dominated by the Cu component. At pH of 10, however, some evidence of limited passivity was seen. Passivity was more evident in buffered chloride (pH=10), in particular for Cu-Zn which showed remarkable passive behaviour over a wide potential range. A sudden increase in the current density occurred when the anodic potential exceeded a certain critical potential, i.e., film breakdown potential. The results of these experiments are discussed in reference to potential-pH (Pourbaix) diagrams of the alloying elements.

PAPER 2.3 — 14:55

INVESTIGATION OF CURRENT OSCILLATIONS OF X70 MICRO-ALLOYED STEEL WITH SCANNING REFERENCE ELECTRODE.

L. LI, J.L. LUO, Y.M. ZENG, B.T. LU, Department of Chemical and Materials Engineering, University of Alberta, Edmonton, Alberta, Canada, and

S.H. CHEN, Department of Chemistry, Shandong University, Jinan, Shandong, China

In this paper, the effect of chloride ions on the oscillatory dissolution of X70 micro-alloyed steel in H_3PO_4 aqueous solution is investigated for the first time by means of perturbing the chemical environment at the X70/ H_3PO_4 interface. A small quantity of chloride ions is injected near the electrode surface during the occurrence of current oscillation. The potential distribution at the electrode/electrolyte is monitored *in situ* by using scanning reference electrode technique (SRET). The results indicate that, in the transition region from the active to the passive state, the current oscillations change from mono-periodic and low frequency oscillations to complex and relative high frequency oscillations after the injection of chloride ions. It implies that chloride ions induce the dissolution of the passive films.

COFFEE BREAK — 15:20 – 15:35

PAPER 2.4 — 15:35

PROPERTIES OF THE PASSIVE FILMS ON NICKEL-CHROMIUM-MOLYBDENUM ALLOYS.

A.C. LLOYD, D.W. SHOESMITH, J.J. NOEL, Department of Chemistry, University of Western Ontario, London, Ontario, Canada, and

N.S. McINTYRE, Surface Science Western, University of Western Ontario, London, Ontario, Canada

Ni-Cr-Mo alloys are among the most corrosion-resistant materials known, showing exceptional localized corrosion resistance under extreme industrial conditions. Accordingly, one such alloy, Alloy-22, is a candidate material for the outer sheathing of nuclear waste packages for the Yucca Mountain repository, Nevada, U.S.A. The authors briefly report their results on the passive behaviour for a series of Ni-Cr-Mo alloys, with the emphasis on determining if there is a temperature dependence associated with it. The change of passive corrosion rate with temperature is a critical parameter required for long-term performance assessment calculations. The results show that alloy C22 performed better than the other members of the C-series of alloys under acidic conditions. This indicates that its selection as a waste package material is appropriate, and that it possesses the potential for long-term containment of radio-nuclides.

PAPER 2.5 — 16:00

ELECTROCHEMICAL NOISE AND CORROSION MECHANISM OF PIPELINE STEEL UNDER SLURRY-EROSION CONDITIONS.

C.W. CHEN, B.T. LU, J.L. LUO, Department of Chemical and Materials Engineering, University of Alberta, Edmonton, Alberta, Canada, and S. CHIOVELLI, Syncrude Canada Ltd., Edmonton Research Centre, Edmonton, Alberta, Canada

The damage mechanism of a pipeline steel under simulated slurry-erosion conditions was investigated using the electrochemical noise technique. After an incubation period, electrochemical noise signals with regular frequency and characteristic shape were observed. The amplitude of both current and potential fluctuations increased but the frequency of fluctuation events decreased with test duration. A two-layer corrosion scale with a dense outer layer and a loose inner layer was found on the steel surface. It was noted that above a certain scale thickness, surface cracking of the corrosion scale occurred. The cracking of outer layer of corrosion scale is believed to lead to the formation of occluded cells resulting in pitting corrosion. The characteristics signals of electrochemical noise are explained with classic occluded cell theory.

PAPER 2.6 — 16:25

ELECTROCHEMICAL INVESTIGATION ON PASSIVATION PROCESS OF IRON IN BORATE BUFFER SOLUTION.

W.S. LI, S.Q. CAI, Department of Chemistry, South China Normal University, Guangzhou, China, and

J.L. LUO, Department of Chemical and Materials Engineering, University of Alberta, Edmonton, Alberta, Canada

The passivation process of iron in borate buffer solution (pH=8.4) is investigated by using linear potential sweep voltammetry, current step chronopotentiometry, open circuit chronopotentiometry, and alternative current (AC) impedance spectroscopy. Iron is characteristic of an active-passive metal in 0.136 M borate buffer solution, with the active region at the potential from -0.78 V to -0.60 V, the active-passive region from -0.6 V to -0.45 V, the passive region from -0.45 V to 0.9 V, and the transpassive region at the potential higher than 0.9 V. In the active region, the oxidation of iron involves two-step charge transfer reactions: one is the formation of a deposited Fe(OH)₂ layer and is the main reaction; the other is the formation of a surface monolayer Fe₃O₄. In the active-passive region, Fe₃O₄ is formed from the deposited Fe(OH)₂. In the passive region, Fe₂O₃ is formed; the reaction involves the oxidation of Fe(II) in the passive film to Fe(III) at lower potential (0.45-0V) and the thickening of the passive film at higher potential (0-0.75V). In the solution without oxygen, iron was in the condition of active dissolution. It is a depolarized corrosion by hydrogen. In the solution containing oxygen, iron can be passivated by the oxygen dissolved in the solution.

PAPER 2.7 — 16:50

ELECTROCHEMICAL VARIABLE DEPENDENCE OF ZINC ELECTRODEPOSITED ONTO ELECTROPOLISHED STEEL SUBSTRATE.

K. RAEISSI, A. SAATCHI and M.A. GOLOZAR, Department of Materials Engineering, Isfahan University of Technology, Isfahan, Iran

The texture and morphology of zinc coatings obtained onto a low-carbonelectropolished steel substrate in an acid sulphate bath have been compared. Morphology of zinc deposit on electropolished surfaces consisted of layered thin hexagonal crystals, which were laid on each other and aligned, in a specific variant on each grain surface. Variants observed on various grain surfaces were different. Partial textures evaluated by means of the In-Sheet-Plane Percentage method revealed that electropolished surface promoted strong basal plane component along with weaker low-angle pyramidal planes. Increasing current density up to 200 mA.cm⁻² or decreasing temperature increased the intensity of basal plane and decreased the intensity of low-angle pyramidal ones. Potentiostatic current-time plots and AC Impedance were used to observe effects of electrochemical variables on nucleation and growth. The results showed that the nucleation process was instantaneous, and the growth process was charge transfer controlled, influenced effectively with overvoltage. It can be concluded that increasing the current density and/or decreasing the temperature would increase the overvoltage, and thus increase the basal planes parallel to steel surface.

TUESDAY, AUGUST 26, 2003, A.M.

SESSION 13: INTERNATIONAL SYMPOSIUM ON ENVIRONMENTAL
DEGRADATION OF MATERIALS AND CORROSION CONTROL IN METALS

STUDIES OF THE CORROSION AND CRACKING BEHAVIOUR

Sponsor: Materials Performance and Integrity, The Metallurgical Society of CIM

Room: Finback

Chairman: D.W. SHOESMITH, University of Western Ontario, Department of Chemistry, London, Ontario
and

B. MCCRADY, IPSCO Saskatchewan Inc., Regina, Saskatchewan

PAPER 13.1 — 8:30 (KEYNOTE)

MICROSTRUCTURAL FEATURES OF ENVIRONMENTALLY ASSISTED CRACKING IN PIPELINE STEEL.

B.W. WILLIAMS, S.B. LAMBERT, X. ZHANG, A. PLUMTREE, Department of Mechanical Engineering, University of Waterloo, Waterloo, Ontario, Canada, and

R. SUTHERBY, TransCanada PipeLines (TCPL) Limited, Calgary, Alberta, Canada

A number of small-scale pipeline specimens containing edge or surface cracks were tested in simulated groundwater (NS4 solution) in an anaerobic environment under cyclic loading conditions. Micrographs of the crack surface generally showed corrosion fatigue at high frequencies. Following large amounts of growth (~200 μ m) for those specimens tested at low frequencies, evidence of transgranular quasi-cleavage was detected. Green rust was found to be present at the crack tips and along their flanks. Iron sulphide, resulting from anaerobic sulphate-reducing bacteria and iron carbonate were also present in the NS4 solution during testing. These corrosion products retarded crack growth in the depth direction of surface cracks. Under variable amplitude loadings conditions, the accompanying increased surface crack growth rate can be accounted for by rupture of the green rust film at the crack tip.

PAPER 13.2 — 9:00

STRESS CORROSION AND CORROSION FATIGUE CRACK GROWTH MONITORING IN STRUCTURAL MATERIALS.

T. SENADHEERA, S.A. SHIPILOV and F. WANG, Department of Mechanical and Manufacturing Engineering, University of Calgary, Calgary, Alberta, Canada

Environmentally assisted cracking (including stress corrosion cracking and corrosion fatigue) is one of the major causes for materials failure in a wide variety of industries. It is extremely important to understand the mechanism(s) of environmentally assisted crack propagation in structural materials so as to choose correctly from among the various possibilities—alloying elements, heat treatment of steels, parameters of cathodic protection, and inhibitors—to prevent in-service failures due to stress corrosion cracking and corrosion fatigue. An important step towards understanding the mechanism of environmentally assisted crack propagation is designing a testing machine for crack growth monitoring and that simultaneously provides measurement of electrochemical parameters. In the present paper, a direct current (DC) potential drop method for monitoring crack propagation in metals and a testing machine that uses this method and allows for measuring electrochemical parameters during stress corrosion and corrosion fatigue crack growth are described.

PAPER 13.3 — 9:25

EFFECT OF MICROSTRUCTURE ON NEAR-NEUTRAL pH SCC RESISTANCE OF PIPELINE STEELS.

B.T. LU, J.L. LUO, Department of Chemical and Materials Engineering, University of Alberta, Edmonton, Alberta, Canada, and B. MCCRADY, IPSCO Saskatchewan Inc., Regina, Saskatchewan, Canada

In this work, the relationship between the near neutral pH SCC resistance and the yield strength of pipeline steels was investigated and an attempt was made to understand the microstructural effect on such a relationship. Pipeline steels X52, X60, X70, X80 and X100 were used as test materials and various heat-treatments were used to achieve different microstructure and strength (hardness) levels. The results indicate that the near-neutral pH SCC resistance of pipeline steel is reduced with an increase in the strength level but the strength dependence of SCC resistance is heavily affected by the microstructures of the pipeline steels. The steels with a fine-grained bainite + ferrite structure possess much better combination of strength and SCC resistance than those with ferrite + pearlite structure. An increase in pearlite content in the microstructure has a detrimental effect on the SCC resistance.

PAPER 13.4 — 9:50 (KEYNOTE)

FROM FIRST DISCOVERIES IN THE LATE 1800S TO ATOMISTIC SIMULATION AND LIFE PREDICTION IN THE EARLY 2000S: 130 YEARS OF STRESS CORROSION CRACKING RESEARCH.

S.A. SHIPILOV, Department of Mechanical and Manufacturing Engineering, University of Calgary, Calgary, Alberta, Canada

Scientific interest in the effects of environment on the mechanical properties and integrity of materials began in the late 1800s. This means that the history of environmentally assisted cracking (EAC) research exceeds a hundred years and is a part of the history of engineering during the 20th century. The EAC problem may have had humble beginnings in observations made of season cracking in the thin-wall necks of brass cartridge cases during the Indian campaigns of the British army, but today EAC is acknowledged as one of the most dangerous engineering problems. Since the early 1960s, EAC (specifically stress corrosion cracking, corrosion fatigue and hydrogen embrittlement) has been responsible for many, if not most, service failures in numerous applications where components and structures come into contact with natural or technological environment. Moreover, the problem of EAC directly affects the safety and reliability of engineering systems such as aircraft and aerospace structures, nuclear and fossil fuel power plants, oil and gas pipelines, field equipment, chemical plants, and marine structures which, if they fail, can cause serious human, environmental and financial losses. EAC seriously retards and makes more expensive attempts to maintain such systems under operating conditions. The economic and humanitarian aspects of EAC failures have led to considerable scientific and engineering efforts directed at understanding and preventing such failures. Despite the progress that has been made, usually in the last three decades, researchers are still far from solving many problems related to EAC. Almost on a daily basis, EAC manifests itself in new and unexpected ways. The purpose of this paper is to review and evaluate experimental results and mechanistic models for stress corrosion cracking, corrosion fatigue and hydrogen embrittlement of metals over the last 130 years.

COFFEE BREAK — 10:15 – 10:30

PAPER 13.5 — 10:30

STUDIES OF THE CORROSION AND CRACKING BEHAVIOUR OF STEELS IN HIGH-TEMPERATURE WATER BY ELECTROCHEMICAL TECHNIQUES.

Y.F. CHENG, J. BULLERWELL and F.R. STEWARD, Centre for Nuclear Energy Research, University of New Brunswick, Fredericton, New Brunswick, Canada

Electrochemical methods were used to study the corrosion and cracking behaviour of five Fe-Cr alloy steels and 304L stainless steel in high-temperature water. A layer of magnetite film forms on the metal surface, which decreases the corrosion rate in high-temperature water. Passivity can be achieved on A-106 B carbon steel with a small content of chromium, which cannot be passivated at room temperature. The formation rate and the stability of the passive film (magnetite film) increased with increasing Cr-content in the steels. A mechanistic model was developed to simulate the corrosion and cracking processes of steels in high temperature water. The crack growth rate on steels was calculated from the maximum current of the repassivation current curves according to the slip-oxidation model. The highest crack growth rate was found for 304L stainless steel in high-temperature water. Of the four Fe-Cr alloys, the crack growth rate was lower on 0.236% Cr- and 0.33% Cr-steels than on 0.406% Cr-steel and 2.5% Cr-1% Mo steel. The crack growth rate on 0.33% Cr-steel was the smallest over the tested potential range. A higher temperature of the electrolyte led to a higher rate of electrochemical dissolution of steel and a higher susceptibility of steel to cracking, as shown by the positive increase of the electrochemical potential. An increase in Cr-content in the steel is predicted to reduce the corrosion rate of steel at high temperatures. However, this increase in Cr content is predicted not to reduce the susceptibility of steel to cracking at high temperatures.

PAPER 13.6 — 10:55

EFFECT OF PIPE MICROSTRUCTURE ON SULPHIDE STRESS CRACKING UNDER CONSTANT LOAD.

D.A. SILIN, Y.V. YUDIN, I.N. VESELOV, I.Y. PYCHMINTSEV, CJSC, Scientific and Research Institute for Materials and Technology, Ekaterinburg, Russia, and
P.Y. GOROZHANIN, JSC, Sinarsky Pipe Works, Sverdlovsk Region, Russia

New design requirements by oil and gas producers call for high-strength materials that in general are more susceptible to sulphide stress cracking. The study was aimed on better understanding the behaviour of low alloyed steels having different microstructures in aqueous environments containing H₂S. The effect of cooling rate in section of quenched parts on the microstructure formation was experimentally studied using SEM and dilatometry. The influence of alloying with Cr, Mn and Mo on austenite decomposition and microstructure was discussed. Variation of fracture mechanisms of samples held in sour hydrogen sulphide environment under constant load was observed in the dependence on microstructure and strength. To predict structure formation and to choose optimal cooling rates the model of austenite decomposition based on known transformation behaviour, heat conductivity in section and heat transfer to cooling media was developed.

PAPER 13.7 — 11:20

STUDY ON FRACTURE AND STRESS CORROSION CRACKING BEHAVIOUR OF CASING SOUR SERVICE MATERIALS.

C. SEQUERA and H. GORDON, PDVSA-Intevep, Research and Technological Support Center, Department of Infrastructure Technologies, Caracas, Venezuela

Present work describes sulphide stress corrosion cracking and fracture toughness tests performed to high strength sour service materials of T-95, C-100 and C-110 oil well tubular grades. P-110 was considered as a reference case, since it is one of the high strength materials included in specification 5CT of American Petroleum Institute, API (1).

Sulphide stress corrosion cracking, impact and fracture toughness values obtained in the tests show that there is a correspondence among them. A decreasing classification order was established, namely C-100, T-95, C-110 and P-110. Special grades steels studied demonstrated a better behavior in the evaluated properties than the reference case material grade: P-110. Results obtained indicate that a higher sulphide stress corrosion cracking resistance is related to a higher toughness. The fracture toughness results evidence the hydrogen influence on reducing the toughness values.

TUESDAY, AUGUST 26, 2003, P.M.

SESSION 23: INTERNATIONAL SYMPOSIUM ON ENVIRONMENTAL DEGRADATION OF MATERIALS AND CORROSION CONTROL IN METALS

HYDROGEN IN STEEL AND PIPELINE CORROSION

Sponsor: Materials Performance and Integrity, The Metallurgical Society of CIM

Room: Finback

Chairman: F.H. STOTT, Corrosion and Protection Centre, UMIST, Manchester, UK and

V.S. SASTRI, Sai Ram Consultants, Ottawa, Ontario

PAPER 23.1 — 14:00 (KEYNOTE)

KINETIC ISOTOPE EFFECTS IN THE CORROSION AND HYDROGEN LOADING OF LINE PIPE STEEL: IMPLICATIONS FOR STRESS CORROSION CRACKING.

T.R. JACK, F. KING, L. YANG, NOVA Chemicals, Calgary, Alberta, Canada, and

R. SUTHERBY, TransCanada PipeLines Ltd., Calgary, Alberta, Canada

Metal loss due to corrosion and hydrogen embrittlement at the tip of a growing crack have been suggested as key processes in the development of stress corrosion cracking (SCC) in line pipe steels. This study compares the rate of corrosion, hydrogen formation and permeation of hydrogen through line pipe steel with the susceptibility of line pipe steel specimens to SCC failure as assessed by slow strain rate tests (SSRT) in electrolyte solutions made up in D₂O and H₂O. Comparison of kinetic isotope effect shows that the ratio of corrosion rates in D₂O and H₂O is 0.56 ± 0.06 while the ratio of the concentration of atomic hydrogen or deuterium diffusing through the steel surface is 0.85 ± 0.24 . The kinetic isotope effect observed for SCC failure in SSRT was 0.83 ± 0.17 suggesting that hydrogen loading of the steel is the key factor in determining the SCC susceptibility of line pipe steel in a given environment by this test method. Comparison of "as received" and polished surfaces indicates mill scale accelerates formation of atomic hydrogen at the surface of the specimen but retards the entry of hydrogen into the steel matrix. Implications of these observations for SCC on operating pipeline systems are discussed.

PAPER 23.2 — 14:30

HYDROGEN IN TRAPPING STATES INNOCUOUS TO ENVIRONMENTAL DEGRADATION OF HIGH-STRENGTH STEELS.

K. TAKAI, Department of Mechanical Engineering, Sophia University, Tokyo, Japan

Hydrogen in trapping states innocuous to environmental degradation of the mechanical properties of high-strength steels has been separated and extracted using thermal desorption analysis (TDA) and slow strain rate test (SSRT). The high-strength steel occluding only hydrogen desorbed at low temperature (peak 1), as determined by TDA, decreases in maximum stress and plastic elongation with increasing occlusion time of peak 1 hydrogen. Thus the trapping state of peak 1 hydrogen is directly associated with environmental degradation. The trap activation energy for peak 1 hydrogen is 23.4 kJ/mol, so the peak 1 hydrogen corresponds to weaker binding states and diffusible states at room temperature. In contrast, the high-strength steel occluding only hydrogen desorbed at high temperature (peak 2), by TDA, maintains the maximum stress and plastic elongation in spite of an increasing content of peak 2 hydrogen. This result indicates that the peak 2 hydrogen trapping state is innocuous to environmental degradation, even though the steel occludes a large amount of peak 2 hydrogen. The trap activation energy for peak 2 hydrogen is 65.0 kJ/mol, which indicates a stronger binding state and non-diffusibility at room temperature. The trap activation energy for peak 2 hydrogen suggests that the driving force energy required for stress-induced diffusion during elastic and plastic deformation, and the energy required for hydrogen dragging by dislocation mobility during plastic deformation are lower than the binding energy between hydrogen and trapping sites. The peak 2 hydrogen, therefore, is believed to not accumulate in front of the crack tip and to not cause environmental degradation in spite of being present in amounts as high as 2.9 mass ppm.

PAPER 23.3 — 14:55

EFFECTS OF HYDROGEN ON THE STABILITY OF THE PASSIVE FILM ON X-70 PIPELINE STEEL.

X. PANG, Y.M. ZENG, J.G. YU, J.L. LUO, Chemical and Materials Engineering Department, University of Alberta, Edmonton, Alberta, Canada

P.R. NORTON Department of Chemistry, Interface Science Western, University of Western Ontario, London, Ontario

The behaviour of the open-circuit potential decay, the galvanostatic cathodic reduction, and the impedance response of the passive films on X70 pipeline steel without and with hydrogen were examined in borate buffer solution. It is observed that after the interruption of applied passive potential, the open-circuit potentials of hydrogen-containing passive films decay more quickly than those of hydrogen-free films. In addition, the final stable potentials for the hydrogen-containing films are lower than that for the hydrogen-free film. Based on the reduction curves, the thickness of the Fe_2O_3 layer was estimated. The results show that hydrogen reduces the thickness of the passive film. The thinning effect was enhanced by increasing hydrogen charging current density until the hydrogen charging current density reached 1.0 mA/cm^2 . Impedance analysis revealed that the charge transfer resistance of the passive film on X70 steel gradually increases with increasing the film formation potential, but this tendency does not occur on the hydrogen-containing film. A linear increase in the reciprocal of capacitance of the passive film with increasing film formation potential is observed for both charged and uncharged cases, with higher capacitance for the charged specimens than the uncharged specimens. These results provide very useful information to explain the mechanism by which hydrogen deteriorates the stability of the passive film and promotes localized corrosion.

COFFEE BREAK — 15:20 - 15:35

PAPER 23.4 — 15:35

STUDIES ON INHIBITION OF HYDROGEN-INDUCED CRACKING OF LINEPIPE STEELS

M. ELBOUJDANI, Materials Technology Laboratory CANMET, Ottawa, Ontario, Canada,

V.S. SASTRI, Sai-Ram Consultants, Ottawa, Ontario, Canada, and

J.R. PERUMAREDI, Chemistry Department, Florida Atlantic University, Boca Raton, Florida, U.S.A.

Experimental results are reported on: i) evaluation of polarization resistance; ii) variation of corrosion currents; iii) variation of corrosion potential; iv) microhardness, and v) quantitative determination of inclusion populations in pipeline steels. The results are discussed in terms of low, medium and high sensitivity of steels to hydrogen induced cracking (HIC) and the role of inclusions on HIC of linepipe steels.

PAPER 23.5 — 16:00

PITTING SUSCEPTIBILITY OF A PIPELINE STEEL WITH BANDED MICROSTRUCTURE MIXED WITH MARTENSITE, FERRITE AND PEARLITE.

W.S. LI, B.T. LU, J.L. LUO, Department of Chemical and Materials Engineering, University of Alberta, Edmonton, Alberta, Canada, and S. CHIOVELLI, Syncrude Canada Ltd., Edmonton, Alberta, Canada

Early failure of an induction-hardening carbon steel pipe, which was used to transport tailing slurry, was induced by pitting corrosion and the microstructure on the internal pipe surface layer was found being a mixture of martensite, pearlite and ferrite. In this paper, the pitting corrosion behaviour of each constitute in the microstructure of steel is investigated with electrochemical noise analyses and anodic polarization measurement and the electronic properties of passive film is studied with Mott-Schottky test in $0.01\text{M Na}_2\text{CrO}_4 + 0.05\text{M NaCl}$ solution. It is found that the passive films of material formed in $0.01\text{M Na}_2\text{CrO}_4$ solution is highly disordered n-type semiconductors in which two donor levels, shallow and deep, exist. The high-to-low pitting susceptibility is ferrite > martensite > pearlite and it is related to the semiconductive nature of passive film formed each constitute. The pitting susceptibility of material increases with the deep donor concentration in the passive film.

PAPER 23.6-16:25

THE VELOCITY AND CONCENTRATION EFFECT ON A PILOT SCALE EROSION-CORROSION SLURRY LINE

S. SANKARAN, C.K. HUANG, J.L. LUO AND K. NANDAKUMAR, Chemical and Materials Engineering, University of Alberta, Edmonton, Canada, and P. MINEV, Department of Mathematical and Statistical Sciences, University of Alberta, Edmonton, Canada

Erosion-corrosion is the primary concern in slurry and oil sand transportation in long pipelines. Extensive research has been conducted on slurry flow erosion-corrosion on the influences of various parameters and the mechanism. However difficulties have arisen concerning the impacts of flow, its control and mitigation in actual slurry pipelines. This is a potential problem not only from the obvious concern of failure following severe attack but also from the localized deep pits, increased pressure drops that may results from the surface roughness. In present work we investigate erosion, corrosion and its synergistic effect on a pilot scale slurry flow pipeline by electrochemical, microscopic analysis and particle trajectory .

PAPER 23.7 — 16:50

AN INVESTIGATION OF THE CORROSION PHENOMENA OF POTENTIAL MATERIALS FOR FABRICATION OF SCWO SYSTEMS.

D.B. MITTON, H. KIM and R.M. LATANISION, Massachusetts Institute of Technology, Uhlig Corrosion Laboratory, Department of Materials Science and Engineering, Cambridge, Massachusetts, U.S.A.

One very effective process for the destruction of both military and civilian hazardous waste is super-critical water oxidation (SCWO). This technology capitalizes on the properties of water above its critical point (374 °C and 22.4 MPa for pure water), and provides rapid and complete oxidation with high destruction efficiencies at typical operating temperatures. Because of the aggressiveness of the feed streams, corrosion of the materials of fabrication is a serious concern. This paper presents experimental results for a number of candidate materials of fabrication and assesses the impact of various localized corrosion phenomena, including stress corrosion cracking (SCC) and de-alloying.

WEDNESDAY, AUGUST 27, 2003, A.M.

SESSION 34: INTERNATIONAL SYMPOSIUM ON ENVIRONMENTAL DEGRADATION OF MATERIALS AND CORROSION CONTROL IN METALS

Corrosion Case Study and Applications

Sponsor: Materials Performance and Integrity, The Metallurgical Society of CIM

Room: Finback

Chairman: M. ELBOUJDAINI, Materials Technology Laboratory, CANMET, Ottawa, Ontario and S.A. SHIPILOV, Department of Mechanical and Manufacturing Engineering, University of Calgary, Calgary, Alberta, Canada

PAPER 34.1 — 8:30 (KEYNOTE)

CONTINUING DATA ASSESSMENT OF 16 IN. WILLIAMS PIPELINE INSPECTED WITH THE RECENTLY DEVELOPED ULTRASONIC CRACK DETECTION TOOL.

D. KATZ, Williams Gas Pipeline West, U.S.A.,

M. GAO, R. SHERSTAN, GE PII Pipeline Solutions, U.S.A.,

M. ELBOUJDAINI AND J. LI, CANMET, Ottawa, Ontario, Canada

The in-line inspection of the Williams Gas Pipeline West 16 in. pipeline in September 2001 was successfully completed using the newly developed 16 in. Ultrasonic Crack Detection tool built by GE/PII. This particular section of pipeline was suspected to have stress corrosion cracking (SCC). The inspection was carried out using a liquid batching technique, supplemented with a transient model analysis. A special launcher and receiver was designed to enable handling of: three batching pigs in front of the inspection tool, the rather lengthy inspection tool, and two trailing batching pigs. The main benefits of this new design were to minimize operational downtime, to ensure complete air and natural gas displacement from the launcher, and to provide for a smoother launching procedure. Due to the large elevation changes within the pipeline section, a key concern was maintaining pig velocity within the 1 m/sec. limitation for adequate data resolution. Rather than rely on a general "rule of thumb," a transient analysis was performed to define a range of possible batch sizes and to better understand the expected pressure gradients encountered while pumping the water slug. Based on the results of this initial pig run, more detailed experimental work remains to successfully model the frictional forces of the many sealing cups. The pig data was successfully acquired, processed, verified, and excavations performed in 2002. Results from the twenty digs will be presented, as well as a discussion of the on-going fracture mechanics assessments which are being used to develop an overall integrity management plan for the continued, safe operation of the pipeline. To better understand the mechanism of SCC and enhance the integrity management, key metallurgical and environment elements are being investigated with advanced analytical tools, including high resolution SEM and EDS. In-situ crack growth monitoring system is also being developed. Preliminary results from these studies will be presented.

PAPER 34.2 — 9:00

CASE STUDY OF THE FAILURE OF SUPERCRITICAL WATER OXIDATION REACTOR TUBING DURING THE TREATMENT OF 2,4 DNP WITH AMMONIUM SULPHATE.

E. ASSELIN, A. ALFANTAZI, The University of British Columbia, Department of Metals and Materials Engineering, Vancouver, British Columbia, Canada,

S. ROGAK, I.V. PEREZ, D. FARAJI, Department of Mechanical Engineering, The University of British Columbia, Vancouver, British Columbia, Canada, and

R. BRANION, Pulp and Paper Centre, Department of Chemical and Biological Engineering, The University of British Columbia, Vancouver, British Columbia, Canada

During the process of Supercritical Water Oxidation (SCWO) organic chemical streams are oxidized at high temperature and pressure, typically in excess of 647 K and 22.1 MPa. Due to high operating temperatures and pressures severely corrosive environments often ensue and eventually lead to SCWO reactor tube failures. This case study looked at one such failure of Alloy 625 (61Ni-21.5Cr-9Mo) tubing which occurred at the UBC/NORAM SCWO pilot plant while treating a feed of waste water containing 2.4 wt% 2,4 dinitrophenolate, 2% ammonium sulphate and 6% excess ammonia. Although the feed pH was approximately 9 and therefore not expected to be corrosive, in fact the tube failed when exposed to this feed (with oxygen) for a period of about 1 hour at 650-655 K.

Through the examination of the ensuing thermodynamic system as well as SEM and Optical Microscope analysis of the ruptured portions of tubing, it was found that the addition of ammonium sulphate to the treated media caused rapid failure due to de-alloying.

Findings show that the high sub-critical temperature and high density of the feed water at failure points, as well as the corrosion morphology are consistent with attack by ammonia. The formation of a stable soluble nickel-ammine phase is suspected. On addition of ammonium sulfate to the treated media caused rapid failure due to intergranular attack.

Findings show that the high sub-critical temperature and high density of the feed water at failure points as well as the corrosion morphology are consistent with attack by sulfuric acid. It is speculated that the ammonium sulfate reacted to form sulfuric acid which caused the corrosive environment. Such a mechanism would depend strongly on the phase behavior of the ammonium sulfate solution, which is not well known near the critical temperature and pressure of water.

PAPER 34.3 — 9:25

ECONOMICS OF WEAR AND CORROSION IN CANADA.

V.S. SASTRI, Sai-Ram Consultants, Ottawa, Ontario, Canada,

M. ELBOUJDAÏNI, Materials Technology Laboratory, CANMET, Ottawa, Ontario, Canada, and

J.R. PERUMAREDI, Chemistry Department, Florida Atlantic University, Boca Raton, Florida, U.S.A.

Canada loses nearly \$8 billion annually due to friction and wear. The total direct costs of corrosion are \$23.6 billion and the cost of corrosion extrapolated to Canadian economy is \$46.4 billion. Methods to combat wear and friction and corrosion when adopted will result in savings of \$2 billion and \$14 billion respectively. Strategies adopted in other countries along with the present scenario in Canada in combating wear and friction and corrosion control are briefly discussed.

PAPER 34.4 — 9:50

PERFORMANCE INVESTIGATION OF LOW TOXIC ORGANIC CORROSION INHIBITORS IN AMINE TREATING UNIT.

A. VEAWAB and W. TANTHAPANICHAKOON, University of Regina, Regina, Saskatchewan, Canada

Amine treating unit is constantly subject to severe corrosion problems leading to extra expenditure and operational limitations. Heavy-metal vanadium compounds are extensively used as corrosion inhibitors to suppress the severe corrosion to an acceptable level. In recent years, the fact that these vanadium compounds are inherently toxic and can potentially pose adverse impacts on the human health and the environment has brought about environmental awareness that causes their uses costly due to the difficulty in waste disposal. To respond to the environmental concern and reduce cost of waste disposal as well as prepare for more stringent regulations for chemical uses, the development of low-toxic corrosion inhibitors is necessary. This work therefore focusses on an investigation of inhibition performance of a number of organic and inorganic compounds that have relatively low toxicity in comparison with conventional inhibitors. The performance evaluation was carried out through corrosion experiments using carbon steel specimens. The experiments were done in 3 and 5 kmol/m³ monoethanolamine (MEA) solution saturated with CO₂ at 80 °C. It was found that several tested compounds have potential to be effective low-toxic corrosion inhibitors. The promising compounds provide reasonable and, in some cases, comparable protection performance to the conventional inhibitor.

COFFEE BREAK — 10:15 – 10:30

PAPER 34.5 — 10:30

MICROBIOLOGICALLY INFLUENCED CORROSION IN A DEPRESSURIZATION WELL PIPING.

B.T. LU, C.W. CHEN, J.L. LUO, Department of Chemical and Materials Engineering, University of Alberta,

Edmonton, Alberta, Canada, and

B.D. CAMPBELL, Syncrude Canada Ltd., Fort McMurray, Alberta, Canada

A depressurization well piping was failed during service because of heavy corrosion. The corrosion morphology of the underground pipe shows that the corrosion is severer at the bottom part than that at the top, indicating the corrosion is promoted by the decrease of dissolved oxygen concentration. Both the appearance of corrosion products and EDX analysis indicate that the corrosion scale at the bottom of pipe contained sulphides. The microbiological examination of groundwater indicates that there are iron bacteria and sulphate-reducing bacteria (SRB). The corrosion potential of material and the pH of corrosive medium show that SRB is active in the service condition of the pipe. Our analysis suggests that the failure of the pipe is induced by the microbiologically influenced corrosion (MIC) caused by SRB.

PAPER 34.6 — 10:55

NOVEL SURFACE COATING MATERIALS FOR ENDODONTIC DENTAL IMPLANT.

M.H. FATHI, Materials Engineering Department, Isfahan University of Technology, Isfahan, Iran,

V. MORTAZAVI and S.B. MOOSAVI, Faculty of Dentistry, Isfahan University of Medical Sciences, Isfahan, Iran

The aim of this study was to design and produce novel coating materials in order to obtain two goals including improvement of the corrosion behaviour of metallic dental endodontic implant and the bone osteointegration simultaneously.

Stainless steel 316L (SS) was used as a metallic substrate and a novel hydroxyapatite/titanium (HA/Ti) composite coating was prepared on it. Structural characterization techniques including XRD, SEM and EDX were utilized to investigate the microstructure and morphology of the coating. Electrochemical tests were performed in physiological solutions in order to determine and compare the corrosion behaviour of the coated and uncoated specimens as an indication of biocompatibility. Two types of endodontic implants including SS with and without (HA/Ti) composite coating were prepared and subsequently implanted in the mandibular canine of 20 cats after completion of root canal treatment and osseous preparation. After a healing period of four months, osteointegration evaluation and histopathological interpretation was carried out using SEM and optical microscopy.

Results indicate that the novel HA/Ti composite coating improves the corrosion behaviour and biocompatibility of SS endodontic dental implant. The clinical evaluation (in vivo test) results showed that there was significant difference in osteointegration between coated and uncoated endodontic dental implants and average bone osteointegration of coated implants were more than uncoated implants. The histopathological results and bone tissue response to the coated implants was acceptable and it was concluded that HA/Ti composite coated SS could be used as well as an endodontic dental implant.

PAPER 34.7 — 11:20

THE EFFECT OF SURFACE TREATMENT AND POSITION OF THE DENTAL RESTORATION ON AMALGAM CORROSION BEHAVIOUR.

V. MORTAZAVI, Faculty of Dentistry, Isfahan University of Medical Sciences, Isfahan, Iran, and
M.H. FATHI, Materials Engineering Department, Isfahan University of Technology, Isfahan, Iran

The aim of this research was to evaluate the effect of surface treatment, clinical operations, and the condition and position of the dental restoration on amalgam corrosion behaviour. Commercial amalgam alloy, namely Oralloy, was selected. Twenty-one amalgam samples were prepared. After triturating and condensation, the samples were divided into three groups and each group was finished by using one of three surface clinical procedures: carving, carving-burnishing, carving-burnishing-polishing. A special cylindrical mould was used in order to simulate the interproximal areas and proximal surfaces of the dental restorations. Stainless steel matrix band was laid on the internal mould surfaces and amalgam paste was compacted in the mould. Electrochemical potentiodynamic tests were performed at a temperature of 37_±1°C in physiological solution in order to determine and compare the corrosion behaviour of dental amalgam samples, as an indication of bio-compatibility. The results showed statistically significant differences between the mean corrosion current density values of three different groups of dental amalgam ($P < 0.05$). The polished group possesses the lowest and the carved group shows the highest corrosion current density. The carved group shows more corrosion resistance in comparison with the sample near the matrix band as an index of the proximal surfaces of restorations. It was concluded that even a simple clinical operation could effect on dental amalgam corrosion resistance. The proximal surfaces of the class II restorations are not only susceptible to concentration cell corrosion but also possess less corrosion resistance because a dentist could not perform clinical surface treatment.

SESSION 35: INTERNATIONAL SYMPOSIUM ON ENVIRONMENTAL DEGRADATION OF MATERIALS AND CORROSION CONTROL IN METALS

Characterization of Corrosion behavior

Sponsor: Materials Performance and Integrity, The Metallurgical Society of CIM

Room: Beluga

Chairman: T.R. JACK, NOVA Chemicals, Calgary, Alberta and

E. GHALI, Department of Mining, Metallurgy and Materials Engineering, Laval University, Québec, Québec

PAPER 35.1 — 8:30 (KEYNOTE)

THE EFFECT OF CARBON AND OXYGEN ON THE METAL DUSTING OF NICKEL-BASE ALLOYS IN CARBON MONOXIDE-RICH GAS AT HIGH TEMPERATURE.

F.H. STOTT, F. DI GABRIELE, J.R. BERNSTEIN and Z. LIU, Corrosion and Protection Centre, UMIST, Manchester, United Kingdom

The recent interest in Fisher-Tropsch gas-to-liquid hydrocarbon processing technologies and the pursuit of maximum efficiency in steam-reforming technologies require the development of equipment operating at increased carbon activities across the temperature range, 450°C to 850°C, where metal dusting can cause severe environmental damage to alloy components. This paper presents and discusses the initial results (after 1000 hr) of some long-term exposures of commercial and recently-developed high-temperature nickel-base alloys (Alloys 600, 601, 602CA, 603XL, 617, 671, 690, 693, 890, H46M) in 20% hydrogen/80% carbon monoxide at 650°C. Most of the alloys showed a good resistance to the dusting environment in the 1000-hr period, although Alloy 600 exhibited significant carbon deposition and, at least, the initial stages of metal dusting after relatively short exposure times (about 100 hr). Preliminary examinations have revealed that initiation of metal dusting was enhanced at stress and defect points. This resulted in localized breakdown of an initially-protective Cr₂O₃-rich scale on Alloy 600, particularly along specimen edges. The other alloys benefitted from more effective Cr₂O₃-rich scales, due to higher alloy chromium contents plus, in some cases, silicon or aluminum. Nonetheless, several specimens of two of these alloys did exhibit some very localized metal dusting damage at relatively deep abrasion grooves in their surfaces. The process of dusting involved deposition of carbon on the exposed metal, diffusion of carbon into the surface regions and disintegration of those regions into a dust-containing nickel (plus iron) and Cr₂O₃ particles.

PAPER 35.2 — 9:00

EFFECTS OF IRON CONTENT ON MICROSTRUCTURE AND CREVICE CORROSION OF TITANIUM GRADE-2.

X. HE, J.J. NOËL and D.W. SHOESMITH, Department of Chemistry, University of Western Ontario, London, Ontario, Canada

The effects of iron content on microstructure and crevice corrosion of titanium Grade-2 (Ti-2) were studied using a galvanic coupling technique combined with optical microscopy and secondary ion mass spectrometry (SIMS) imaging. The study reveals that iron content has a significant effect on the microstructure and crevice corrosion behavior of Ti-2. The grain size decreases significantly with the increasing iron content. For Ti-2 material of medium iron content, crevice corrosion was readily initiated and exhibited extensive intergranular attack which could be associated with the more reactive iron-stabilized β -phase within the α -phase matrix as revealed by SIMS imaging. By contrast, Ti-2 materials with low and high iron content showed suppressed crevice attack. The small surface area of available grain boundaries in Ti-2 of low iron content accounted for this limited attack. For the material with high iron content, SIMS imaging suggest that some Ti_xFe intermetallic particles were formed. These particles may act as proton reduction catalysts and enhance crevice corrosion resistance.

PAPER 35.3 — 9:25

EFFECTS OF FLOW RATE, SAND CONCENTRATION AND CORROSION CURRENT DENSITY ON SYNERGISM IN EROSION-CORROSION OF CARBON STEEL

J.F. LU, B.T. LU and J.L. LUO, Department of Chemical and Materials Engineering, University of Alberta, Edmonton, Alberta, Canada

In this paper, the slurry-erosion behavior of carbon steel was investigated. The synergism due to the interaction of erosion and corrosion was further divided into the erosion enhanced by corrosion and corrosion promoted by erosion and effort was made to experimentally measure corrosion-enhanced erosion component. The results indicated that the corrosion rate is promoted with increasing flow rate and the sand concentration. The corrosion-enhanced erosion is caused by the degradation of the mechanical erosion resistance and the non-uniform dissolution of surface. The mechanism of the erosion-enhanced corrosion was discussed in line with the changes in material properties during the erosion-corrosion processes.

PAPER 35.4 — 9:50

CORROSION OF TITANIUM AND TI-ALLOYS AT HIGH TEMPERATURES AND PRESSURES.

J. VAUGHAN, P. REID, A. ALFANTAZI, D. DREISINGER, D. TROMANS, Department of Metals and Materials Engineering, The University of British Columbia, Vancouver, British Columbia, Canada, and M. ELBOUDJAINI, CANMET-MTL, Ottawa, Ontario, Canada

In this study, pure Ti and select Ti alloys (ASTM Grades 1, 2, 7, 12, and 18), those typically employed as autoclave linings and internal components, were tested in sulphate media (30 g/L) at elevated temperatures (423 K to 523 K) and pressures (700 kPa to 4200 kPa), simulating conditions found during the high-pressure acid leaching of nickel laterite ores. The DC electrochemical testing employed was cyclic polarization. Analysis of uncorroded and select corroded samples was done using SEM, XPS, and AES. Pitting of the samples was not apparent. The alloys adapted to the high-temperature environment by thickening of the protective oxide layer.

COFFEE BREAK — 10:15 – 10:30

PAPER 35.5 — 10:30

CORROSION OF CARBON STEEL LINERS WITHIN FAILED NUCLEAR WASTE CONTAINERS.

C.T. LEE, Z. QIN, J.J. NOËL and D.W. SHOESMITH, Department of Chemistry, University of Western Ontario, London, Ontario, Canada

The corrosion of carbon steel liners in failed Canadian nuclear waste containers could have a major effect on the redox conditions controlling the subsequent dissolution of the fuel waste form. Consequently, the authors have been studying the corrosion of carbon steel in anoxic simulated groundwaters, which could flood a failed container. Voltammetric scans were performed on a rotating ring-disc electrode to quantify the amount, and potential region, of active Fe^{2+} release. Potentiostatic experiments were performed to monitor corrosion product deposit growth rates. Raman spectroscopy and scanning electron microscopy of surface deposits indicated surface composition varied from predominantly siderite ($FeCO_3$) (nodular deposits) in carbonate-dominated waters to magnetite (Fe_3O_4) (compact deposit of very small crystals) in sulphate-dominated waters. Open circuit measurements accompanied by periodic electrochemical impedance spectroscopy measurements showed that active corrosion conditions with the accumulation of a Fe_3O_4 deposit appear sustainable under natural corrosion conditions.

PAPER 35.6 — 10:55

EFFECT OF Y_2O_3 PARTICLES ON CORROSIVE WEAR OF ALUMINUM MADE USING AN ARC MELTING PROCESS.

W.B. BOUAESHI and D. Y. LI, Department of Chemical and Materials Engineering, University of Alberta, Edmonton, Alberta, Canada

Aluminum is one of the most attractive metals, which has found many engineering applications due to its great formability, low density, and high resistance to corrosion. Since aluminum is not strong, it is usually strengthened by introduction of second phases, reinforcing particles or fibres. However, when second phases reinforcing particles or fibres are introduced, the corrosion resistance of aluminum may decrease due to the formation of microelectrodes that accelerate electrochemical reactions. Such decrease in corrosion resistance negatively influences industrial application of aluminum-based materials.

The objective of this work was to strengthen aluminum without decreasing its corrosion resistance. Yttria was selected as a reinforcing phase to make yttria-aluminum composites using an arc melting process. It was demonstrated that by adding yttria particles, the modified aluminum exhibited higher hardness, improved polarization behaviour and higher resistance to corrosive wear in a sulphuric acid solution. Microstructural examination showed that the microstructure of aluminum became finer when yttria powder was added. However, the added yttria particles were not observed in the modified aluminum. Instead, a new phase, Al_3Y , had formed, which could result from possible decomposition or melting of the yttria particles during the arc melting process. The improved properties of aluminum by yttria addition could thus be attributed to the formation of Al_3Y phase and the resultant finer microstructure.

PAPER 35.7 — 11:20

EFFECT OF SANDBLASTING AND SHOT-PEENING ON THE CORROSION BEHAVIOUR OF Pb-AG ALLOY ANODES IN ACID ZINC SULPHATE ELECTROLYTE AT 38°C.

S. JIN, E. GHALI, Department of Mining, Metallurgy and Materials Engineering, Laval University, Québec, Québec, Canada,

G. HOULACHI and G. ST-AMANT, Hydro-Québec, Shawinigan, Québec, Canada

The surface treatment of Pb-Ag alloy anodes is a measure used in the zinc electrowinning industry to stabilize the anode surface and decrease the lead contamination of the zinc cathode. In this work, the effect of sandblasting and shot-peening treatments on the corrosion behaviour of the Pb-Ag alloy anodes in zinc electrolyte was studied using electrochemical methods. The results showed that the sandblasting treatment slightly decreased the corrosion rate of the anode in acid zinc sulphate solution without manganese addition, while the shot-peening treatment remarkably decreased the corrosion rate of the anode when it was immersed in the same electrolyte. In zinc electrolyte containing Mn^{2+} and MnO_4^- , the corrosion potentials of the untreated and sandblasted anodes were ca. 750 mV higher than that those observed in the zinc electrolyte without manganese. As a result the corrosion rates were greatly decreased. The presence of Mn^{2+} and MnO_4^- in the zinc electrolyte shifted the corrosion potential of the shot-peened anode in the positive direction by 400 mV, but did not influence its corrosion rate. The sandblasting and shot-peening treatments made the MnO_2 - PbO_2 layer formed on the anodes during the electrolysis more compact and slightly increased the overpotential of the anodic reaction during five hours of electrolysis. One hour after the electrolysis, the corrosion rates for the three anodes were: shot-peened anode > sandblasted anode > untreated anode. Five hours after the electrolysis, the order of the corrosion rates changed to: sandblasted anode > untreated anode > shot-peened anode.

WEDNESDAY, AUGUST 27, 2003, P.M.

SESSION 45: INTERNATIONAL SYMPOSIUM ON ENVIRONMENTAL DEGRADATION OF MATERIALS AND CORROSION CONTROL IN METALS

CORROSION PROTECTION COATINGS I

Sponsor: Materials Performance and Integrity, The Metallurgical Society of CIM

Room: Finback

Chairman: A. ALFANTAZI, Department of Metals and Materials Engineering, The University of British Columbia, Vancouver, British Columbia, and

A. VEA WAB, University of Regina, Regina, Saskatchewan

PAPER 45.1 — 14:00

CORROSION AND TRIBOLOGICAL PROPERTIES OF MAGNETRON SPUTTERED AL-MO COATINGS.

M. BIELAWSKI and R.C. McKELLAR, Institute for Aerospace Research, National Research Council Canada, Ottawa, Ontario, Canada

Al-Mo coatings deposited by an unbalanced magnetron sputtering (UMS) technique were evaluated as a possible alternative to electrodeposited cadmium. These coatings were produced over the full binary range of compositions to exploit the potential of the Al-Mo system to produce functional coatings with enhanced corrosion and tribological properties. The coating characterization included, besides standard microstructural examination (SEM, EDX, microhardness), the tribological (pin-on-disc) testing and corrosion (electrochemical polarization) tests in a 3.5% NaCl solution. In summary, the Al-Mo coatings produced by magnetron sputtering show uniform thickness, a fully dense, featureless or columnar structure (depending on composition) and a good adhesion to steel. Increasing Mo content resulted in a gradual increase of the corrosion potential (from -0.750 V for 0% Mo to -0.220 V for 90% Mo) and pitting potential (respectively from -0.650 V to +0.200 V). Coatings with the Mo content below 14 wt.% were found to be sacrificial to steel. Coefficient of friction of Al-Mo coatings was tested to be between 0.2 and 0.9, with the lowest value obtained for the Al-95Mo composition at low speed and low load conditions.

PAPER 45.2 — 14:25

EROSION BEHAVIOUR OF HYOF THERMAL-SPRAYED NiAl INTERMETALLIC COATINGS WITH DIFFERENT CeO₂.

Y. WANG and W. CHEN, Department of Chemical and Materials Engineering, University of Alberta, Edmonton, Alberta, Canada

The influence of CeO₂ and heat treatment on the microstructure, hardness and especially erosion behavior of HVOF thermal sprayed NiAl intermetallic coatings was studied in this investigation. Among the NiAl intermetallic coatings studied, the NiAl coating containing 8 wt.% CeO₂ has the highest erosion rate, while the coating containing 2-5 wt.% CeO₂ exhibits the lowest erosion rate. Erosion surface morphologies showed a combined ductile and brittle feature. Heat treatment at temperatures higher than 600°C softened the coating materials, leading to an increased erosion rate. Work hardening has occurred during erosion testing, and the highest degree of work hardening occurred in the NiAl coating containing about 5 wt.% CeO₂. The degree of work hardening of the as-sprayed coating appeared larger than that of coating being heat-treated. Due to work hardening, the erosion rate becomes less discernible at the elongated erosion time among coatings with different hardness values.

PAPER 45.3 — 14:50

WATER-BASED SOL-GEL HYBRID CORROSION PROTECTION COATING.

Y. HUANG, H. ZHENG, Chemat Technology Inc., Northridge, California, U.S.A.,

W. VAN OOIJ, University of Cincinnati, Cincinnati, Ohio, U.S.A., and

J. OSBORNE, Phantom Works Seattle, The Boeing Company, Renton, Washington, U.S.A.

Non-chromate waster-based conversion coating based on the Sol-Gel/bis-silane hybrid system was developed for corrosion protection of aluminum alloys. The latest developments, including methods to incorporate a colour in the silane coating, as well as imparting an organic and inorganic inhibitor to the coatings, is presented and discussed. DC and AC electrochemical test results showed one to two orders of decreasing in corrosion currents with these non-VOC and non-chromate contained waster-based conversion coatings. Some formulations have passed paint adhesion tests in accordance with BSS7225 Type III Class 3. Bare corrosion resistance was tested to ASTM B117 and some showed marginal results.

COFFEE BREAK — 15:15 – 15:30

PAPER 45.4 — 15:30

DEVELOPMENT OF A THIN FILM VITREOUS BOND-BASED COMPOSITE CERAMIC COATING FOR CORROSION AND ABRASION SERVICES.

B. FRANKE, International Polymer Canada Ltd., Edmonton, Alberta, Canada

IPC has been involved with the Alberta Research Council in developing a vitreous bond (VB)-based composite ceramic fluoropolymer coating technology. Compared to the present state-of-the-art which is based on a hard discontinuous phase (ceramic particles) suspended in a soft continuous matrix (fluoropolymer mix) the novelty of our approach consists of designing a composite system in which both the ceramic and the fluoropolymer phases are continuous. The ceramic matrix will provide the strength and the erosion resistance for the fluoropolymer matrix even at high temperatures. The ceramic formulation employed is not affected by temperatures up to 500 F while the fluoropolymer matrix provides a corrosion protection seal for the ceramic matrix. The inherent flexibility of the polymer matrix will protect against brittle fractures that may develop by handling or impact. Therefore the composite coating is able to withstand the deformation of the substrate without chipping or disbonding. The fluoropolymer matrix also provides dry lubrication properties further enhancing the erosion resistance of the ceramic phase. The thickness of the coating is very thin, in the 25 to 100 micron range.

In summary, the coating technology is able to provide the following features:

- Bullet:corrosion protection levels similar to those of fluoropolymer coatings;
- erosion resistance similar to that of ceramic coatings;
- price comparable to that of polymer coatings;
- exceptional wear resistance properties; and
- capability for coating complicated shapes internally or externally or both.

This paper will discuss the theory and development of this new technology and the resultant coating and potential properties.

PAPER 45.5 — 15:55

MICRO SCRATCH AND CORROSION BEHAVIORS OF NANOSTRUCTURED WC PARTICLES-ENHANCED POLYMER COMPOSITE COATINGS.

Y. WANG, S. LIM, Z.H. XU and J.L. LUO, Department of Chemical and Materials Engineering, University of Alberta, Edmonton, Alberta, Canada, T6G 2G6

In this paper, the scratch and corrosion behaviors of nanostructured WC particles-enhanced polymer composite coatings were studied by using micro scratch technology and electrochemical technique. The coatings containing nanostructured WC particles showed a significant increase in the hardness and scratch resistance compared with that of pure polymer coating. The remarkable improvement in hardness and scratch resistance is attributed to the dispersion hardening of nanostructured WC particles in polymer coatings. Corrosion test results showed that the nanostructured WC particles-enhanced polymer composite coatings exhibit a better or at least equivalent corrosion resistance than the pure polymer coating.

PAPER 45.6 — 16:20

ELECTROPOLYMERIZED COATING OF PYRROLE AND METHYLPYRROLE ON MILD STEEL SURFACE.

A. ASHRAFI, M. A. GOLOZAR, Department of Materials Engineering, Isfahan University of Technology, Isfahan, Iran, and S. MALLAKPOUR, Organic Polymer Chemistry Research Laboratory, College of Chemistry, Isfahan University of Technology, Isfahan, Iran

Electrochemical polymerization of various ratios of pyrrole and methylpyrrole monomers were performed in aqueous toluene-4-sulfinic acid sodium salt (T4SNa) electrolyte, using galvanostatic method. In order to prevent corrosion of mild steel substrates during coating deposition, all samples were pretreated in 0.5 M oxalic acid solution. Corrosion resistance of coated substrates was investigated in 1 M NaCl solution using Tafel polarization technique. In addition, using scanning electron microscopy (SEM), morphological characterization of coatings produced was investigated. The ratio of 1 to 1 (pyrrole/methylpyrrole), could play an important role on corrosion properties of the resulting coated mild steel.

SESSION 46: INTERNATIONAL SYMPOSIUM ON ENVIRONMENTAL DEGRADATION OF MATERIALS AND CORROSION CONTROL IN METALS

CORROSION PROTECTION COATINGS II

Sponsor: Materials Performance and Integrity, The Metallurgical Society of CIM

Room: Beluga

Chairman: A. ALFANTAZI, Department of Metals and Materials Engineering, The University of British Columbia, Vancouver, British Columbia, and

A. VEA WAB, University of Regina, Regina, Saskatchewan

PAPER 46.1 — 14:00

VITREOUS ENAMEL COATINGS AS POROUS COMPOSITES.

N.T. CHARDAKOV, I.Y. PYCHMINTSEV, Science and Research Institute for Materials and Technology, Ekaterinburg, Russia, and

V.Y. KUDYAKOV, Institute of High Temperature Electrochemistry, Ekaterinburg, Russia

Recent investigations have shown, that vitreous enamel coatings can be considered as composite materials properties of which are determined more by macrostructure rather than microstructure. The detrimental effect of both the bubble structure and the presence of solid inclusions on such important properties as adhesion and protection potential in different corrosive environment was found. Typical microstructure parameters found experimentally were applied for analytical macrostructure-properties relationships.

PAPER 46.2 — 14:25

FORMATION OF NiAl INTERMETALLIC COATINGS ON STAINLESS STEEL BY A CONVENTIONAL DUPLEX PROCESS.

F. ASHRAFIZADEH, A.H. HAJDAIE and S. MIRAGHAIE, Department of Materials Engineering, Isfahan University of Technology, Isfahan, Iran

Nickel-aluminide coatings were formed on 403 stainless steel samples by a duplex process incorporating electro-deposition and diffusion coating. Nickel was deposited by conventional electroplating on some specimens to appropriate thickness. The uncoated and nickel-coated samples were then aluminized by a powder pack method. Process parameters including pack composition, temperature, coating and annealing cycles were optimized in terms of the intermetallic phases produced in the near surface layers. The coatings and interface regions were characterized by optical and scanning electron microscopy, x-ray diffraction, glow discharge spectroscopy, micro-hardness measurements and pin-on-disc wear testing.

Experimental results indicate that deposition of nickel on 403 steel before aluminizing produced two distinct layers of NiAl and FeAl on the surface and below that, respectively. The formation of these phases depends on the coating and annealing temperatures. The intermetallic phase NiAl on steel substrate acts as alumina forming material to increase the life of aluminized layer. The intermetallic coatings produced by this duplex process had dense structure and excellent adhesion to the substrate; these are suitable candidates for high temperature applications of steel components under oxidation and hot corrosion conditions.

PAPER 46.3 — 14:50

INFLUENCE OF NiAl COATINGS ON HOT CORROSION BEHAVIOUR OF 403 STAINLESS STEEL.

M. EBRAHIMIAN, High Temperature Coatings, Iranian Surface Research and Engineering Centre, Isfahan, Iran, and M. MORADI, M. PARTOVI RAD and F. ASHRAFIZADEH, Department of Materials Engineering, Isfahan University of Technology, Isfahan, Iran

Hot corrosion behaviour of nickel-aluminide coatings on stainless steel 403 substrate was evaluated in an attempt to improve the performance of this alloy for hot section components of gas turbines. Ni-Al coatings were produced by a duplex process including electrodeposition of a nickel layer followed by pack aluminizing at suitable temperature time cycles. The coatings and interfaces were characterized by optical and scanning electron microscopy, X-ray diffraction and EDS micro-analysis. Hot corrosion resistance was evaluated by a modified furnace test. Experimental results indicate that nickel-aluminide coatings are resistant to higher temperatures compared to pure aluminides under hot corrosion atmosphere. The intermetallic phase NiAl on steel substrate acts as an alumina-forming material; a behaviour similar to aluminized nickel-base superalloys in some ways. The results suggest that such coatings can be suitable candidates for high-temperature application of steel components.

PAPER 46.4 — 15:15

EFFECT OF STRAY CURRENT ON THE PERFORMANCE OF THE CATHODIC PROTECTION SYSTEM WITH DIFFERENT COATINGS.

Q. ZHANG, Chinese Corrosion and Protection Society, Beijing, China,

Y. WU, H. XIAO, L. YANG and B. DING, University of Science and Technology Beijing, Beijing, China

The effects of the magnitude and direction of the stray current on the Mg sacrificial anode-coating cathodic protection system have been investigated in the simulated soil solution. The results indicate that effect of the directions of the stray current and protection current follows certain rule. The harmful effect of the stray current can be especially severe in case of the existence of pre-made little holes on the coatings, which will increase the protection current by about 20 to 200 times. Between the two coatings studied, compound epoxy tar is better than thermal shrink wrap in resisting the stray current effect.