

Oxidation of a cold-worked 316L stainless steel in pressuriezd water reactor primary water environment

M. Maisonneuve, C. Duhamel, C. Guerre, J. Crepin, I. de Curieres, L.

Verchere

► To cite this version:

M. Maisonneuve, C. Duhamel, C. Guerre, J. Crepin, I. de Curieres, et al.. Oxidation of a cold-worked 316L stainless steel in pressuriezd water reactor primary water environment. EUROCORR 2017, Sep 2017, Prague, Czech Republic. cea-02434524

HAL Id: cea-02434524 https://cea.hal.science/cea-02434524

Submitted on 10 Jan2020

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers. L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Ces

OXIDATION OF A COLD-WORKED 316L STAINLESS STEEL IN PRESSURIZED WATER REACTOR PRIMARY WATER ENVIRONMENT



IRSN INSTITUT DE RADIOPROTECTION ET DE SÛRETÉ NUCLÉAIRE

<u>Marc Maisonneuve ^(a,b), Cécilie Duhamel ^(b), Catherine Guerre ^(a), Jérôme Crépin ^(b), Ian de Curières ^(c), Léna Verchère ^(a,b)</u>

(a) Den-Service de la Corrosion et du Comportement des Matériaux dans leur Environnement (SCCME), CEA, Université Paris-Saclay, F-91191, Gifsur-Yvette, France (b) MINES ParisTech, PSL Research University, MAT - Centre des matériaux, CNRS UMR 7633, BP 87 91003 Evry, France (c) IRSN, Pole sûreté nucléaire, 31 avenue de la division Leclerc, BP 17, 92262 Fontenay-aux-Roses cedex, France

Introduction

- Pressurized Water Reactors (PWR) represent 76.3 % of the electrical power produced in 2015 in France [1]
- **Operational feedback** \rightarrow intergranular Stress Corrosion Cracking (SCC) affecting cold-worked stainless steel components in PWR primary water [2]
- PWR primary water : pure hydrogenated and deaerated water, with Li and B additions, 150 bars and 290-340 °C
- **Oxygen transients** (oxygen injections in PWR primary water [3, 4]) = **Possible detrimental factor**
- Dissolved oxygen in PWR primary water has an impact on the :
 - \rightarrow Location of initiation sites (trans- or intergranular sites) [5]
 - \rightarrow Oxide layer properties (inner layer morphology and composition) [6]





- However, the oxygen transient effect on SCC susceptibility has not been extensively investigated to date

Objectives

General aim: Determine the effect of dissolved oxygen on SCC susceptibility of a cold-worked stainless steel in PWR primary water

- Hypothesis: Link between oxidation and SCC susceptibility
- In particular, localized oxide penetrations are suspected to play a crucial role in crack initiation

On oxidation kinetics and surface oxide layers nature First step: effect of dissolved oxygen in PWR primary water

On localized oxide penetration kinetics, morphology and nature



Oxidation of a stainless steel specimen exposed to PWR primary water

non cold-worked Pre-strained 316L stainless steel specimens

Material and Experimental Conditions

Composition (weight %)	С	S	Ρ	Si	Mn	Ni	Cr	Мо	Cu	Ν
316L – this study	0,016	0,0009	0,026	0,62	1,86	10	16,54	2,03	-	0,022

Annealing treatment (1050°C, Ar overpressure, 1h) applied to our specimens \rightarrow Isotropic austenite grains (50 ± 10 µm) and residual ferrite (1-5 % in volume)

 \rightarrow Non-sensitized material



Results

Ni coating	Oxida	Oxidation kinetics				= 0% - 500h		
	Au coating			Mean localized penetration depth (nm)	40	■ 11% - 500h		
	Outer oxide layer	Specimen	Mean oxide thickness (nm)		th 30	0% - 1000h		
¢	Inner oxide layer				20			
	Ion cold-worked specimens	500 h	140 ± 41	92 ± 78	10 10			
Alloy F	Pre-strained specimen	11% - 500 h	89 ± 43	87 ± 64				
Localized Oxide penetration SEM (backscattered electrons) micrograph, cross-section of C2 specimen	→ at slip bands	1000 h	146 ± 42	105 ± 74	<pre><0 0-50 50-1 Localized penet</pre>	LOO 100-150 150-200 200-250 >250		

TEM characterization of a non cold-worked specimen oxidized 500h at 340° C





STEM-HAADF micrograph of the surface oxide layer and corresponding EDS profiles

Conclusions

SEM observations after oxidation tests in nominal PWR primary water

Duplex surface oxide layer

 \rightarrow

Localized oxide penetrations at grain boundaries or at slip bands

Cold-working \rightarrow lower mean oxide thickness

Increasing oxidation times \rightarrow increase of the deepest localized penetration density

TEM characterization of a non cold-worked specimen oxidized 500h at 340°C

Inner oxide layer: randomly-oriented nano-grains of spinel structure, composition close to $(Fe,Ni)(Fe,Cr)_2O_4$

Outer oxide layer: Fe-rich, possibly magnetite Fe_3O_4 (to be confirmed)

Tests in nominal PWR primary water: oxidation kinetics and impact of cold-working on oxidation Adjustment of the experimental methodology for tests in aerated PWR primary water Next steps Tests in aerated PWR primary water \rightarrow effect of dissolved O₂

[1] : Commissariat à l'Energie Atomique, Mémento sur l'énergie 2016, 2016 [2] : ILEVBARE, G., et al, Fontevraud 7, Avignon, 2010

[3] : COMBRADE, P., et al, Dossier Technique de L'ingénieur, bn3756, 2014 [4] : BETOVA, I., et al, rapport VTT-R-00699-12, 2012

[5] : HUIN, N., et al, EnvDeg 2015 [6] : TERACHI, T., et al, 61st NACExpo, Paper 06608, 2006

Eurocorr 2017, September 3-7, Prague