AVANT PROPOS

Depuis sa première édition en 1986, le colloque international sur la corrosion haute température a remporté un succès croissant qui en fait maintenant l'une des rencontres internationales les plus importantes dans son domaine. Sa sixième édition, qui s'est déroulée comme les précédentes sur l'île des Embiez, du 16 au 21 Mai 2004, organisée sous les auspices du centre Français de l'Anticorrosion (CEFRACOR), de l'EPRI, de l'Université Henri Poincaré - Nancy 1 et de l'Oak Ridge National Laboratory, a rassemblé quelque 200 participants venant de 28 pays.

Ce symposium a permis de faire le point sur les connaissances relatives à la corrosion et à la protection des matériaux soumis à des températures élevées et à des environnements agressifs. Tous les problèmes de dégradation des matériaux liés à l'action conjointe de la température, de l'environnement chimique multioxydants, des sollicitations mécaniques et de tous autres paramètres représentatifs de leurs conditions de service, ont été abordés.

Ces actes contiennent ainsi 139 articles, co-rédigés par plus de 350 Auteurs, sélectionnés parmi près de 200 communications proposées. La présentation de ce volume, le 6ème dans la série des Actes intitulés « HIGH TEMPERATURE CORROSION 1-6U », obéit aux mêmes canons que ceux de la version précédente, avec une présentation des articles suivant la série des thèmes présentés lors du symposium :

Chapitre I : Développements Récents Dans la Compréhension de la Corrosion Haute Température (*23 articles*)

Chapitre II : Revêtements Haute Température et Barrières Thermiques (*27 articles*)

Chapitre III : Alliages Haute Température et Intermétalliques, Metal Dusting et Carburisation, Modélisation et Prédiction des Durées de Vie (*22 articles*)

Chapitre IV : Méthodes Avancées de Caractérisation de la Corrosion. Ecaillage et Aspects Mécaniques (*17 articles*)

Chapitre V : Influence de la Vapeur d'Eau (*11 articles*)

Chapitre VI : Céramiques et Composites (*3 articles*)

Chapitre VII : Turbines à Gaz Terrestres, Machines Diesel, Chaudières, Incinérateurs, Brûleurs, Gazéification du Charbon, Industrie Aéronautique (*24 articles*)

Chapitre VIII : Industrie Nucléaire, Piles à Combustible, Systèmes d'échappement et de Filtration à Haute Température, Procédés Haute Température dans l'Industrie (*12 articles*)

Chaque thème a été introduit par une conférence plénière, permettant ainsi de positionner au mieux les travaux du colloque et leur répartition dans les sessions qui ont suivi. Celles-ci comprenaient une série de « keynote lectures » mettant l'accent sur des sujets d'intérêt particulier, suivies d'une ou deux séances de posters sur le thème considéré. Ce sont ainsi 51 présentations orales et environ 110 par affiches qui ont été effectuées durant ces six journées d'intenses discussions scientifiques.

L'ensemble des articles publiés dans ces actes ont été minutieusement revus par des membres du Comité Scientifique International et du Comité Technique, afin d'une part d'en évaluer le contenu scientifique et d'autre part de les adapter aux normes de la revue internationale « Materials

Science Forum ». Comme ceux des précédentes éditions de cette conférence, ces actes devraient constituer un ouvrage de référence dans le domaine de la Corrosion Haute Température et de la Protection des Matériaux.

Pierre Steinmetz, Ian Wright

G. Meier, R. Podor, A. Galerie et B. Pieraggi

Coordonnateurs des Actes du Colloque

PREFACE

This sixth Symposium in a series spanning eighteen years (1986, 1989, 1993, 1996, 2000, 2004) was the first in which neither of the founders, Roland Streiff of the Université de Provence, and John Stringer of EPRI, nor their stalwart collaborators, Marcel Caillet (formerly of the Institut National Polytechnique de Grenoble) and Richard Krutenat (formerly of Textron), were involved in its planning, organization, and execution. Nevertheless, the Planning and Program Committees involved very much the same personnel who have worked with the founding group over the years, and so are imbued with the sentiments that established the format used and are thus well equipped to continue the style and character of the Symposium. Control of the organization of the Symposium is now centered at the Université Henri Poincaré de Nancy, which has undertaken the responsibility for the administrative and financial aspects, including the setting up and maintenance of the Symposium web site. The burden that was borne with such determination and tenacity in the past by Roland Streiff and his staff in Provence has been passed to the Nancy Secretariat, headed by Jean-Jacques Kuntz. Prof. Gerry Meier of the University of Pittsburgh has taken over the role and responsibilities of leading editor of the Symposium Proceedings, which until now was shouldered most ably by Richard Krutenat. It is hoped that the evolving application of electronic media will rapidly ease a task that has, in the past, included formidable logistical problems. Finally, after serving as chairman of the International Scientific Advisory Committee for the last three symposia, Prof. Bob Rapp of The Ohio State University handed on the responsibility to Prof. Francesco Gesmundo, of the Università de Genova.

In keeping with the historical aims of this Symposium, the major theme for this one was high-temperature corrosion issues of current interest for gas turbines (land-based and aircraft), as well as for the power generation (coal combustion; gasification; nuclear; diesel engines), incineration, and process industries. The most popular technical issues for high-temperature corrosion research in the past four years have been related to the needs of major international programs:

- advanced, land-based gas turbines (as the Advanced Turbine Systems program in the U.S. wound down, efforts in the European Union's COST 522 program were gaining momentum);
- ultra-supercritical steam (in the EU, Japan, and U.S.);
- fuel cells and the needs for surface scales with combined low ionic conductivity and high electronic conductivity;
- advanced coal combustion and conversion systems, such as those that form modules of the U.S. Department of Energy's Vision 21 program; and
- the search by the process industries for resistance to carburization/metal dusting.

Hot corrosion and the need for understanding the susceptibility of new alloys and coatings has been discussed recently in the US, but has not yet reappeared as a 'hot topic.' Interest in the acceleration of high-temperature oxidation by water vapor has continued, driven not only by the desire to use silicon-based ceramic composites in gas turbine combustors, but also by the need for materials in the form of thin foils capable of operation as high-temperature recuperators in small gas turbines and reciprocating engines. The adoption of staged combustion in coal-fired steam generators and the resulting severe fireside corrosion of furnace wall tubes has led to renewed research on sulfidation processes. Recently, an international effort to examine new concepts for nuclear power systems for power generation as well as for the supply of process heat has been started, reviving interest in areas such as high-temperature helium, liquid metals, and molten salts.

Following one of the points that was raised at the last Symposium, the call for papers emphasized interest in focusing on the mechanistic aspects of the topics considered to be major problems by the

relevant industries. Of the 144 papers accepted from the resulting response, seventy-five percent were categorized as contributing predominantly mechanistic information. This year, there were eight themed sessions:

A. *Developments in understanding high-temperature corrosion and protection in aggressive environment*: in this session, a number of papers reflected the continued interest in understanding and modeling of processes that contribute to the degradation of protective scales, especially alumina scales formed on bond coatings and FeCrAl alloys, but other topics, in particular, sulfidation, and corrosion in molten salts, also were popular.
B. *High-temperature coatings (including thermal barrier coatings):* as expected, the majority of papers in this session addressed the issues of TBCs, particularly compositional and process-related modifications to bond coatings, but there was significant interest in coatings for other alloy systems.
C. *High-temperature alloys and intermetallics; Metal dusting and carburization; Modeling and lifetime prediction:* for Mo-, Fe- and Ti-based alloys, interest focused on understanding the influence of microstructure and minor alloying additions on oxidation behavior, and on the resistance of Ti-based alloys to aggressive environments (such as sulfidation). Development of modeling approaches for oxidation behavior was another developing area, with interest in understanding the evolution of scale morphologies, oxidation kinetics, and substrate depletion patterns with time. Surprisingly, given the extent of recent interest in metal dusting, there were only a few papers that addressed this topic.
D. *Spalling and mechanical aspects; Advanced techniques for characterizing degradation:* this session was particularly well focused, with obvious interest in the need to better measure, understand, and model the parameters involved in scale spallation processes. Much of the emphasis was on alumina scales, but papers also addressed other scales, as well as creep-scale integrity interactions.
E. *Role of water vapour and steam on high-temperature corrosion:* this session reflected the progress in understanding the major aspects of water vapor-accelerated oxidation of chromia-forming alloys, with papers reporting approaches to gain mechanistic details, to describe the phenomenon for other scales, as well as approaches to improve performance.
F. *Ceramics and composites:* the two main themes of this small session were understanding of the oxidation behavior of composite materials, which can be susceptible to inter-phase attack, and measurement of properties of ceramics such as wettability by molten metals, and ionic conductivity.
G. *Land-based gas turbines, diesel engines; Boilers; Incinerators; Burners; Coal Gasification; Aerospace industry*: all of the topic areas in this session were addressed, with most emphasis on gas turbine issues such as hot corrosion of recently-deployed alloys; interaction with gases and deposits expected from the use of biomass; and steam-side oxidation in boilers.
H. *Nuclear industry; Fuel cells; Exhaust systems and high-temperature filtration; High-temperature processes in industry:* the materials issues from the nuclear industry discussed in this session involved molten salts and high-temperature helium. Despite the intense materials efforts in support of the development of fuel cells, only two papers addressed this area. In fact, the most popular theme was the influence of the evolution of alloy microstructure with time at temperature, and its influence on oxidation behavior.

The format used for the Symposium again was based on coordinated oral and poster presentations; the former were chosen to provide either overviews of recent developments in a given field, or to highlight the latest advances. The use of poster sessions in this setting has proved, as with the Gordon Research Conferences on High-Temperature Corrosion, to be an extremely valuable feature. An encouraging aspect is that discussion groups often form around given posters and then proceed to some leisure activity together, so promoting prolonged interactions. In the recent

Symposia, there has been a noticeable increase in the quality of the posters over time, suggesting that such sessions are considered to be very important by the participants.

The three- to four-year cycle of these Symposia is relatively unusual these days, but appears to be very useful in terms of providing an opportunity to observe substantial progress in individual programs, and to recognize overall trends in focus on topic areas. In some countries, notably the US, four years is a very significant period since it coincides (though slightly out of synchronization) with the period of office of the governing administration, the policies of which can greatly influence the emphasis and direction of research funding. Four years also can represent a significant period in a person's career, and the continued interest and participation in the Symposia of individuals as they occupy positions of increasing importance and influence is not only very encouraging, but also plays an extremely valuable role in encouraging the participation of the next generation of researchers. A further feature is that colleagues who do not have an opportunity to spend time together on a more frequent basis, are able to judge how increasingly distinguished they each become with time.

Acknowledgements

We would like to express our gratitude to our sponsors for making this sixth Symposium possible. The output from the previous Symposia set a very high standard, and we hope that the technical quality of the presentations and of the papers published in these proceedings lives up to that standard, and is in accord with the expectations of our sponsors. We thank EPRI for their continued, long-term support and encouragement, the Oak Ridge National Laboratory (especially Dr. R. R. Judkins of the Fossil Energy Materials Program), Université Henri Poincaré NANCY1, and the SAINT GOBAIN company. The success of the Symposium stems from the dedication of a relatively small number of hard-working people: we would like to mention especially Jean-Jacques Kuntz, Renaud Podor, Fabienne Rocher, and the other members of the Secretariat at the Université Henri Poincaré de Nancy, who ensured a seamless transition of the organization of the Symposium; Alain Galerie, Bernard Pieraggi and the committees who planned the program, and who took care of the on-site organization; the International Advisory Committee, for their efforts to ensure that the papers published conform to the high scientific standards set by earlier proceedings.

Pierre Steinmetz
Ian Wright
Symposium Co-Chairmen
March, 2004.