Jurnal Sains Materi Indonesia
Indonesian Journal of Materials Science

Vol. 14, No. 1, Oktober 2012, hal : 56 - 61
ISSN : 1411-1098

Akreditasi LIPI Nomor : 395/D/2012
Tanggal 24 April 2012

FAILURE ANALYSIS OF ALUMINIUM AND ZINC HEAT REFLECTOR IN TIMBER DRY KILN

Sulistioso Giat S.[1], A. Sitompul[1], M. N. Indro[2] and A. Rahmatika[2]

[1]*Center For Technology of Nuclear Industry Materials (PTBIN)-BATAN*
Kawasan Puspiptek Serpong 15314, Tangerang, Indonesia
[2]*Department of Physics, IPB*
Jl. Meranti, Darmaga, Bogor 16680, Indonesia

Received: 11 Mei 2012 Revised: 7 Agustus 2012 Accepted: 11 September 2012

ABSTRACT

FAILURE ANALYSIS OF ALUMINIUM AND ZINC HEAT REFLECTOR IN TIMBER DRY KILN. Aluminium and Zinc (Al-Zn) alloy coated steel sheet (JIS G3141) was used as a heat reflector in timber dry kiln. After six months continuous service at 110^{0}C in moist condition, the heat reflector is corroded. Failure analysis method was used to analyze this corrosion phenomena. Macroscopic and microscopic examination with some characterization have been performed to determine the elemental composition and corrosion products. The elemental composition of corroded heat reflector that were detected by SEM-EDS are sulphur, chloride, calcium, and potassium. XRD analysis revealed the zinc aluminium carbonate hydroxide hydrate ($Zn_6Al_2(OH)_{16}CO_3.4H_2O$) known as black rust staining and iron oxide (Fe_3O_4), as corrosion products. Environmental condition in timber dry kiln with the existence of acid and alkaline elements cause the corrosion process occur. Those elements come from the dried timber and steam that adhered on the heat reflector surface attacked the Al-Zn coating and base metal. Humidity and high temperature in timber dry kiln environment increase the corrosion rate of the heat reflector.

Keywords : Corrosion, Failure analysis, Al-Zn coating, Timber dry kiln

ABSTRAK

ANALISIS KEGAGALAN DARI LAPISAN ALUMINIUM DAN *ZINC* SEBAGAI *HEAT REFLECTOR* PADA *TIMBER DRY KILN*. Paduan Aluminium and Zinc (Al-Zn) dilapiskan pada baja JIS G3141, sebagai *heat reflector* pada *Timber Dry Kiln*. Setelah digunakan selama 6 bulan, pada suhu 110 ^{o}C, dan kondisi uap basah, secara terus menerus, *heat reflector* terkorosi. Metode análisis kegagalan digunakan untuk menganalisis fenomena terjadinya korosi. Pengujian secara mikroskopis dan makroskopis dilakukan untuk menentukan komposisi dan produk korosi yang terjadi pada heat reflektor. Unsur-unsur yang terdeteksi dengan *Scanning Electron Microscope* (*SEM*)-*Energy Dispersive Spectroscopy* (*EDS*) adalah Sulfur, Klorida, Kalsium dan Natrium. Analisis X-Ray Diffractometer (*XRD*) menunjukkan adanya fasa *zinc aluminium carbonate hydroxide hydrate* ($Zn_6Al_2(OH)_{16}CO_3.4H_2O$)) yang dikenal dengan nama *Black Rust Staining*, muncul juga fasa Fe_3O_4 atau oksida besi, sebagai produk korosi. Lingkungan dari *Timber Dray Kiln* ini mengandung asam dan alkalin sebagai penyebab terjadinya korosi. Unsur unsur tersebut berasal dari timber yang dikeringkan dan uap yang keluar menyusup ke permukaan *heat reflector* kemudian merusak lapisan Al-Zn dan *base* metal nya. Kelembaban dan suhu tinggi pada lingkungan *timber dry kiln*, menaikkan laju korosi pada *heat reflector*.

Kata kunci : Korosi, Analisis kegagalan, Lapisan Al-Zn, *Timber dry kiln*

INTRODUCTION

Corrosion can be defined as a degradation in properties of material or mass over time because of environmental effects. It is a natural tendency that the chemical composition in a material return to a stable state thermodynamically. This mean that the basic metallic compounds generally considered to be ores. In order to prevent or control corrosion, the structural metals like irons and steels are coated by a protective coating [1].

The most common chemical composition of anti corrosion coating is pure zinc (galvanized) coating. It contain a good combination of galvanic and barrier protection to prevent corrosion attack [2]. Many researchers have attempted to develop coating materials for steel that have superior corrosion resistance and better coating formability. A combination of Aluminium-Zinc was found as an excellent coating material for steels or irons.

The alloy coating of Aluminium and Zinc known as Al-Zn coating. Its combination may produce several advantages in many applications if both of them are contribute their properties. Al-Zn coating steel sheets are used widely in applications both indoors and outdoors. It is intended for applications where superior corrosion resistance is required, as in roofing, walling, cladding and other uses. Besides it has a good corrosion resistance, Al-Zn coating also has a good heat reflectivity [3]. That was the reason why they can be used as a heat reflector.

A timber dry kiln is simply defined as a closed structure designed or adapted for the purpose of reducing the moisture content of timber and wood based products. Sample that will be analyzed in this case is low carbon steel JIS G3141 [4] coated by Al-Zn alloy that was used as a heat reflector in timber dry kiln. The function of heat reflector is to isolate heat in kiln, so the heat is reflected back into the timber that being dried. The purpose of using Al-Zn heat reflector is to get good heat reflectivity with long service life and high corrosion resistance [4,5]. After 6 months continuous service at 110^{o}C in moist condition, the heat reflector is corroded and become rusty. Failure analysis method was conducted to analyze the corroded heat reflector [7,8]

EXPERIMENTAL METHOD

Failure analysis method was used as a tool to investigate this corrosion failure. Stages of failure analysis are, the first is data collection from history of failed part then selection and preparation of corroded samples, first samples are cutting, then examination macroscopic by stereo microscope using the magnitude between 8X to 16X , and digital camera for examinatian almost all of the sample then we analysis to obatin the part of the sample will be focusing in microscopic examination, after the location will be focusing is, was carried out, the second stage was microscopic examination, by using optical microscope with magnitude 240X to 400X , after analised the result of photograph and then we choice the focus objet to more deep analised by Scanning Electron Microscope (SEM), from both apparatus we find out the micromorphology the sample, final stage is phase analysis of the located sample by using X-ray diffraction with degree of diffraction (2θ) from 10 to 80. and microchemical analysis by Energy Dispersive Spectroscopy (EDS) that attachment in SEM apparatus. Finnaly analysis of the data and conclusion of the investigation [9-11].

RESULTS AND DISCUSSION

History of Failed Part

The temperature of the kiln is 110 ^{o}C and the kiln was operated in 24 hours non stop. Aluminium and Zinc (Al-Zn) alloy in this kiln to function as a sub ceiling. This ceiling was used as a heat reflector in order to isolate the heat and the heat can be reflected back to the timber. Kind of wood that was dried in timber dry kiln is Sengon wood. After six months continuous service, the Al-Zn heat reflector was corroded and rusty. Figure 1 showing the corroded and rusty Al-Zn alloy that was used as heat reflector.

Macroscopic Examination

Observation by using digital camera showed that the surface texture was relatively rough and thin particularly at the edge of the sample, see Figure 2.

Figure 1. The corroded Al-Zn heat reflector.

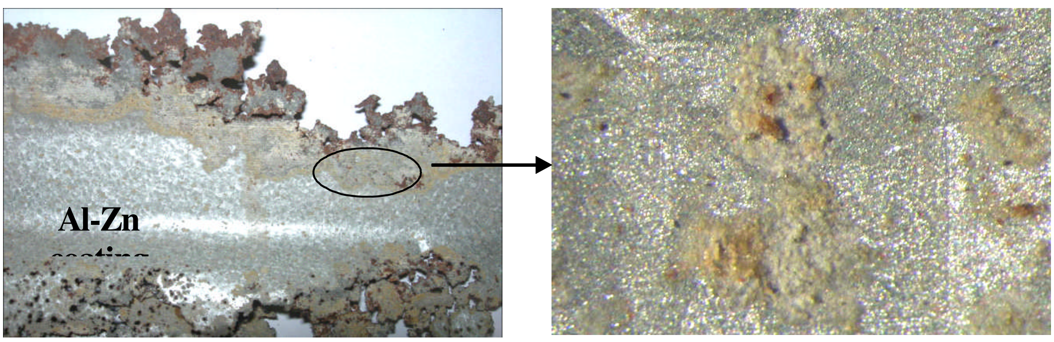

Figure 2. Photograph of surface exhibit the deposit around the perforated area (a) and exhibit the corrosion product seems like deposit (b).

Vol. 14, No. 1, Oktober 2012, hal : 56 - 61
ISSN : 1411-1098

It can be seen that the thin of the sample also followed by the existence of dark-brownish perforated area. It means the Al-Zn coating at the sample's edge has flaked off and corrosion products were observed around the perforated area on the surface. In the contrary, the visible of spangle in the middle of sample proves that Al-Zn alloy still remain. Observation of corrosion products can be clearly seen by using stereomicroscope. They adhered on the surface layer of the sample seems like deposit. [12,13].

Microscopic Examination

Figure 3 showing the microstructures of Al-Zn coating surface that was used as a heat reflector and corrosion deposit observed at cross section. The coating on the surface still remain intact but there is corrosion deposit adhered on the above of coating, it appear as somewhat dark reddish stain. The existence of deposit obviously detected by SEM.

Phase Analysis

Phase analysis by using X-Ray Diffraction (XRD) in Figure 4 revealed compounds that contain in heat reflector consists of coating composition just like the fresh sample, they are Al-Zn as a strongest peak. Small amount of iron oxide (Fe_3O_4) and Zinc aluminum carbonate hydroxide hydrate ($Zn_6Al_2(OH)_{16}CO_3.4H_2O$) were also identified in the corroded heat reflector. The latter phase is predicted as dark reddish corrosion deposit that adhered on the coating.

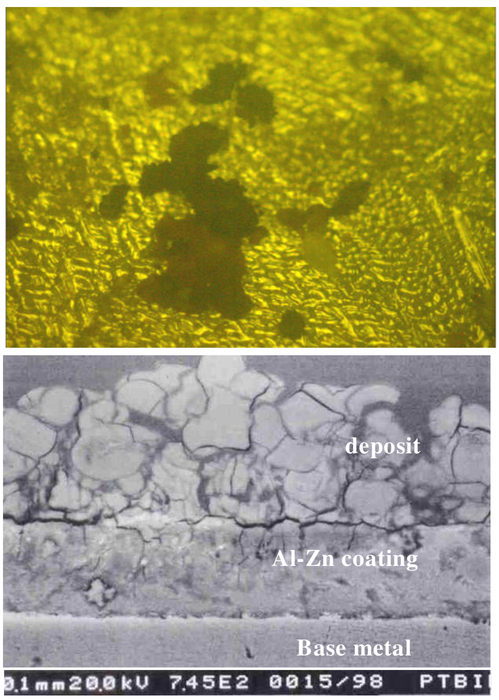

Figure 3. Surface (left, 200X) and cross section microstructures of Al-Zn heat reflector.

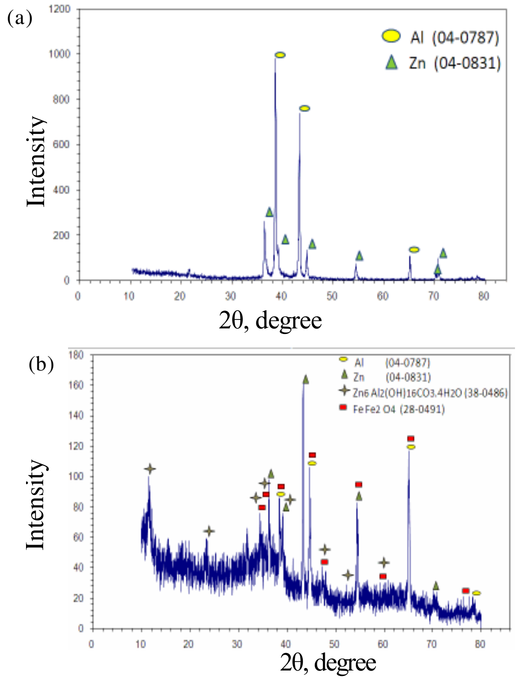

Figure 4. XRD pattern of (a). fresh sample Al-Zn coating and (b). corroded Al-Zn heat reflector

Chemical Analysis

Figure 5, 6, and 7 shows the SEM image of corroded heat reflector at surface and cross-section, respectively. Chemical analysis is to determine the elemental composition of corroded heat reflector using EDS. Table 1, 2 and 3 is the percentage of weight of elements that contain in corroded heat reflector.

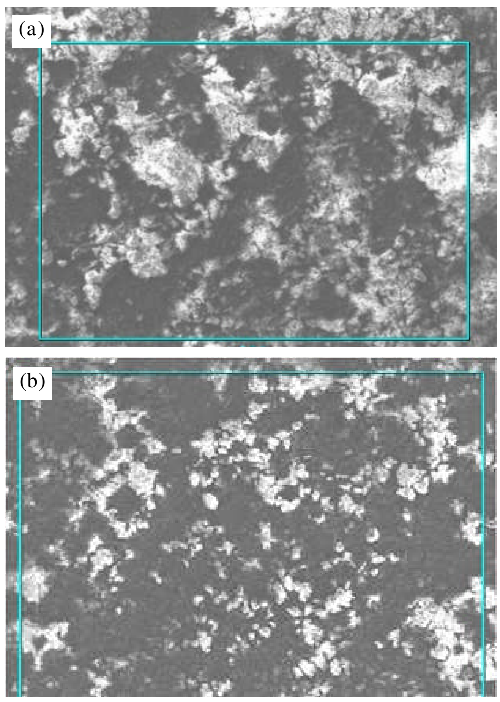

Figure 5. Square analysis of corroded Al-Zn heat reflector.

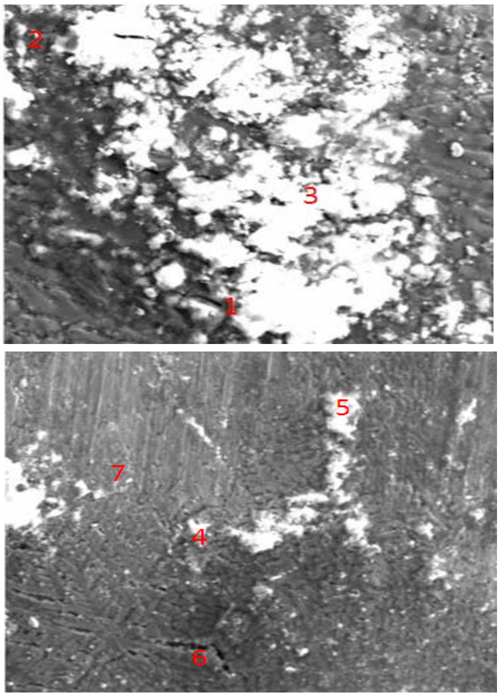

Figure 6. Point analysis on the corroded surface Al-Zn heat reflector.

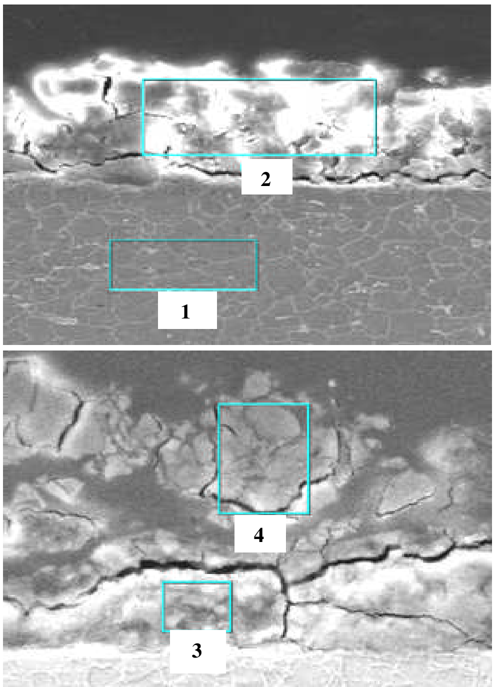

Figure 7. Square analysis at the cross section of corroded Al-Zn heat reflector.

Table 1. Chemical composition of square area in Figure 5

Element (wt.%)	Square Area 1	Square Area 2
C	18.34	10.34
O	38.84	43.15
Al	10.09	17.87
S	1.82	0.73
Cl	0.62	1.70
Ca	3.91	1.44
K	--	0.09
Fe	3.82	0.91
Zn	21.17	23.62

Table 2. Chemical composition for every point in Figure 6

Element (wt.%)	Points						
	1	2	3	4	5	6	7
C	13.13	16.30	28.51	13.54	12.67	67.58	34.27
O	48.58	31.13	37.56	33.57	40.18	3.77	7.16
Al	15.48	2.99	5.85	14.60	12.61	9.69	21.53
Si	---	3.97	---	3.25	0.49	0.24	0.09
S	1.28	1.59	3.78	0.44	---	---	---
Cl	1.75	5.98	0.82	---	---	---	---
Ca	0.84	0.80	0.59	2.09	1.83	0.03	0.09
Fe	0.51	1.30	1.02	12.48	8.39	0.27	0.60
Zn	17.95	35.93	21.86	19.65	22.04	18.21	36.22
K	0.49	---	---	---	---	---	---

Table 3. Chemical composition of square area analysis in Figure 7

Element (wt.%)	Square Area			
	1 Base metal	2 coating	3 coating	4 deposit
C	2.27	30.47	19.34	22.46
O	0.41	35.36	34.13	43.69
Al	---	13.30	22.49	18.77
Si	0.09	1.12	2.92	0.32
S	---	0.97	1.18	1.47
Cl	---	---	0.56	0.12
Ca	---	0.55	---	1.64
Fe	97.23	0.89	1.52	0.37
Zn	---	17.25	17.86	11.16
K	---	0.09	---	---

Timber emit the chemical elements when being dried and adhered to the surface of heat reflector become deposit. Phase analysis of the deposit revealed that it consisted of Zincalume carbonate hydroxide hydrate ($Zn_6Al_2(OH)_{16}CO_3.4H_2O$) and iron oxides ($Fe_3O_4$). The presence of the zinc aluminum carbonate hydroxide hydrate on the surface is most probably the result from a reaction, taking place contact with carbon dioxide in air. When Al-Zn heat reflector exposed to the environment, zinc will form thin film of zinc oxide to give galvanic protection. Because of the presence of moisture in the kiln from timber and steam, zinc oxide will react with water and form zinc hydroxide.

In contact with water that contain in air, zinc hydroxides precipitate mainly in the zinc rich interdendritic alloy regions while aluminum hydroxides mainly precipitate on the aluminum rich dendrite branches. Zinc aluminum carbonate hydroxide

Vol. 14, No. 1, Oktober 2012, hal : 56 - 61
ISSN : 1411-1098

Table 4. List of the elemental composition that contain in Al-Zn heat reflector and probability source.

Element	Source of Element
Al	Coating
Zn	Coating
Si	Timber
Fe	Base metal
C	Thin organic coating
O	Environment
S	Timber, Natural water
Cl	Timber, Natural water
Ca	Timber, Natural water
K	Timber, Natural water

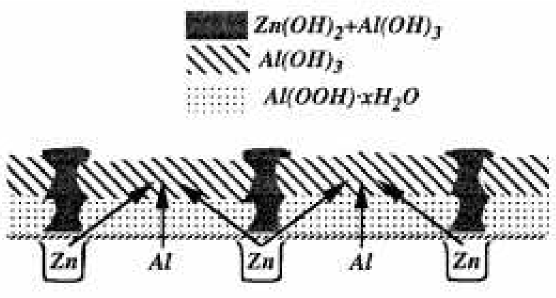

Figure 8. Formation of corrosion products in Al-Zn heat reflector.

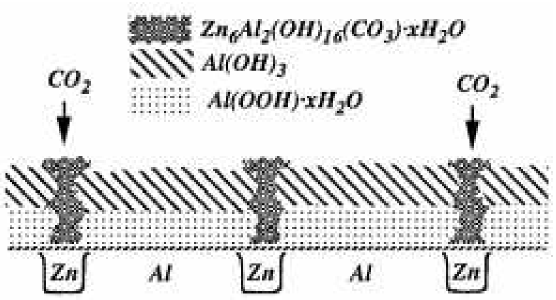

Figure 9. Formation of corrosion products of corroded Al-Zn heat reflector on the underside surface in contact with air.

hydrate is formed by the reaction between Zn $(OH)_2$ (zinc hydroxide) and Al $(OH)_3$ (aluminum trihydroxide) [14,15].

EDS analysis revealed the deposit contain some contaminants such as Sulphur, Chloride, Calcium, and Potassium come from timber and steam.The presence of Sulphur and Chloride indicate the acid condition in kiln environment. These elements are so aggressive to dissolve the corrosion product and lead to higher corrosion rates.[16].

Factors that influence corrosion of Al-Zn heat reflector

Corrosion of Al-Zn heat reflector is due to several factors. These factors are :

Timbers are slightly acidic. Therefore when Al-Zn heat reflector are indirectly contact with timber, they have a low corrosion resistance. Alkaline elements such as Calcium (Ca), and Potassium (K) influence the increase of corrosion rate of Al-Zn heat reflector .

The environment of the kiln were very humid. It can be detected by the presence of steam and moisture that evaporated from timber.

The temperature of the kiln, 110ÚC, increases the corrosion rate of Al-Zn heat reflector.

CONCLUSION

Contaminant elements such as sulphur, chloride, potassium and calcium are adhered on the coating surface become corrosion agent and increase the corrosion rate of heat reflector. The compound of corrosion deposit is detected as a zinc aluminum carbonate hydroxide hydrate or known as black staining. Corrosion that attacked Al-Zn heat reflector are influenced by pH, humidity, temperature and the environment of the kiln (timber and steam).

REFERENCES

[1]. SCHWEITZER, PHILIP, *Corrosion Engineering Handbook, Fundamentals of Metallic Corrosion.* Second Edition, New York, CRC Press, (2007) 1
[2]. GALV INFO NOTE 1.4., *Metallic-Coated Products & Specifications: 55% Aluminum-Zinc,* (2011)
[3]. ZINCALUME, BLUESCOPE STEEL, *Roofing and Walling*, *We'll Make Your Dream a Reality,* (2007) 6
[4]. ZINCALUME, BLUESCOPE STEEL, *The Ideal Steel*, Steelscape, Company, (2007) 2
[5]. HAMED ABBASFARDA, MEHDI GHANBARIB, AMIN GHASEMIC, SATTAR GHADERA, HASAN HASHEMIPOUR RAFSANJANIA, ALI MORADIA, *Engineering Failure Analysis*, **18** (2011) 285-292
[6]. JAGANATHAN SWAMINATHAN, KRISHNA GUGULOTH, MANOJKUMAR GUNJAN, PRABIRKUMAR ROY, RABINDRANATH GHOSH, *Engineering Failure Analysis*, **15** (4) (2008) 311-331
[7]. DE RENZO DJ, *Corrosion Resistant Materials Handbook*, Fourth Edition, New Jersey, Noyes Data Corporation, (1985) 638
[8]. CHENG-HONG PENG, ZHENG-YI LIU, XING-ZHAO WEI, *Engineering Failure Analysis*, **25** (2012) 13-28
[9]. E. A. KENIK, P. J. MAZIASZ, R. W. SWINDEMAN, J. CERVENKA, D. MAY, *J. Scr. Mater.*, **49** (2003) 117-122

[10]. ASM International Metals Handbook, *Failure Analysis and Prevention*, Ninth Edition, ASM International, **11** (1986)

[11]. L.H. DE AMEIDA, A.F. RIBEIRO, L. LE MAY I, *Materials Characterization*, **49** (2003) 219-229

[12]. ALION SCIENCE AND TECHNOLOGY, *A Program Management Guide for Selecting Materials*, Second Edition, Advanced Materials, Manufacturing, and Testing Information Analysis Center (AMMTIAC), New York (2006) 72

[13]. YONGDE LI, NA XUA, XIAOFENG WUA, JUNBO SHIA, LILI ZHANGA, MEI ZHAOA, QISHAN ZANG, *Engineering Failure Analysis*, **20** (2012) 35-42

[14]. A. J. BAKER, Corrosion of Metal in Wood Products, *Durability of Building Materials and Components, ASTM STP 691.* P. J. SEREDA and G. G. LITVAN, Eds., *American Society for Testing and Materials*, (1980) 981-993

[15]. A. F. RIBEIRO, L. H. DE ALMEIDA, D. S. DOS SANTOS, D. FRUCHART, G. S. BOBROVNITCHII, *J. Alloys Compd.*, **356-357** (2003) 693-696

[16]. WALLINDER, ODNEVAL, W. HE, P-E. AUGUSTSON and C. LEYGRAF, *Corrosion Science,* **41** (1999) 224