FIRE: Education program in Refractory Engineering

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1 THE CONTEXT IN REFRACTORY SCIENCE AND ENGINEERING

Refractory ceramics are materials which resist high temperatures. They are used in the “heat industries”: steel making, foundries, non-ferrous metals, cement, glass and ceramics and, to lesser extent, in the petrochemical and the chemical industries, in the incineration of waste and energy production. These materials are of considerable economic and strategic importance and striving for better performances is a major challenge to these industries. Education and Research is a key ingredient to insure the long-term prosperity of the refractory industry. However, with the globalization, the competition among the refractory producers is fierce and the profit margins are reduced. One solution frequently considered in the industry is the outsourcing of R&D centers, for both strategic and economic reasons. With the down-sizing in the refractory human resources, the demand on the quality and the efficiency of those being in place has increased. One new request has been the necessity of the engineers to acquire an international vista.

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The function of FIRE (Federation for International Refractory Research and Education) is to stimulate and reinforce the higher education system in high temperature (refractory) materials engineering in order to fulfil the cultural educational and research related needs of the Refractory Industry [1]. FIRE's strength is in its unique grouping of expertise and the interplay amongst its members: academic researchers and producers learning from each other what to do to train qualified human resources to fill the demands of an international market place. FIRE is also offering Ad Hoc education programs upon request, and organizing periodically seminars and colloquiums on advances in refractory research [2, 3].

2 WHAT'S FIRE

FIRE is a worldwide network of academic and industrial partners (manufacturers, suppliers, users and other services providers), promoting research and education in refractory engineering (*Fig.1 and 2*). It is a non-profit organization, managed by a board of Members and an Executive Committee.

Fig.1. Logo and FIRE Members at work, in Ludwigshafen (D), Nov. 11th, 2013

Currently, there are ten academic institutions in the FIRE network, located in Austria, Brazil, Canada, France, Germany, Japan, USA, and China. The FIRE program is financially supported by 16 industrial FIRE members. Alcoa (Brazil), Almatis GmbH (Germany), Altéo (France), ANH (USA), Calderys (France), Elkem (Norway), Imerys (France), Kerneos (France), Magnesita S.A. (Brazil), Pyrotek InC. (USA), RHI (Austria), Rio Tinto Alcan (Canada), Saint Gobain (Brazil), Tata Steel (The Netherlands), Tenaris (Argentina) and Vallourec (France).

Fig. 2. The academic and industrial FIRE Members

The purposes of FIRE [4, 5] are:

- To support academic education by promoting student exchanges and generating double (multiple) degree programs organized by two or more universities.

- To fund international studies and research activities in the field of refractories
- To pool the expertise, the experience and the willingness of the worldwide most competent persons, institutions and companies in the field of refractories.

Funding is obtained through membership fees, and is supplemented by Granting Agencies fostering international exchanges and synergies – to implement FIRE's activities.

3 FIRE EDUCATION PROGRAMS IN REFRACTORY SCIENCE AND ENGINEERING

The FIRE Education Programs have started during the 2006-2007 academic year.

They comprise three activities: certificates, schools and compendium Series.

3.1 FIRE certificates

FIRE favors the multi-linguist and the cultural exchanges. It offers a broader educative experience to students. FIRE has defined accredited Master's and Ph.D. Educational programs. Specific details of the FIRE admission and program requirements are detailed on the FIRE website www.polymtl.ca/fire.

FIRE does not deliver diplomas. Students who have satisfied the FIRE requirements receive a certificate to recognize their results, after completion of a degree, as a master of applied sciences and/or a Ph.D. program, in a FIRE academic institution. Knowledge of English is a prerequisite. FIRE may also grant certificates to trainees from the industry who have completed a specified resident time in a FIRE academic institution.

FIRE Certificates validate international exchanges for M.Sc. and Ph.D. students between academic institutions. They aim is to testify that students have studied in at least two different countries and have been "coached" by two interacting groups of researchers.

Fellowships are offered to FIRE students to cover their traveling, lodging and a part of their indirect costs as well as they have to study abroad for at least 4 months to obtain a FIRE Master certificate and at least 6 months for a FIRE Ph.D. certificate.

The minimum requirements to be met for the issuance of FIRE's certificates are the following:

- The program of study for students must incorporate a training period in at least one FIRE network campus, which implies that at least two different FIRE professors are to be involved;
- The program of study for the students must be duly sanctioned by the academic institution to which they belong, in accordance with the local university requirements.

During their studies, each FIRE certificate recipient must have acquired during their studies a working knowledge of refractories.

The FIRE teaching courses, set by its academic members with the full recognition of the members from the industry, are to be accredited by FIRE's Board. The list of courses includes a certain minimum number of refractory related courses as well as some humanities, economic and financial courses, as optional courses (Table 1).

To obtain a FIRE certificate at the Master level, the strict requirement is 36 credits of courses, seminars and research on refractory materials sciences and/or engineering. Those 36 credits are to include:

- 6 credits of course work from FIRE course, to be obtained abroad.
- 30 other credits related to a refractory subject (courses, seminars and research).

- An international paper with authors of the based and visiting institution (abroad).

FIRE students must have established a list of all the refractory related courses they successfully completed, as undergraduate student, then at the master level, from the program they have chosen. The candidates must have accumulated in all a minimum number of coursework, equivalent to 20 credits in total on refractory related courses (including all courses completed successfully since the first undergraduate year).

To obtain a FIRE certificate at the Ph.D. level, the requirement is 86 credits of course work, seminars and research, on refractory material sciences and engineering. Those 86 credits are to include at least:

- 6 credits of course work to be obtained abroad;
- 76 credits for a Ph.D. thesis on a refractory subject, part of the work being done for two-semesters abroad;
- An international peer reviewed paper.

Table 1. List of the FIRE accredited subjects

List of subjects
1. Raw Materials: mineralogical aspects and minerals treatments.
2. Manufacturing Processes – batching to packaging.
3. Physical Chemistry Principles – particle packing, surface chemistry, capillarity, colloidal, binders, rheology, sintering.
4. Use of Phase diagrams and thermodynamics calculations for multicomponent systems.
5. Heterogeneous kinetics – Heat and Mass Transfers.
6. Thermo-mechanical properties and testing
7. Thermo-physical properties and testing.
8. Thermochemical properties and testing.
9. Special Topics.
i. Refractory Selection Strategy for specific usages
ii. Strategic planning and technical forecasting for the refractory industry.
iii. Management Principles, Technical-Economic Issues.
10. Research Topics.

FIRE's certificates are presented every two years during the biennial Unified International Technical Conference on Refractories: UNITECR *(Fig. 3).*

Fig. 3. Graduation Day: Bahia (Br) - Oct. 10th, 2009 and Victoria (Can)- Sept. 9th 2013

FIRE has delivered its first Master degree certificates in Dresden (September 2007).

During the period 2007-2013, FIRE has delivered 60 certificates (50 to Master students, 10 to Ph.D) and has also granted fellowships to facilitate the exchanges in the network.

The students 'outputs is impressive: the number of paper published in the literature exceeds 150. Numerous prizes have been awards to FIRE students: Gustav Eirich Award, 2009 (1st place), 2012 (2nd place), Wakabayashi Prize, 2010, 9th India International Refractory Congress 2011 (2nd place), ALAFAR International Award 2012 (1st place), V International Aluminum Congress 2012 (1st place),III Casimiro Montenegro Filho Award on Strategic Issues.

The next FIRE diplomas ceremony will take place in Vienna in September 2015.

3.2 FIRE Schools and FIRE Short Courses

FIRE Schools gather together at one place, for a week, all FIRE students, FIRE alumni and FIRE research associates, from academia and industries, to develop a common language through the presentation of lectures by FIRE professors. The goal is to review the fundamental principles, to define key challenges to be addressed by a younger generation of researchers and to open questions to move toward effective solutions.

The first SCHOOL was held at Polytech Orléans (Fr), from June 17 to June 21, 2013 (*Fig 4*). 63 people have participated at this FIRE School: 23 Industrials, 25 students and 15 academics. Different topics were taught and discussed during this week:

- Understanding refractory science - what could it mean?
- Fracture mechanics of refractories
- Designing thermal shock resistant refractory microstructures
- Multi-scale composite approach to effective thermal and mechanical properties of refractories: from grains to material level
- Analytical methods for continuum micromechanics: useful analytical bounds for prediction of effective properties of random media.
- Modelling and design of refractory lining masonries
- Phase transformation and corrosion of refractories
- Application of thermodynamic calculations for the understanding of refractories corrosion
- Coupling effect between phase transformations and thermo-mechanical behavior

Globally, the 5 days were well balanced and appreciated. The results of the evaluation of this school are very satisfying with positive comments: "It was a real success", "Thanks to the organizers, for a job well done", "A very good start", "Excellent idea", "Excellent opportunity to meet", etc…The benefits of the 1st FIRE School for student, academic and industrial partners have been identified and are indicated in the *table 2*.

Fig.4 The first FIRE SCHOOL, at Polytech Orléans (Fr), June 17 to June 21, 2013

Table 2. Benefits of the 1st FIRE School for student, academic and industrial partners

Benefits for students
- Repetition of important contents presented from another point of view
- Direct practical transfer from theory to practice
- Short course introductions to raw materials, materials and systems, methods of characterisation and interpretation of findings, industrial processes, equipment and facilities by academics and industrial specialists with scientific expertise and practical long-term experiences
- direct contact and opportunity for discussions with internationally highly recognised docents and advanced students of other countries and cultures
Benefits for Universities and Research Institutions
- Mutual improvement regarding teaching topics, presentation techniques and didactics
- Development of interdisciplinary concepts of teaching
- Development of complementarity among the Universities inside the FIRE framework
- Development of interdisciplinary concepts for innovation
- Adaptation of industrial interests and input in the goals of teaching courses
- Transfer of novel R&D results to publications and teaching
- Dissemination of novel R&D results to FIRE-members
Benefits for industrial partners
- Strengthening of communication between raw material suppliers, developers of refractory materials and customers, between R&D engineers, marketing group, and board members
- Comprehensible presentation of (novel) functionalities of refractory products
- Identification and fostering of an international use of a “common language”
- Learning of a precise and comprehensible presentation on properties, functionality and excess value of a product, on the processes, boundary conditions, needs and requirements.
- Adopting a professional argumentation
- Recognition and identification of technical problems and solutions.
- Early notification of potentials and trends of further development
- Identification and recruiting of skilled young employees
- New methods (experimentation, modelling, numerical approach), new concepts
- New ideas for future R & D programs and future developments
- Identification of fundamental mechanisms of refractory wear

Short courses are given by FIRE during the Unified International Technical Conferences on Refractories (Kyoto-Japan 2011, Victoria Canada 2013 and Vienna Austria 2015):

- Mechanical behaviour and fracture of refractories
- Fundamentals on corrosion behaviour of refractories
- Dispersion and packing of ceramics particles for advanced refractory castables

These courses are intended for a broad spectrum of people (engineers, scientists, students, technicians, managers) willing to learn the basics and their possible applications to refractories and high temperature ceramics.

3.3 FIRE Compendium Series

The FIRE Compendium Series provides a frame-work for educating refractory engineers since the challenges are to train them to design, implement and operate value-added refractory products. Göller Verlag GmbH, partner of FIRE, is the publisher of the FIRE compendium Series. The first volume of the FIRE Compendium Series on "Refractory Castable Engineering" is dedicated to the segment of

refractories that has been growing the fastest among all refractory materials over the last 15 years (*Figure 5*).

Fig.5. The first volume of the FIRE Compendium Series

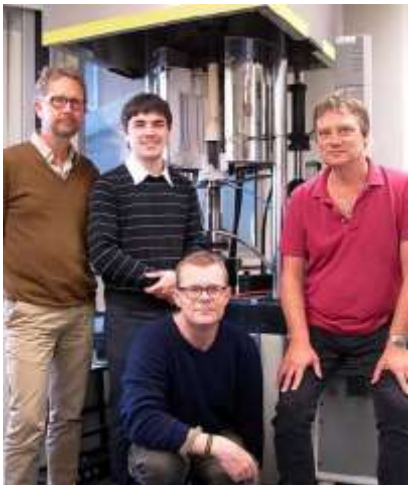
The authors: Ana Maria Luz, Mariana Braulio and Victor Pandolfelli (Federal University of Sao Carlos/ Brazil) have not only covered the fundamentals (e.g. particle dispersion, particle size distribution and packing design, binder additives) and processing stages (setting mechanisms, curing and drying, installation techniques) of refractory castables, they also discuss properties and optimization systems of MgO-containing compositions, spinel-containing alumina-based castables and carbon-containing castables. Furthermore an outlook on designing new microstructures is given based on the use of nano-scaled materials or the development of a new generation of bio-inspired and transient liquid-containing formulations.

4 FIRE RESEARCH PROGRAMS

To accompany the Education programs in Refractory Science and Engineering, FIRE is involved in specific research programs with multiple FIRE partners. These research programs are pre-competitive refractory projects that are the responsibility of an academic FIRE member, with contributions from other members to promote international networking. All of the research projects involve the participation of selected FIRE students (*Fig. 6*) as well the research staff attached to the refractory labs. *Table 3* gives the list of the research programs for the 2008-2015 period. Project funding are sought from FIRE, government agencies, industry and internal funds from the participating universities.

Adrian VILLALBA (Master Student)
from RWTH Aachen to CEC-Limoges (Fr)

Yueting QIAN (Master Student)
from Polytech Orleans (Fr) to Leoben (A)



Florian Genty (Master Student)
from Polytech Orléans (Fr) to Tata Steel CRC (NL)

Fig. 6. FIRE student during their research interships

Table 3. FIRE research programs

2008-2011 1st 4-year plan
- Thermo-mechanical behavior of refractories, modelling and testing
- Engineering microstructure of alumina magnesia castables
- Thermo-chemical behavior of refractories, modelling and corrosion testing
2011-2015 2nd 4-year plan
- Insulating refractories and their applications in multilayer lining designs
- Energy efficient refractories: a holistic approach based on fundamentals, processing and evaluation
- Liquid phase and vapor phase corrosion: new methodologies and new cases of corrosion
- Dense refractories with enhanced flexibility

5 SUMMARY AND ACKNOWLEDGMENTS

FIRE is an outsourcing network with today some 26 partners, in 10 academic institutions, in 8 countries supported by 16 industrial companies from 11 different countries distributed over 4 continents.
To train efficient refractory engineers, FIRE refractory educators have created an environment where the students are be able to learn materials and refractory technology in an economical, ecological and ethical context, much broader than it was the case previously, in order to understand the business and the cultural issues the industry is facing. To cope with so many challenges, new forms of collaboration between the academics themselves and between the refractory industrialists and academics have been invented. Outsourcing has also been introduced in the academic world, to keep the costs of education at a level where it can be attractive to recruit graduate students and to follow a more systematic approach to pool the resources and the expertise more efficiently to find complementarities, in teaching as well as in research.
Fire's long term objectives will remain to contribute to the education and assimilation of knowledge, with wisdom to the benefit of all players, in the chain of values along the global life cycle of refractories, absolutely essential to industrial life.

The authors want to express their sincere thanks to all the industrial and academic FIRE members, for their full supports

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