Workshop on « Hydrogen-Assisted Cracking: multiscale interactions between theoretical concepts, simulations and experiments »

June 25th 2014

Pprime Institute, Labex Interactifs

ISAE-ENSMA, room A101

Final program

Morning

9h15-9h30	Welcome address		
9h30-10h30	S. P. Lynch	DSTO, Melbourne, Austalia	Introductory lecture
10h30-11h00	Coffee Break		
11h00-11h20	Eric Olivier	AIRBUS Group Innovations	CATHODIC CHARGING OF Al 7XXX T7 ALLOYS TO DEVELOP HYDROGEN ASSISTED CRACKING (HAC)
11h20-11h40	Giovambattista Bilotta	P'	Hydrogen-Assisted Cracking in a 15-5PH martensitic stainless steel: experimental and numerical approaches
11h40-12h00	Yan Charles	LSPM, Université Paris XIII	Finite element modeling of hydrogen sensitivity tests for metallic sheets
12h00-12h20	Qianqiang Chen	UME, ENSTA ParisTech	Modeling of hydrogen embrittlement by a local cohesive damage law
12h20-14h00	Lunch		

Afternoon

14h00-14h20	Mohan Ranganathan	LMR, Université François Rabelais, Tours	Effect of environment in variable amplitude fatigue
14h20-14h40	Arina Marchenko	Centre des Matériaux, Mines ParisTech	Effect of hydrogen on room-temperature creep and sustained load cracking of commercially pure titanium alloys
14h40-15h00	Jean-Marc Olive	I2M, Bordeaux	An insight of some real and numerical experiments in relation with HAC
15h00-15h20	Daniella Guedes	LaSie, Univ, La Rochelle	The impact of hydrostatic stress states on hydrogen flux In martensitic steels
15h20-15h40	Abdelali Oudriss	LaSie, Univ, La Rochelle	The influence of the baking time on the Hydrogen Embrittlement of Martensitic steels
15h40-16h15	Concluding remarks (link with LME, inventory of available resources,…)		
16h15-16h45	Refreshments		
16h45	End of Workshop		

List of participants

First Name	Name	Affiliation
Mandana	Arzaghi	P'
Thierry	Auger	MSSMAT, Ecole Centrale Paris
Quentin	Auzoux	CEA LECA
Guillaume	Benoit	P'
Denis	Bertheau	P'
Giovambattista	Bilotta	P'
Christine	Blanc	CIRIMAT
Séverine	Boyer	P'
Damien	Campello	LaMCos
Yann	Charles	LSPM, Université Paris XIII
Qianqiang	Chen	UME, ENSTA ParisTech
Gaelle	Chrétien	P'
Xavier	Feaugas	LaSie, Université de La Rochelle
Marion	Fregonese	MATEIS
Monique	Gaspérini	LSPM, Université Paris XIII
Daniella	Guedes	LaSie, Université de La Rochelle
Jean	Grilhé	P'
Samuel	Hemery	PIMM, Arts&Métiers ParisTech
Gilbert	Hénaff	P'
Anis	Hor	Institut Clément Ader, ISAE
Diego	Leyser	ENSMSE, Saint-Etienne
Stan	Lynch	DSTO, Melbourne, Australia
Arina	Marchenko	Centre des Matériaux, Mines ParisTech
Frédéric	Menan	Durbilité.info
José	Mendez	P'
Grégory	Odemer	CIRIMAT
Jean-Marc	Olive	I2M, Université Bordeaux
Eric	Ollivier	AIRBUS Group Innovations
Abdelali	Ouidriss	LaSie, Université de La Rochelle
Jean	Petit	P'
François	Pineau	Vallourec Research Center
Thibault	Poulain	P'
Mohan	Ranganathan	LMR, Université de Tours
Christine	Sarrazin-Baudoux	P'
Florian	Thébault	Vallourec Research Center

Abstracts

CATHODIC CHARGING OF Al 7XXX T7 ALLOYS TO DEVELOP HYDROGEN ASSISTED CRACKING (HAC)

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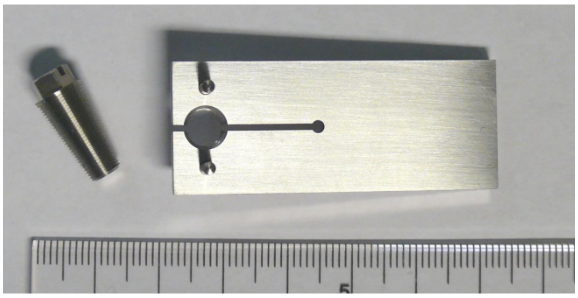
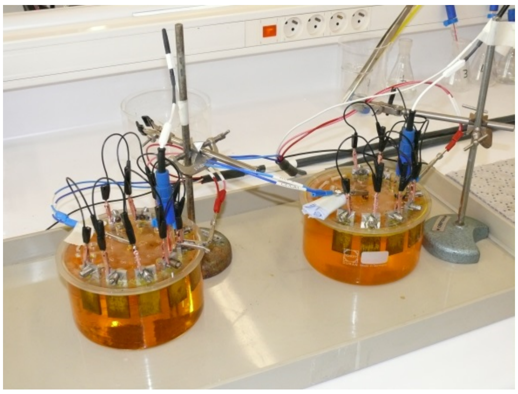
About one year ago, we had to develop a quick test to evaluate HAC sensitivity and characterize fracture surface features for several Aluminum 7XXX alloys (T7) and load conditions.

Small specific but simple samples have been designed that can be loaded in tension with a screw (constant displacement mode) and cracked in a NaCl+Na2Cr2O4 solution with a cathodic polarization applied.

This test has permitted to reach the initial objective which was to initiate HAC cracking with clean brittle fracture surfaces with low level of corrosion pitting at initiation and post-corrosion on fracture surface. Cracks between 0.5 mm to 1 mm can be developed within 400h-500h.





After this test, samples can be submitted to other environments such as wet air to develop further cracking.

Examples of fracture surface examinations obtained after these tests will be given.

Hydrogen-Assisted Cracking in a 15-5PH martensitic stainless steel: experimental and numerical approaches

Giovambattista Bilotta [(a)], Clara Moriconi [(a)], Gilbert Henaff [(a)], Mandana Arzaghi [(a)], Damien Halm [(a)]

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Experimental studies indicate a detrimental influence of a hydrogenous environment on the fatigue crack propagation resistance of metallic materials, called Hydrogen-Assisted Cracking (HAC). In this study we will focus on the embrittlement of a 15-5PH martensitic stainless steel by gaseous hydrogen.

Based on the experimental results, a model to predict the fatigue crack propagation assisted by hydrogen is developed. This numerical model is intended to help in understanding the role of hydrogen in the modification of damage mechanisms in fatigue crack tip.

For this purpose, a cohesive zone model dedicated to cracking under cyclic loading has been implemented in the finite element software ABAQUS. The simulations attempt to predict the crack propagation rate depending on the hydrogen pressure and the applied load. In addition the model provides the opportunity to know the hydrogen concentration in the specimen. The simulation results are compared to fatigue crack propagation tests performed on CT specimens under different hydrogen pressures on the Hycomat test bench. It is been shown that the cohesive zone model with the TSL developed predicts qualitatively the detrimental influence of hydrogen on the propagation rate of fatigue cracks.

Finite element modeling of hydrogen sensitivity tests for metallic sheets

Y. Charles, M. Gaspérini, HT Nguyen, K. Ardon, S. Ayadi

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Finite element modeling of metallic structures submitted to an hydrogen environment has to account for hydrogen-material interactions to predict their early failure. Hydrogen sensitivity of metallic sheets might be evaluated at the macroscopic scale thanks to specific tests, as the Disk Pressure test (with gaseous hydrogen) or the U-Bend test (for cathodic hydrogen). In this context, the material experiences both large plastic strain under complex mechanical loading and interactions with hydrogen, from surface adsorption to bulk diffusion and trapping, leading to final embrittlement-induced failure.

To account for both hydrogen-plasticity interactions, the general hydrogen diffusion equation (considering pressure gradient and plastic strain influence) has been introduced in the Finite Element code Abaqus, using user subroutines. This implementation has been validated based on literature works. The implementation strategy has been chosen so that both mechanical and diffusion problem are simultaneously solved.

These numerical tools have been used to model the Disk Pressure and the U-Bend tests. For each case, simulations have been first performed at the macroscopic scale, based on an isotropic elastoplastic behavior, and then at the polycristal one. Anisotropic cristalline elastoplasticity has been defined in Abaqus using a user subroutine, and Voronoi tessellations have been used to create virtual polycristalline aggregates, on which boundary conditions have been applied using computed macroscopic fields (“submodelling” procedure). Such computations allow the analyze of local heterogeneities on diffusion and trapping hydrogen repartition, considering various loadings.

Title: Modeling of hydrogen embrittlement by a local cohesive damage law

Authors: Q. Chen, Z. Moumni, J. Angles, C. Rouby

Abstract: Hydrogen induced cold cracking is due to residual stress and hydrogen embrittlement in a susceptible microstructure such as martensite or bainite. In order to investigate hydrogen embrittlement and microstructure's susceptibility, a combined HEDE-HELP-AILS model has been proposed. Tensile tests with varying content of hydrogen concentration and martensite are performed. Experimental results confirm the reliability of the model. A local cohesive damage law is then adopted to give the numerical simulation. The simulation shows that hydrogen with a content of 1.9 wt ppm decreases the fracture energy of steel 16MND5 by a factor of 20.

Effect of environment in variable amplitude fatigue

Pr N.Ranganathan, Directeur LMR , Université François Rabelais de Tours

Certain aspects of variable amplitude fatigue associated with the effect of environment are discussed.

It is shown that delay effect following an overload is more pronounced in vacuum than in air for conventional aluminum alloys – this effect is coherent with the constant amplitude crack growth resistance near threshold. In general, a planar slip like behavior leads to higher delay than a multiple slip situation. The exception is an Al Li alloy where delay in air is higher than in vacuum. This effect is discussed in terms of an incompatible cracking mechanism after an overload in air.

Under spectrum loading, a change in crack growth mechanism occurs in air in the Al Li alloy – leading to a four-fold increase in crack growth accompanied by the formation of striations with a special morphology. This mechanism is not observed in vacuum.

Finally, some questions arise concerning faceted crack growth. These questions will be presented at the end of the talk.

Effect of hydrogen on room-temperature creep and sustained load cracking of commercially pure titanium alloys

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Keywords: Titanium; Toughness; Sustained load cracking; Creep; Hydrogen.

Abstract: Widely used for aircraft or rocket engine manufacturing titanium and its alloys are prone to the room-temperature creep that leads to the phenomenon of sustained_load subcritical crack growth (SLC). The slow extension of the crack occurs at stress intensity factors below the fracture toughness of the material[1]. This phenomenon is usually attributed to the presence of interstitial atoms of hydrogen that can be concentrated at the crack tip leading to creep-induced cracking, or to the hydrides precipitation[2]. In the range between 60 and 200 ppm hydrogen has a large but yet unexplained influence on room-temperature creep. For some alloys solute hydrogen can enhance the cold creep and thus trigger the sustained load cracking, while for the others it slows down the creep and increase the threshold for the crack extension. A clear understanding of the physical mechanisms governing the influence of hydrogen on sustained load cracking is necessary to predict the optimum range of hydrogen to improve the resistance of titanium structures to delayed fracture. The present project investigates the correlation between the hydrogen content, the viscoplastic behavior and the resistance to sustained load cracking. Two commercially pure alpha titanium with different content of oxygen and hydrogen are considered. Two corresponding sets of parameter of the same viscoplastic material model are identified using monotonic tensile, creep, and relaxation experiments. Experiments on compact tension (CT) specimens are further carried out for both materials under constant crack mouth opening displacement rate (toughness test), and also at different constant load levels (sustained load cracking test). The finite element simulations of toughness and sustained load cracking test using the aforementioned viscoplastic model were carried out. A cohesive zone model is then introduced ahead crack tip to simulated crack propagation. The hydrogen content is finally used to control the parameters of this cohesive zone and investigate its influence on sustained load cracking.

References:

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2. G.R.Yoder, C.A. Griffis, T.W. Crooker. 1974. The cracking of Ti-6Al-4V alloys under sustained load in ambient air. ASME J. Eng. Mater. Tech., vol.96, p.268.

The influence of the baking time on the Hydrogen Embrittlement of Martensitic steels

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Martensitic Steels may be subject to hydrogen embrittlement (HE) sometime following surface treatments. This type of damage appears to be dependent on baking time during which hydrogen can leave the sample and/or be redistributed within the material. The present study aims to identify the evolution of different states of hydrogen in a martensitic steel during the desorption phase and to evaluate their effects on the mechanical behavior in simple tension test on smooth specimens [1]. Clearly, during baking phase meaningful competition exists between the desorption and the deep trapping on specific defects (vacancies and dislocations) of diffusible hydrogen. The transition between these two regimes involve a times range for which the initially ductile rupture becomes a quasi-cleavage process which results to decohesion and/or shearing of martensite laths. The latter is directly correlated to a time at which the flux of hydrogen is maximized. For low hydrogen mobility we observed classical ductile fracture with decohesion of precipitate and inclusions segregated near prior austenitic grain-boundaries.

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THE IMPACT OF HYDROSTATIC STRESS STATES ON HYDROGEN FLUX IN MARTENSITIC STEELS

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Abstract

A specific dependency of elastic tensile stress on the hydrogen solubility is identified for martensitic steels[1]. In the present work, we explore the effects of elastic tensile stress applied on the hydrogen concentration and mobility in martensitic steel. The complementary analysis were used to improve the investigation: Electrochemical Permeation under Stress (EPS), Thermal Desorption Spectroscopy (TDS), Differential Scanning Calorimetry (DSC), X-ray Diffraction (XRD) and Transmission Electronic Microscopy (TEM). The detail of the experiments performed has been previously reported[2]. Thus we have correlated the hydrogen flux dependence of stress with the different microstructural features. The diffusion coefficient is independent from the elastic distortion in opposition with the hydrogen solubility, which increases with the applied stress. This last result depends on the considered material and cannot be explained only by the contribution of hydrostatic stress on the energy of solubility[3]. To explain this discrepancy between experiment and theory, we explore the impact of vacancies concentration and internal stress measured respectively by DSC and XRD. The main conclusions suggest that internal stresses are less dependent on the considered alloys and that the elastic distortion around vacancies affects probably the hydrogen solubility.

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[2] S. Frappart, X. Feaugas, J. Creus, F. Thebault, L. Delattre, H. Marchebois, Mater. Sci. Eng. A 534 (2012) 384–393.

[3] J.D. Eshelby, Solid. State Phys. 3 (1956) 79-144.